

Head of Hummock Pond

The 2011 Water Quality Program

A Summary of Physical, Chemical and Biological Monitoring



Prepared by:

James W. Sutherland, Ph.D.
NYS Department of Environmental Conservation (retired)
P.O. Box 2641
Nantucket, MA 02584

Prepared for:

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

February 2012

DISCLAIMER

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

TABLE OF CONTENTS

	<u>Page</u>
Chapter 1	Executive Summary
	1
1.0	Project Location and Boundary
	1
1.1	Background
	1
1.2	Purpose of the 2011 Project
	2
1.3	2011 Project Description
	3
1.4	Presentation of the 2011 Report
	3
1.5	2011 Project Findings and Conclusions
	4
1.6	Recommendations
	5
1.7	Literature Cited
	5
Chapter 2	Description of the 2011 Program and Methodology
	6
2.0	Background
	7
2.0.1	Purpose of the 2011 sampling program
	7
2.0.2	Description of the 2011 sampling program
	7
2.1	Methodology
	9
2.1.1	Routine sample collection and processing
	9
2.2	Analytical Techniques
	10
2.2.1	Phytoplankton Identification-Enumeration
	11
	Counting method
	11
	Conversion to density (cells mL ⁻¹)
	11
	Conversion to biovolume (mg ³ mL ⁻¹)-biomass (mg m ⁻³)
	11
2.2.2	Cyanophyte toxin analysis
	12
2.3	Literature Cited
	12
Chapter 3	2011 Water Quality Results
	12
3.0	Introduction
	13
3.1	Results
	13
3.1.1	Physical characteristics
	13
	General
	13
	Water depths
	14
	Thermal cycle
	14
	Transparency
	15
3.1.2	Chemical characteristics
	15
	Specific conductance
	15
	pH
	16
	Dissolved oxygen concentration-percent saturation
	17
3.1.3	Plant nutrients
	18
	Nitrogen
	18
	Phosphorus
	21
3.1.4	Phytoplankton
	24
	Overview
	24
	Description of the assemblage
	24
	Density
	26
	Biomass
	26
	Seasonality and associations
	27
	Dominance
	28

TABLE OF CONTENTS

	<u>Page</u>
Chapter 3	Water Quality Results for 2010 (continued)
3.1.4	Phytoplankton (continued)
	Diversity
	Chlorophyll <i>a</i>
	SUNY-ESF report on cyanophyte toxins
3.1.5	Trophic status
3.2	Literature Cited
Chapter 4	A Comparison of 2009, 2010 and 2011 Water Quality
4.0	Introduction
4.1	Presentation of Results
4.2	Comparison of 2009, 2010 and 2011 Data
4.2.1	Physical characteristics
	Thermal cycle
	Transparency
4.2.2	Chemical characteristics
	Specific conductance and pH
	Dissolved oxygen concentration and percent saturation
4.2.3	Plant nutrients
	Nitrogen
	Phosphorus
4.2.4	Phytoplankton
	Total assemblage
	Density
	Biomass
	Seasonality
	Dominance
	Diversity
	Chlorophyll <i>a</i>
4.2.5	Trophic status
4.3	Summary
4.4	Literature Cited
Chapter 5	A Review of Historical and Current Water Quality Data
5.0	Introduction
5.1	Analysis and Summary of Historical Data
5.2	Review of Historical Data
5.2.1	Physical characteristics
	Transparency
5.2.2	Plant nutrients
	Nitrogen
	Phosphorus
5.2.3	Phytoplankton
5.2.4	Trophic status
5.3	Summary
5.4	Literature Cited

TABLE OF CONTENTS

	<u>Page</u>
Chapter 6	2011 Project Summary, Discussion, Conclusions and Recommendations
	55
6.0	2011 Project Summary
	55
6.1	Discussion
	57
6.2	Conclusions
	59
6.3	Recommendations
	60
6.4	Literature Cited
	60
Appendix	Material Referenced in the Report
	52
	2011 Pond Field Sheet
	53
	Chain of Custody Form
	54
	2011 HHP Temperature Profiles
	55
	2011 HHP Dissolved Oxygen Profiles
	56

LIST OF TABLES

		<u>Page</u>
Table 2.1	Summary of the HHP sampling dates during 2011	8
Table 2.2	Summary of physical, chemical and biological parameters that were monitored in HHP during 2011	9
Table 2.3	The physical, chemical and biological parameters included in the 2011 HHP water quality study, their collection technique and methodology	10
Table 2.4	Chemical parameters and analytical methods for the 2011 study of water quality in HHP	11
Table 3.1	The major groups and taxa of phytoplankton identified in HHP during 2011	24
Table 3.2	Characteristics of the most commonly occurring phytoplankton taxa by major group in HHP during 2011	26
Table 3.3	Rank of phytoplankton taxa dominance, using biomass, in HHP on each 2011 sampling date	29
Table 3.4	A summary of results from SUNY-ESF for Cyanophyte toxin analysis in 2011	31
Table 3.5	A summary of the relationships among Trophic Index (TI), chlorophyll <i>a</i> ($\mu\text{g L}^{-1}$), phosphorus ($\mu\text{g L}^{-1}$), Secchi depth (meters) and Trophic Class	32
Table 4.1	Summary of physical-chemical parameters in HHP during 2009, 2010 and 2011. The 2010 and 2011 data are summarized for the entire season and for a 4-month period similar to the length of the 2009 sampling program	34
Table 4.2	Summary of phytoplankton community parameters in HHP during 2009, 2010 and 2011. The 2010, 2011 data are summarized for the entire season and a 4-month period similar to the length of the 2009 sampling program	40
Table 4.3	Summary of phytoplankton community dominant taxa that occurred in HHP during 2009, 2010 and 2011. Highlighted taxa were common to the 2009, 2010 and 2011 communities	44
Table 4.4	A summary of Trophic State Indices calculated for HHP for 2009, 2010 and 2011 and based upon similar 4-month sampling periods	45
Table 5.1	Summary of all known water quality data collected from HHP	47
Table 5.2	A summary of Trophic State Indices (TSIs) calculated for all known HHP water quality data	53
Table 6.1	A summary of Cyanophyte species identified in the HHP phytoplankton community during 2009, 2010 and 2011. Highlighted species were common to all three sampling seasons	56

LIST OF FIGURES

		<u>Page</u>
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	1
Figure 2.1	Aerial view of HHP showing the location of the <i>SolarBee</i> ® unit and the 2011 sampling stations #4 and #4A	8
Figure 3.1	Aerial view of Head of Hummock Pond (from <i>Google Maps</i>)	13
Figure 3.2	Average water depths (in meters) at HHP sampling stations #4 and #4A during 2011	14
Figure 3.3	The average monthly water temperature measured in HHP during 2011	15
Figure 3.4	The seasonal pattern of Secchi depth transparency measured in HHP during 2011	15
Figure 3.5	The seasonal pattern of specific conductance measured in HHP during 2011	16
Figure 3.6	The seasonal pattern of pH measured in HHP during 2011	17
Figure 3.7	The seasonal pattern of average dissolved oxygen concentration-percent saturation measured in HHP during 2011	18
Figure 3.8	The seasonal pattern of nitrate-nitrogen concentrations measured in HHP during 2011	19
Figure 3.9	The seasonal pattern of ammonia-nitrogen concentrations measured in HHP during 2011	20
Figure 3.10	The seasonal pattern of organic nitrogen concentrations calculated for HHP during 2011	20
Figure 3.11	The seasonal pattern of total nitrogen concentrations measured in HHP during 2011	21
Figure 3.12	The seasonal pattern of total nitrogen concentration measured in the upper and lower regions of HHP during 2011	21
Figure 3.13	The seasonal pattern of total phosphorus concentrations measured in HHP during 2011	22
Figure 3.14	The seasonal pattern of total phosphorus concentrations measured in the upper and lower regions of HHP in 2011	23
Figure 3.15	The seasonal pattern of TN and TP measured in HHP during 2011	23
Figure 3.16	The seasonal pattern of the number of phytoplankton taxa that occurred in HHP during 2011	25
Figure 3.17	The ranking of phytoplankton taxon occurrence in HHP during 2011	25

LIST OF FIGURES

		<u>Page</u>
Figure 3.18	The seasonal pattern of phytoplankton density in HHP during 2011	26
Figure 3.19	The seasonal pattern of phytoplankton biomass in HHP during 2011	27
Figure 3.20	The seasonal distribution of major phytoplankton groups in HHP during 2011	27
Figure 3.21	The seasonal pattern of phytoplankton community density in HHP during 2011	28
Figure 3.22	The seasonal pattern of phytoplankton community biomass in HHP during 2011	28
Figure 3.23	The seasonal pattern of phytoplankton community indices in HHP during 2011	30
Figure 3.24	The seasonal pattern of chlorophyll <i>a</i> concentration in HHP during 2010	30
Figure 4.1	Summary of average monthly temperature in HHP during 2009, 2010 and 2011	35
Figure 4.2	Summary of average Secchi depth transparency in HHP during 2009, 2010 and 2011	35
Figure 4.3	Summary of average specific conductance values in HHP during 2009, 2010 and 2011	36
Figure 4.4	Summary of average pH values in HHP during 2009, 2010 and 2011	36
Figure 4.5	Seasonal pattern of average monthly pH values in HHP during 2009, 2010 and 2011	36
Figure 4.6	Summary of average nitrate-nitrogen values in HHP during 2009, 2010 and 2011	37
Figure 4.7	Summary of average ammonia-nitrogen values in HHP during 2009, 2010 and 2011	38
Figure 4.8	Seasonal pattern of average monthly ammonia-nitrogen values in HHP during 2009, 2010 and 2011	38
Figure 4.9	Summary of average total nitrogen values in HHP during 2009, 2010 and 2011	39
Figure 4.10	Seasonal pattern of average monthly total nitrogen values in HHP during 2009, 2010 and 2011	39
Figure 4.11	Summary of average total phosphorus values in HHP during 2009, 2010 and 2011	40

LIST OF FIGURES

		<u>Page</u>
Figure 4.12	Seasonal pattern of average monthly total phosphorus values in HHP during 2009, 2010 and 2011	40
Figure 4.13	Summary of phytoplankton average density during 4-month periods in 2009, 2010 and 2011	41
Figure 4.14	Seasonal pattern of average monthly phytoplankton densities in HHP during 2009, 2010 and 2011	41
Figure 4.15	Average proportion of major groups in the phytoplankton community density, 2009-2011	42
Figure 4-16	Summary of phytoplankton community average biomass during 4-month periods, 2009-2011	42
Figure 4-17	Seasonal pattern of average monthly phytoplankton community biomass in HHP, 2009-2011	43
Figure 4.18	Average proportion of major groups in the phytoplankton community biomass, 2009-2011	43
Figure 5.1	Summary of mid-summer and fall average Secchi depth transparency data available for HHP	48
Figure 5.2	Summary of mid-summer and fall average nitrate-nitrogen data available for HHP	49
Figure 5.3	Summary of mid-summer and fall average ammonia-nitrogen data available for HHP	50
Figure 5.4	Average monthly concentrations of total nitrogen from HHP data collected in 2005, 2006 and 2007	50
Figure 5.5	Average monthly concentrations of total nitrogen from HHP data collected in 2009, 2010 and 2011	50
Figure 5.6	Summary of mid-summer and fall average total nitrogen data available for HHP	51
Figure 5.7	Summary of mid-summer and fall average total phosphorus data available for HHP	52
Figure 5.8	Average monthly concentrations of total phosphorus from HHP data collected in 2005, 2006 and 2007	52
Figure 5.9	Average monthly concentrations of total phosphorus from HHP data collected in 2009, 2010 and 2011	52
Figure 6.1	Photograph of a shoreline surface concentration of a Cyanophyte mat on HHP taken on July 1 st 2011	59

ACKNOWLEDGEMENTS

Funds for this work were provided by the Nantucket Land Council, Inc. The University of Massachusetts Boston Nantucket Field Station loaned different pieces of equipment on a regular basis, without which, the 2011 sampling program would not have been possible.

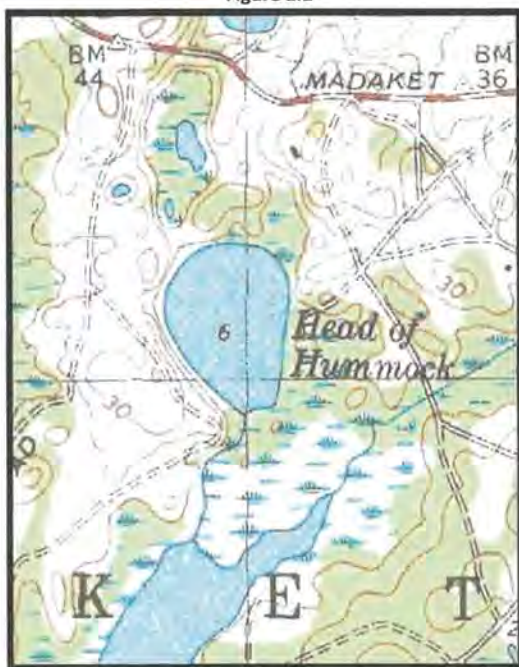
The author would like to personally thank the following individuals whose assistance was instrumental in completing the field work, data analysis and report writing phases of this project: Alex Barham, Cormac Collier, Dave Fronzuto, Emily MacKinnon and Dr. Sarah Oktay.

Chapter 1 Executive Summary

1.0 Project Location and Boundary

Head of Hummock Pond, 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°16'38" and longitude of 70°08'00" (Figure 1-1).

Figure 1.1



HHP is part of the Hummock Pond system and the two ponds are connected by the HHP outlet channel which winds through an extensive wetland and enters Hummock Pond at the northeast end. HHP and its surrounding watershed are located within the Town of Nantucket and the Town has jurisdiction for stewardship of the Pond. HHP and Hummock Pond are used for contact recreation including boating, kayaking, fishing, sailing and swimming. Both ponds also provide important habitat for a variety of waterfowl, including migrating and resident populations. Hummock Pond is listed as one of seven Great Ponds located within Nantucket County by the MA Department of Environmental Protection.

1.1 Background

During 1994, the Nantucket Marine and Coastal Resource Department initiated monthly monitoring of water quality on Hummock Pond during the ice-free period of the year, focusing on temperature, dissolved oxygen, salinity, Secchi depth, water depth and nutrient chemistry. Annual reports were issued.

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 and reported by Knoecklein (2006). Subsequently, Conant (2007, 2008) continued to sample Hummock Pond and included an HHP station which was reported in the 2006 and 2007 annual reports.

During 2009, the UMass Boston Field Station and Nantucket Land Council (NLC) 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 exhibited water quality at certain times of the year that could be characterized as hyper-eutrophic, or extremely productive. The NLC funded a subsequent monitoring program that sampled HHP during 2010. This program began in early April and continued through mid-November, collecting samples for all of the parameters studied during 2009 and, in addition, collecting samples that were analyzed for the Cyanophyte neurotoxin, microcystin. The 2010 water quality continued to be poor, with very high nutrient and chlorophyll a concentrations exhibited during mid-summer, and the neurotoxin, microcystin, detected in the pond during the height of productivity.

During September 2010, the report author and the NLC prepared and submitted a grant application to the local Conservation Preservation Committee. The application requested funding to install a *SolarBee*® long distance circulation unit in HHP to evaluate the potential for this technology to prevent harmful algal blooms (HABs), i.e., episodes of excessive Cyanophyte growth. The restoration project proposed for HHP was within the goals and objectives of the Community Preservation Act (CPA) since one of the CPA's stated objectives is "the acquisition, creation and preservation of open space." Furthermore, a precedent had been established for this type of project since several CPA communities have used CPA funds to preserve and restore important water resources that are integral to their unique character with water-related projects ranging from purchasing land for the protection of drinking water sources to eliminating invasive species from key water bodies. The CPC grant application was approved and the solar-powered long-distance circulation unit was ordered, delivered and installed on HHP on April 18th 2011. An evaluation of the effectiveness of this unit in breaking the cycle of Cyanophyte blooms in HHP is the subject of a separate report.

During 2011, the NLC continued to fund water quality monitoring on HHP and also provided funding for other scientific investigations, conducted by the author (JWS), including the following:

- The purchase of equipment/materials/supplies to install three subsurface wells around the perimeter of HHP and sufficient funding to monitor the 2011 summer and fall physical and chemical characteristics of groundwater surrounding the pond that has the potential to affect HHP water quality,
- The purchase and installation of a continuous water level recording device in the near-shore area of HHP to gather detailed information that will aid in the development of a hydrologic (water) cycle for the pond.
- The purchase and installation of a series of continuous temperature data-loggers in HHP to record the ambient temperature at different depths in the pond and evaluate the effectiveness of the *SolarBee*® in maintaining the type of water circulation that is the basis for advertising and promoting this unit for the control of Cyanophyte blooms.

The data collected in conjunction with the above investigations has been summarized and discussed in interim reports separate from this report on water quality of the pond.

1.2 Purpose of the 2011 Project

A primary goal of the 2011 project was the collection of sufficient data to evaluate HHP water quality from early spring through the fall. A secondary goal was to evaluate the *SolarBee*® unit and whether it could interrupt the pattern of mid-summer harmful algal blooms (HABs) that were occurring in the pond. Another goal of the 2011 effort was to continue documenting the seasonal succession of water quality in the pond and increase the water quality database that could be used for future decisions in pond management. And finally, the 2011 program was

designed to sample Hummock Pond and HHP prior to, and following, the spring and fall openings to the Atlantic Ocean and determine whether pond flushing has a positive or negative effect on water quality.

The specific objectives of the 2011 monitoring program were to

- Define and quantify the 2011 water quality of HHP and compare it to the 2010 water quality, and
- Compare the 2011 database with the 2009 and 2010 databases to evaluate the effectiveness of the *SolarBee*® in improving the poor water quality of HHP, and
- Incorporate the 2011 water quality data into the recent and the historical database to evaluate the occurrence of any significant trends in water quality over the time that data have been collected.

The *SolarBee*® unit was rented on a monthly basis until such time that a decision could be made about whether the unit was effective in altering the poor water quality conditions in HHP. The evaluation of the *SolarBee*® unit is presented in a separate report.

1.3 2011 Project Description

The Nantucket Land Council (NLC) provided almost all of the funding necessary to implement the 2011 water quality project except for a small portion of the CPC grant that had been allocated for 2009 monitoring. The plan for 2011 was to sample HHP about every two weeks for a 7-8 month period. The study began during early April and continued through mid-November. A total of 17 sampling trips were made to HHP, with a full regimen of physical, chemical and biological information collected on all 17 trips. The permit issued by the Nantucket Conservation Commission for installation of the *SolarBee*® in the pond stipulated that a minimum of two separate sampling stations be established for the duration of the 2011 season. As a result, two separate locations were selected on opposite sides of the *SolarBee*® unit and permanently marked with a float and anchor.

1.4 Presentation of the 2011 Report

The performance of the *SolarBee*® long-distance circulation unit on HHP and its effectiveness in breaking the cycle of Cyanophyte blooms has been discussed in a separate report. The material presented here deals strictly with the 2011 water quality of HHP and is organized as follows:

Chapter 1 provides an Executive Summary of the 2011 Project and its findings, some goals for improving HHP water quality, and a summary of the recommendations that have resulted from the 2011 Project.

Chapter 2 explains the 2011 sampling program that was conducted on HHP and the methodology used during the sampling program.

Chapter 3 describes the 2011 water quality of HHP as evaluated through the analysis of physical, chemical and biological data.

Chapter 4 compares the 2009, 2010 and 2011 HHP data to evaluate overall water quality using the three-year database as a reference.

Chapter 5 compares the 2009-2011 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 promote improved water quality in HHP.

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

1.5 2011 Project Findings and Conclusions

HHP is a eutrophic body of water that has exhibited concentrations of total phosphorus and chlorophyll *a* far enough beyond the eutrophy/hyper-eutrophy boundary to be cause for concern. The high levels of total phosphorus measured in HHP during the growing season probably are generated within the system, given the elevated levels of primary productivity in the form of phytoplankton standing crop 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 2009-2011 reflect the extensive blooms of Cyanophytes that were observed and measured during the three years of investigation.

The primary source of the high total nitrogen concentrations documented in HHP during the past two years is not entirely understood. With a small watershed and only a few homes within the area that contributes groundwater to the pond, it is important that the relative contribution of internal versus external cycling of nitrogen be determined for HHP so that long-term remediation can be designed and implemented. Groundwater nutrient data was collected during 2011 from a series of wells surrounding the perimeter of the HHP. The analysis of these data is presented and discussed in a separate report.

Microcystin (MC), a Cyanophyte neurotoxin, was detected in HHP during the mid-summer and fall of 2011. Although the MC occurred in concentrations below recommended maximum levels for drinking water and recreational use, there still should be some concern over the public health and safety issues associated with this substance. In many instances, the greatest damage resulting from Cyanophyte blooms occurs during calm, windless periods on the pond or after cells die and float to the pond surface where they lyse (rupture) and release their 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 and thereby posing 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 Cyanophyte populations identified in HHP during 2009-2011 and the intensity of the mid-summer and fall blooms during the past three years emphasize the serious negative response of the pond to excessive nutrient concentrations and the deteriorated condition of the entire HHP ecosystem. There is no balance in the system; everything in the pond occurs at an accelerated and extreme level. The pond requires considerable attention directed toward the water quality problems that are manifested each year.

Based upon the previous three years of water quality data and the recent historical information that has been collected from HHP and summarized in this report, it appears that 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. The lack of any remedial action, however, will allow the ecosystem 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 Cyanophytes are well-known for their nitrogen-fixing capability which gives this group a highly competitive advantage over the other groups of phytoplankton in the ecosystem. The ideal course for remediation would be to control both nitrogen and phosphorus, with the key focus on phosphorus.

A multi-faceted approach toward water quality management is required for HHP.

1.6 Recommendations

- (1) Head of Hummock Pond requires continued scientific investigation directed toward a series of water quality issues that have been manifested for part of the past decade, including high nutrient enrichment and extended blooms of Cyanophytes that, on different occasions, produce neurotoxins and pose a public safety threat for recreational users of the pond and local residents.
- (2) The Nantucket Land Council, Inc. (NLC) should continue to implement a short-term action plan toward water quality management and remediation for HHP and also for Hummock Pond, two separate but connected bodies of water that both require attention. The NLC has sponsored the previous three years of investigation on HHP and has a strong vision toward stewardship and environmental management on Nantucket Island.
- (3) The 2011 HHP water quality monitoring program should be extended through 2012 to continue documenting water quality issues on the pond and the response of pond water quality to any remediation activities that might be implemented during 2012.
- (4) Continue to monitor groundwater at the well system in the HHP watershed during 2012 according to the plan and protocol implemented in 2011.
- (5) Continue to sample the water quality of Hummock Pond and Head of Hummock Pond before and after the bi-annual spring and fall openings to the Atlantic Ocean in order to evaluate the effect of that flushing event on pond water quality.
- (6) Continue to collect samples in HHP during the mid-summer and fall for the analysis of the Cyanophyte neurotoxin, microcystin.
- (7) Continue to maintain surveillance 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).

1.7 Literature Cited

- Knoecklein, G. 2006. Hummock Pond 2005 Monitoring Report. Prepared for Nantucket Marine and Coastal Resource Department. Northeast Aquatic Research, LLC. 54 pp.
- Conant, K.L. 2008. Hummock Pond Annual Report 2007. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.
- Conant, K.L. 2007. Hummock Pond Annual Report 2006. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.
- 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.

Sutherland, J.W. 2011. Head of Hummock Pond. The 2010 Water Quality Program. A Summary of Physical, Chemical and Biological Monitoring. 51 pp. + Appendix.

Chapter 2

Description of the 2011 Program and Methodology

2.0 Background

Head of Hummock Pond (HHP) is a small water-body, an extension of Hummock Pond (HP), and is connected to HP by a narrow channel traversing a wetland. HHP is considered a kettle pond and has one poorly-defined, intermittent stream channel that enters the pond from the north.

The following is a brief summary of the history of water quality investigations that have occurred on HHP:

- Knoecklein (2006) described eutrophic water quality in HHP following a 2004-2005 comprehensive study of Hummock Pond.
- Conant (2007, 2008) sampled a station on HHP during water quality studies on Hummock Pond by the Nantucket Marine Coastal Resources Department and reported high nutrient concentrations during the 2007 growing season.
- Sutherland and Oktay (2010) reported on a 4-month study of Hummock Pond during 2009 that sampled a single station on HHP and documented hyper-eutrophic water quality conditions that included an intense, season-long bloom of Cyanophytes.
- Sutherland (2011) sampled HHP during 2010, expanding the 2009 water quality program to include spring, summer and fall. The pond exhibited hyper-eutrophic water quality and a season-long Cyanophyte bloom produced neurotoxins that were detected in the water column from early summer into the fall.

2.0.1 Purpose of the 2011 Sampling Program

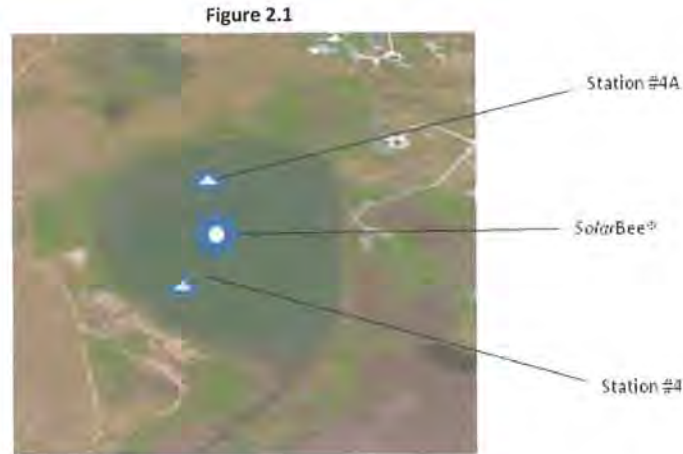
The 2011 sampling program focused on HHP water quality and particularly the parameters that would allow a comprehensive evaluation of the *SolarBee*® unit installed in the pond during April. The promotional material provided by the manufacturer described the ability of the long-distance circulation unit to prevent blooms of Cyanophytes by ending stagnation in the pond and thereby removing the competitive advantage enjoyed by these organisms and their ability to regulate buoyancy and position in the water column. The *SolarBee*® was installed in the pond with the lower end of the intake hose set at about 5-6 feet of water depth to promote total mixing of the water column from the surface down to that depth. According to the manufacturer, this pattern of circulation set up by the *SolarBee*® would prevent internal loading of nutrients from deeper, anoxic areas of the pond which would occur periodically during periods of wind-induced turbulence and circulation of the entire water column.

The report author and Cormac Collier, Executive Director of the Nantucket Land Council Inc. (NLC), developed a monitoring plan which was submitted to the local CPC as part of the application for funding attached to the *SolarBee*® grant request. Although some funding was provided to document 2011 water quality by the CPC grant award, the total amount was not enough to cover the entire 2011 program proposed for evaluation of the unit effectiveness. Furthermore, the local Conservation Commission had attached conditions to the permit allowing the installation of the *SolarBee*® unit in HHP. The primary condition was the addition of a second sampling station on HHP since Conservation Commission members didn't feel that water quality monitored at a single station would necessarily reflect conditions throughout the entire 16-acre pond.

2.0.2 Description of the 2011 sampling program

Water quality was monitored on a regular basis, starting in early April and continuing through early November at a single station (#4) located in the deep area of HHP, just southwest of the pond center and the anchored *SolarBee*®

unit. A secondary sampling station (#4A) was a condition of the Conservation Commission permit and was established north of the *SolarBee*® unit, midway between the unit and the north shore of the pond. Figure 2-1 is an aerial view of the pond (from *Google*™ earth) showing the approximate location of the *SolarBee*® unit as well as Stations #4 and #4A.



Permanent marker buoys were placed at the Station #4 and #4A locations so that the same areas were sampled on each visit to the pond. Station latitude-longitude was recorded on many of the sampling visits using a Garmin GPS 60™ unit. The latitude-longitude coordinates of the *SolarBee*® unit in the pond was about 41.27866 and -70.13439, respectively.

While Station #4 was sampled on every HHP visit during 2011, Station #4A was sampled less frequently to keep the total cost of the 2011 sampling program from doubling. Station #4A was sampled a sufficient number of times, however, to determine whether any significant differences in water quality conditions occurred between the two stations, which was the primary reason the Conservation Commission required this station as a permit condition.

Pond sampling was conducted on about a bi-weekly basis except that more frequent sampling did occur when sudden changes in water quality conditions were observed. HHP was sampled 17 times during 2011, and the sampling dates are summarized in Table 2.1 below.

Table 2.1

Head of Hummock Pond – 2011 Sampling Dates	
April	8 th
May	3 rd , 17 th , 31 st
June	14 th , 28 th
July	5 th , 12 th , 26 th
August	2 nd , 9 th , 23 rd
September	6 th , 20 th
October	4 th , 18 th
November	9 th
Station #4 – sampled on all dates	
Station #4A – sampled on 'greyed' dates	
pond opened on April 27 th , October 28 th	

The data and types of samples collected from 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 to be analyzed for total phosphorus, a series of nitrogen analytes, chlorophyll *a*, algal toxins, specific conductance, pH and (4) samples collected for analysis of the phytoplankton community

Table 2.2 summarizes the water quality parameters that were monitored in HHP during the 2011 sampling season.

Table 2.2	
Water Column	
Physical	
	water temperature
	Secchi depth transparency
	water color
Chemical	
	total phosphorus
	nitrogen series (total nitrogen, ammonia-nitrogen and nitrate-nitrogen)
	pH
	specific conductance
	dissolved oxygen (concentration and percent saturation)
	total dissolved solids
Biological	
	phytoplankton community response
	Chlorophyll <i>a</i> , species composition, diversity, relative abundance, biomass
	Cyanophyte toxins

2.1 Methodology

This section describes the field procedures that were used to collect the samples and the processing that occurred, following collection.

2.1.1 Routine sample collection and processing

Sample collection occurred at the permanent HHP stations, either #4 or #4A, or both. The boat was anchored at the site. The total depth of the water column was measured with a weighted Secchi disk attached to a marked line, and then recorded. Latitude-longitude was recorded on most sampling visits using a Garmin GPS 60™ unit.

Secchi depth was measured using a standard 20 cm weighted disk. 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 2-foot intervals on each sampling date using a Yellow Springs Instrument (YSI) ProODO™ optical Dissolved Oxygen meter.

Water samples for chemistry, phytoplankton and chlorophyll *a* analyses 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 water samples were transferred to cleaned and pre-rinsed 500-mL polyethylene (PE) sample bottles and then stored on ice and in the dark until processing, usually within 2 hours of collection.

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

The samples collected for nutrient chemistry, algal toxins, and chlorophyll *a*, and the phytoplankton samples, were processed immediately following each pond visit. About 75-100 mL aliquots of the raw nutrient chemistry sample was poured into each of 3 separate 125 mL PE containers with screw-top lids labeled either TP, TN, NH3 and NO3

and the accession numbers (sample label code) for the 2011 Nantucket sampling program. The accession format was **11-NIP-###**, with **###** being a series of consecutive numbers, starting at 001, that identified each sample set.

The water sample collected for algal toxin analysis was concentrated through a 47 mm Whatman Glass Microfibre Filter with a nominal pore size of 1.5 μm . The goal was to filter at least 1000 mL of sample through each filter, or some combination of volumes that totaled 1000 mL through several different filters (up to a total of 3 filters). The filters were wrapped in aluminum foil, labeled (date, location, volume filtered, contact information) and placed in a freezer for about 1 hour prior to shipment.

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

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

The filtered samples for algal toxin analysis were placed in a zip-loc bag and envelope and shipped FedEx (overnight delivery) to SUNY-ESF, the Jahn Microbiology Lab in Syracuse, NY. The Jahn Lab has a number of projects underway on developing new detection techniques for cyanophyte toxins in freshwater ecosystems, including the use of molecular techniques (PCR), HPLC and MALDI-TOF mass spectrometry. Cyanophytes produce a number of different toxins, including the hepatotoxic toxins, *microcystins* and *cylindrospermopsin*, and the neurotoxins, *anatoxin-a*, and the PSP toxin, *saxitoxin*. In most cases, the biological function of these toxins is not known. They may serve as antifeedants, metal-binding compounds, growth regulators, or store essential nutrients such as nitrogen. Understanding the biological function of these toxins is a key goal of the Jahn Lab. A Chain of Custody form also accompanied these samples.

Phytoplankton samples were stored in 125 mL amber PE bottles, preserved with gluteraldehyde solution following collection and sent to Ms. Jill Scaglione at Aquatic Analysts Inc. in Middleville, NJ for analysis. Ms. Scaglione is certified in phytoplankton identification and enumeration techniques.

2.2 Analytical Techniques

The methods for water column measurements and sample 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 2.3

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	Ion Chromatograph, Atomic Absorption, Autoanalyzer, Spectrophotometer, pH meter
Biological Characteristics - Phytoplankton	Integrated photic zone sample (Integrated epilimnetic sample archived)	chlorophyll <i>a</i> , species identification and enumeration, biomass
Biological Characteristics - Phytoplankton	Integrated photic zone sample (Integrated epilimnetic sample archived)	microcystin, cylindrospermopsin and anatoxin-a analysis

The report author (JWS) collected most of the data and samples in the field and processed these samples immediately following collection. On two separate occasions, the samples were collected by an intern from the Nantucket Land Council who had been trained, on-site, with the collection techniques and processing protocol.

Samples for nutrients were analyzed by the Keck Water Lab on the RPI Campus in Troy, NY, using standard procedures presented in Table 2.4. Chlorophyll *a*, retained on a filter, was broken down by grinding, extracted in 90% acetone, centrifuged, and determined fluorometrically (Table 2.4).

Table 2.4

PARAMETER	ANALYTICAL METHOD
pH	Electrometric (US EPA Method 150.1)
Specific Conductance	Wheatstone Bridge type meter (US EPA Method 120.1)
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 preserved sample is required for this 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 Utermohl 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, about 3 days). Sedimentation is the preferred method of concentration since it is nondestructive and non-selective. After the settling period, the chamber tower is gently slid off with a cover slip, removing all but 1 mL of sample in a small well at the chamber bottom.

First, the sample is 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 µm 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.

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

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

where, C = number of cells counted (average of two settling chambers)

A_s = area of settling chamber bottom, (mm²)

V = volume of sample settled (50 mL)

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

F = number of fields counted

Conversion to biovolume (mg³ mL⁻¹) - biomass (mg m⁻³). Phytoplankton data derived on a volume-per-volume basis are more useful than numbers per milliliter (density) since algal cell sizes can differ in various bodies of water or within the same body of water at different times of the year. Average measurements were made from

approximately 20 individuals of each 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 ($\mu\text{m}^3\text{mL}^{-1}$) 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 ($\text{mg}^3/\text{mL}^{-1}$) by 1,000.

Author's Note: In general discussions of the 2011 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 phytoplankton cells to species level. The term 'species' is used only when there is discussion concerning cells, colonies or other forms that were positively identified.

2.2.2 Cyanophyte toxin analysis.

Samples were collected for Cyanophyte toxin analysis on 13 different dates during 2011 and shipped FedEx Priority Overnight to the laboratory at SUNY-ESF.

At the SUNY-ESF Jahn Lab in Syracuse, NY, filters with the algal cells are extracted in 10 mL of 50% methanol using ultrasound as described in Boyer 2008. Samples were clarified by centrifugation, and voucher samples stored at -20°C . Microcystin hepatotoxins were determined using the protein phosphatase inhibition assay (PPIA), an enzymatic test closely tied to biological activity of the toxins, using a standard curve of microcystin -LR between 6 and 40 μg per liter. The other toxins including the ATX group consisting of Anatoxin-a and homo-Anatoxin-a; the CYL group including cylindrospermopsin, epi-cylindrospermopsin and deoxycylindrospermopsin; free beta methyl amino alanine (BMAA), and confirmation of microcystin activity or determination of the microcystin variants were done using liquid chromatography coupled with mass spectroscopy (LC-MS) or tandem mass spectrometry (LC-MS/MS). The sensitivity of these tests is dependent on the volumes filtered, therefore the actual method detection limit for any samples that tested negative are provided preceded by a "<" sign. This gives an upper threshold of toxicity and does not mean that samples are necessarily toxic.

2.3 Literature Cited

Boyer, G.L. 2008. Cyanobacterial Toxins in New York and the Lower Great Lakes Ecosystems. In: Proceedings of the Interagency International Symposium on Cyanobacterial Harmful Algal Blooms, H.K. Hudnell (Ed.), Adv. Exp. Med. Biol., 619:151-163.

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

Conant, K.L. 2008. Hummock Pond Annual Report 2007. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.

Conant, K.L. 2007. Hummock Pond Annual Report 2006. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.

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.

Sutherland, J.W. 2011. Head of Hummock Pond. The 2011 Water Quality Program. A Summary of Physical, Chemical and Biological Monitoring. 51 pp. + Appendix.

Chapter 3

2011 Water Quality Results

3.0 Introduction

The HHP ecosystem includes physical and chemical environments and the biotic community. The physical environment consists of 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 (1) the geologic watershed and its contents, (2) land use in the watershed and related human activities, and (3) the hydrology of the pond. The biotic community of the pond results from physical and chemical environments and manifests the quality of these components in species composition and abundance of organisms.

3.1 Results

This chapter presents a summary and discussion of HHP water quality data collected during 2011.

3.1.1 Physical characteristics

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

Figure 3.1



The outlet of HHP is located at the south end of the pond and is a narrow channel about 3-5 m wide that traverses a wetland over a distance of about 250 m before it enters the main body of Hummock Pond at the northeast end.

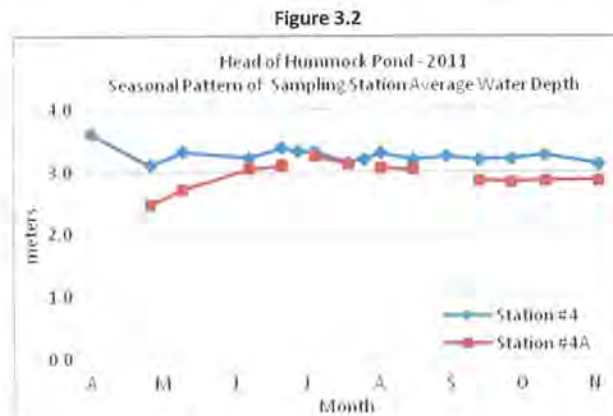
Within the range of normal summer water levels, HHP measures about 260 m wide and 340 m long, and occupies a surface area of about 64,000 m², or 6.5 hectares¹. For the purpose of calculating an approximate volume, if the pond outline is considered to be an exaggerated circle, then the radius is 140 m 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

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

¹ 1 hectare = 2.47 acres

Using this equation, the estimated volume of HHP is 5,772,827 m³, or 4680 acre-feet. One acre-foot is the volume of water sufficient to cover an acre of surface to a depth of 1 foot. 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.

Water depths. Water depth was recorded at the Station #4 and #4A permanent marker buoys during each 2011 sampling visit. Figure 3.2 summarizes the average water depth, in meters, at the two sampling stations.



Except for the April and early May measurements at Station #4, which represent high (3.6 m) and low (3.1 m) depth readings that occurred prior to, and following, the opening of Hummock Pond to the Atlantic Ocean, the average water depth at the station during the remainder of the season was 3.3 m (10.7 ft). Station #4A was sampled less frequently during 2011, and the average depth at this station was 2.9 m (9.6 ft).

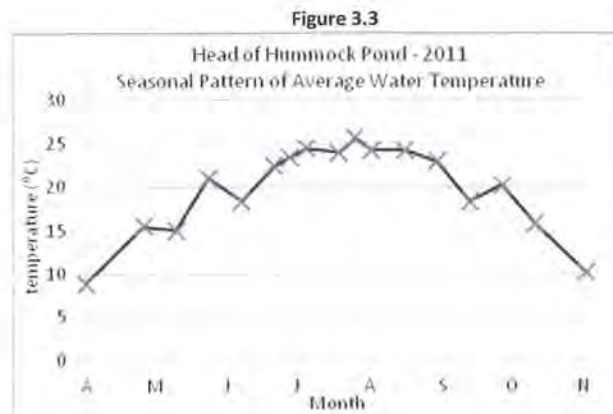
There were 17 sampling trips to HHP during 2011 to collect water column profile data and samples for chemistry and biology. The average water depth during the 2011 sampling season at the primary sampling station, Station #4, was 11 feet during the 17 sampling trips, and integrated hose samples were collected from the surface of the pond down to a depth of 8 or 9 feet on 14 out of the 17 sampling trips.

The fact that integrated samples were collected on most site visits means a more thorough description of the 'water column' characteristics since integrated samples are a cross-sectional view of the entire pond, from surface to the bottom, as compared with grab samples which only represent a specific depth within the water column.

Thermal cycle. Temperature profile data were collected on all 17 sampling trips to HHP during 2011. After analyzing the 2011 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. The individual temperature profile graphs are presented in Appendix 1; only the summary data are presented in this chapter.

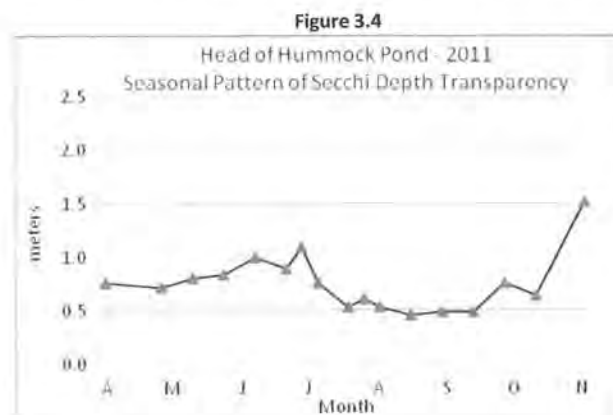
During 2011, HHP exhibited limited temporary stratification during spring and early summer as the water column warmed up; however, by late July and continuing through the remainder of the season, the water column usually was isothermal from surface to bottom. There was a brief period during early August when the average water temperature reached ~26°C, the highest level for the season, and then decreased as ambient air temperatures on the Island decreased during late September, October and early November.

Figure 3.3 is a summary of the average water column temperature at the HHP primary sampling station (Station #4) during the 2011 sampling season.



Minimum temperatures of 8-10°C occurred during the spring and fall; the maximum temperature was ~26°C on August 2nd (Figure 3.3). The 2011 pattern of average water temperature in HHP resembled a bell-shaped curve, with minimum temperatures during the spring and fall and maximum temperatures during the mid-summer.

Transparency. HHP water transparency was low during 2011, averaging only 0.76 m (2.5 ft) during the entire season. The 2011 seasonal pattern of Secchi depth transparency in HHP is presented in Figure 3.4.



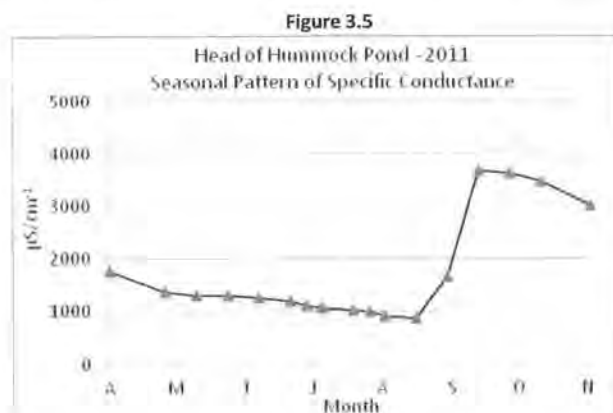
There was a slow rise in transparency from early April to a mid-summer high of 1.1 m on July 5th, followed by a fairly steady decline from then until September 20th when the transparency was 0.48 m. Thereafter, the transparency continued to show an increase until the last reading on November 9th of 1.5 m, which also was the highest reading of the entire 2011 season.

3.1.2 Chemical characteristics

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

HHP specific conductance levels measured during 2011 were very low when compared with measurements from previous seasons, ranging from ~860-3,700 $\mu\text{S}/\text{cm}$ and reflecting only slight estuarine conditions and salt water intrusion from the spring opening of Hummock Pond to the Atlantic Ocean.

Figure 3.5 summarizes the 2011 average conductance values in HHP during the 2011 sampling season.



Following the winter of 2010-2011, the initial pond conductance measured on April 8th, prior to the opening of Hummock Pond to the Atlantic Ocean on April 27th, was 1,773 $\mu\text{S cm}^{-1}$. The next conductance reading was taken on May 3rd, after the closure of Hummock Pond on April 30th, and was slightly lower at 1,364 $\mu\text{S cm}^{-1}$. The following 10 conductance readings showed a steady decline through the August 23rd value of 863 $\mu\text{S cm}^{-1}$, the lowest value recorded during 2011.

Subsequently, there were several high wind events which raised the HHP conductance levels from the low value 863 $\mu\text{S cm}^{-1}$ on August 23 to the highest recorded 2011 reading of 3,677 $\mu\text{S cm}^{-1}$ on September 20th. These high wind events included Hurricane Irene on August 28th-August 29th, an event that occurred on September 4th-September 5th and another sustained wind event on September 9th-September 10th. The effect of sustained high winds events is to drive seawater from the Atlantic Ocean into the main body of Hummock Pond and set up internal waves which move the mass of water and salinity up toward the northeastern end of the pond. From this location, the water with increased salinity (i.e. conductance) is driven into HHP through the small connecting channel. This explains the difference between the extreme values of conductance measured in HHP on August 23rd and September 20th, 863 $\mu\text{S cm}^{-1}$ and 3,677 $\mu\text{S cm}^{-1}$, respectively.

The lack of any delayed increase in conductance following the April 2011 opening of Hummock Pond to the Atlantic Ocean is explained by the fact that the April breach lasted only 3 days (opened on April 27th; closed on April 30th) and there was insufficient exchange of pond water with sea-water to raise the conductance level accordingly. This same phenomenon occurred on October 28th when the fall opening to the Atlantic Ocean was initiated. On that occasion, the breach was initiated just prior to a major high sustained wind coastal storm and only remained open for about 24 hours or less, with the HHP water level only dropping about 12 inches (JWS, personal observation) before the breach was closed and the ponds started filling again.

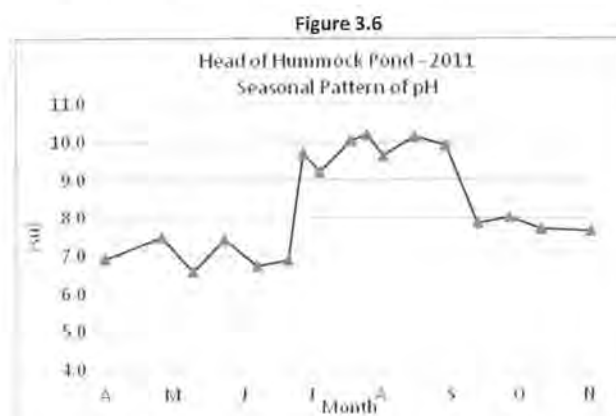
pH. 'pH' is a mathematical transformation of the hydrogen ion [H^+] concentration and expresses the acidity or basicity of water. The lowercase 'p' in pH refers to 'power' or exponent, and pH is defined as the negative logarithm of the hydrogen ion concentration. A change of one pH unit represents a 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 and plants can, however, become stressed or even die when exposed to pH extremes or when pH changes rapidly. In addition to the direct effects of pH on aquatic organisms, the hydrogen ion

concentration affects the aqueous equilibria that involve 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 2011 (Figure 3.6); the seasonal average was 8.4 s.u. Eight (8) of the 17 pH readings taken in 2011 were above 8.0 s.u.; seven (7) readings were greater than 9.0 s.u.; three (3) readings were in excess of 10.00 s.u.



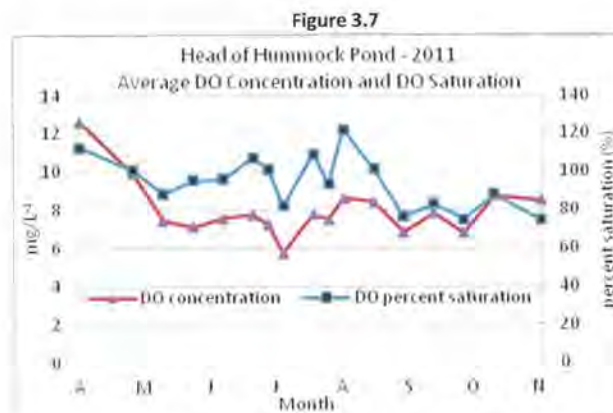
The high pH readings in HHP are related to a considerable imbalance between pond respiration and photosynthesis which results from the intense Cyanophyte bloom that occurred during most of the growing season. Additional sampling during the dark period of the day would be required to determine whether pH levels in the pond decrease to lower levels when there is no photosynthesis occurring and whether carbon dioxide is being replenished by respiration. However, it also is likely that dark respiration in the pond is insufficient to counteract the high productivity and carbon dioxide update during photosynthesis.

Dissolved 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 (phytoplankton, rooted plants) living in the water. Oxygen consumption results from the respiration of aerobic organisms and decomposition in the lower waters by organisms that metabolize the organic material settling down from the productive upper pond levels.

HHP exhibited oxygen concentration and saturation patterns during 2011 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 2011 sampling dates are summarized in Figure 3.7. Detailed graphs showing individual depth profiles of percent saturation on each sampling date are presented in Appendix 1.

The upper portion of the HHP water column usually was either near-saturation or super-saturated with dissolved oxygen (≈ 80 -120%) during most of the 2011 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 during periods when the wind was insufficient to mix the entire water column of the pond from the surface to the bottom.



The oxygen saturation gradient that occurred from surface to bottom on each sampling date (see Appendix) was a visual display of the relative rates of photosynthesis and decomposition occurring in the pond at that moment in time. There were only three (3) sampling dates during the entire 2011 sampling season when oxygen saturation essentially was the same from surface to bottom. The occurrence of significant oxygen saturation gradients on 14 of 17 sampling dates indicates that the pond was sampled during a period of time when surface winds were insufficient to mix the pond from surface to bottom, thus allowing a gradient to become established.

The average depth profile temperature in HHP was $>18^{\circ}\text{C}$ from late May until at least early-to-mid October (Figure 3.3), 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 $9\text{--}160\ \mu\text{g L}^{-1}$ and averaged $34.9\ \mu\text{g L}^{-1}$, a moderate level that suggests bloom conditions of phytoplankton.

In summary, the 2011 seasonal depth profile of oxygen concentration/saturation in HHP was characteristic of waters that concurrently experience 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-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.

3.1.3 Plant Nutrients

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

$$\text{Total nitrogen (TN)} = \text{Organic nitrogen (ON)} + \text{Ammonia-nitrogen (NH}_3\text{-N)} + \text{Nitrate-nitrogen (NO}_3\text{-N)} + \text{Nitrite (NO}_2\text{)}$$

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 waters since it is readily converted to **nitrate** if enough oxygen is present for oxidation.

Although **TN** is an essential nutrient for plants and animals, excess amounts of nitrogen in a waterway can lead to low levels of dissolved oxygen and negatively affect 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 water produces forms of nitrogen that are assimilated by aquatic plants during photosynthesis. There are several nitrogen forms that are important to the biota of water bodies including inorganic **nitrate** and **ammonia**, and the **organic nitrogen** fraction.

Ammonia-nitrogen, $\text{NH}_3\text{-N}$, 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.

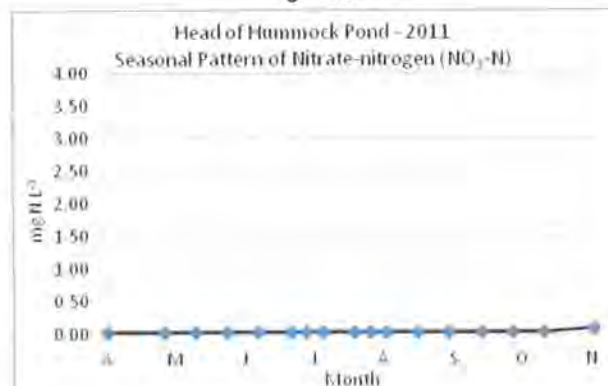
Nitrate-nitrogen, $\text{NO}_3\text{-N}$, is produced by the bacterial conversion of organic and inorganic nitrogen compounds from a reduced state to an oxidized state and is readily assimilated by algae and other green plants. Collectively, **nitrate** and **ammonia** provide most of the nitrogen available for assimilation by green plants. Organic nitrogen in lakes consists of dissolved and particulate forms, and represents nitrogen contained in the plankton and seston.

Some important characteristics of the nitrogen dynamics in HHP during 2011 are as follows:

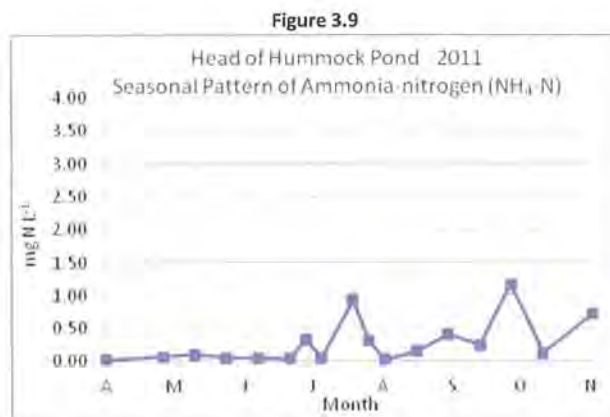
- Nitrate concentrations were below 2009-2010 values and at the level of detection for the entire season,
- Ammonia concentrations were higher than measured in 2009 and 2010, and exhibited a seasonal pattern which was different than the pattern observed in the previous years,
- Organic nitrogen concentrations were less than 2010 values, indicating reduced phytoplankton productivity,
- Total nitrogen concentrations in HHP during 2011 were lower than 2010 values and showed the same seasonal pattern of progression as observed in 2009 and 2010,
- The average concentration of total nitrogen indicates that HHP is a highly productive water body.

The average **nitrate-nitrogen** concentration in HHP was extremely low during 2011; nitrate-nitrogen averaged 0.03 mg N L^{-1} for the season (Figure 3.8), which is the analytical laboratory level of detection for this analyte.

Figure 3.8



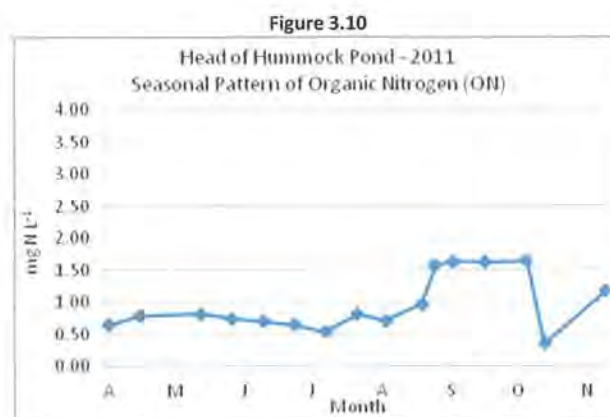
Ammonia-nitrogen averaged 0.28 mg N L^{-1} during 2011. Concentrations generally were low from April through June (Figure 3.9) and exhibited peaks on July 26th (0.93 mg N L^{-1}) and October 4th (1.1 mg N L^{-1}).



The 2011 period of elevated ammonia-nitrogen concentrations corresponds to the highest recorded pH values in HHP, averaging 9.4 s.u. on eight sampling dates.

In view of the high pH values in HHP during this period, most of the ammonia-nitrogen probably 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.

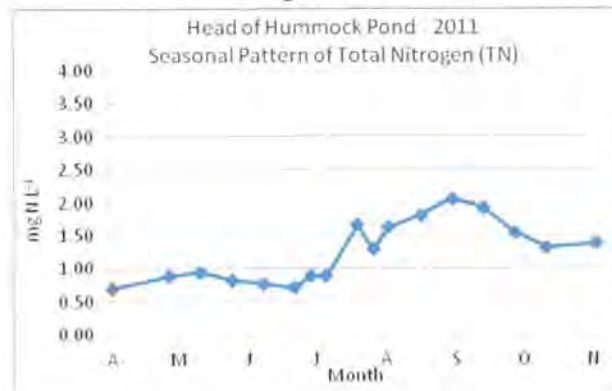
A simple method for calculating **organic nitrogen** in water is to subtract ammonia+nitrate concentrations from the TN concentration. The result for the 2011 HHP data is shown in Figure 3.10.



The average concentration of organic nitrogen in HHP during 2011 was 0.93 mg N L^{-1} , about one-half of the average value calculated for 2010 (1.66 mg N L^{-1}). Although some portion of the organic nitrogen is in soluble, or dissolved, form, the organic nitrogen concentrations from 2011 are high and correspond to high densities and biomass of phytoplankton in the water column throughout the sampling period.

The seasonal pattern of **total nitrogen** (TN) concentration measured in HHP during 2011 is summarized in Figure 3.11.

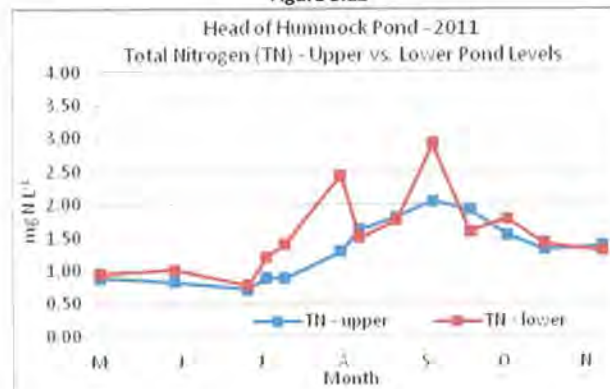
Figure 3.11



TN values generally increased during the first five months of the season, reached a maximum of 2.1 mg N L⁻¹ on September 6th, and declined about 30 percent thereafter and then leveled off. The average TN value for 2011 was 1.2 mg N L⁻¹.

There were 13 sampling dates in 2011 when TN samples were collected from both the upper and lower regions of HHP. As shown in Figure 3.12, TN concentrations were slightly higher in the lower region of the pond during the early part of 2011.

Figure 3.12



Thereafter, TN concentrations in the lower waters peaked in early August and early September (Figure 3.12), then were similar for the remainder of the season. The TN peaks in the lower waters summarized in Figure 3.12 correspond to the period of intense Cyanophyte blooms in the pond. The greater TN concentrations during most of that period in the lower waters can be explained by the biomass of phytoplankton cells that settle to the bottom, become concentrated, and increase the TN concentration above ambient levels.

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

The most important substance in lake and pond metabolism is the **total phosphorus (TP)** content of unfiltered lake water which contains **particulate phosphorus** (in suspension as particulate matter) and the **dissolved**, or **soluble**, **phosphorus** fraction. Particulate phosphorus includes 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 varies in lakes and ponds, probably as a function of allochthonous material (coming from outside the system) containing phosphorus, which enters at different times of the year.

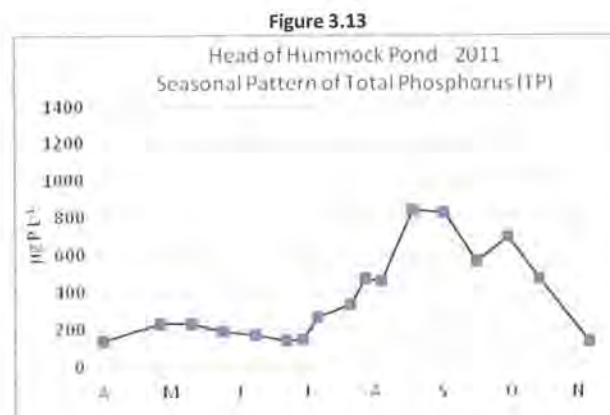
A 'typical' pond would receive significant inputs of phosphorus during periods of high runoff, such as spring snowmelt. In fact, in many north temperate lakes and ponds in the northeastern United States, the period of spring runoff represents about 60-70 percent of the average annual runoff that enters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

Pathways of total phosphorus (TP) introduction to HHP include atmospheric deposition (both dryfall and wetfall) and groundwater flow at a rate that is affected by precipitation falling on the pond and the surrounding watershed. The concentration of TP in the groundwater is a function of watershed land use and the effectiveness of individual wastewater treatment systems which contribute groundwater discharge to the surrounding area and the pond. Groundwater flow in the watershed would vary based upon precipitation patterns during the year.

The TP dynamics observed in HHP during the 2011 study include the following:

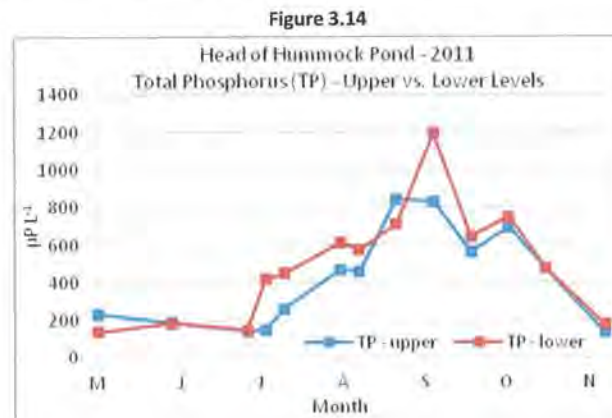
- Concentrations of TP exhibited a distinct seasonal pattern; they were high from early April until late June-early July, became higher from late August through early October and declined thereafter,
- High TP concentrations during the sampling period indicates that a continual source of TP was available, either in the form of autochthonous (from inside the system) or allochthonous (from outside the system) material.
- Concentrations of TP near the bottom generally were the same or greater than TP concentrations in the remainder of the pond on any sampling date, which probably reflects the mobilization of TP from the bottom sediments during periods of anoxia.
- There generally was good agreement between the seasonal patterns of TP and TN concentrations in HHP suggesting a relative steady state equilibrium with regard to the intense productivity occurring in the pond.

The TP concentration in HHP was high during 2011 and exhibited a pronounced seasonal pattern (Figure 3.13). The average TP concentration was $370.1 \mu\text{g P L}^{-1}$, for the 17 sampling dates. This average is misleading, however, since the early season TP concentration averaged only $177.6 \mu\text{g P L}^{-1}$ from April through early July. Thereafter, the TP concentration averaged $504.8 \mu\text{g P L}^{-1}$ for the remainder of the sampling season, which was indicative of excessive pond productivity and extensive algal blooms.



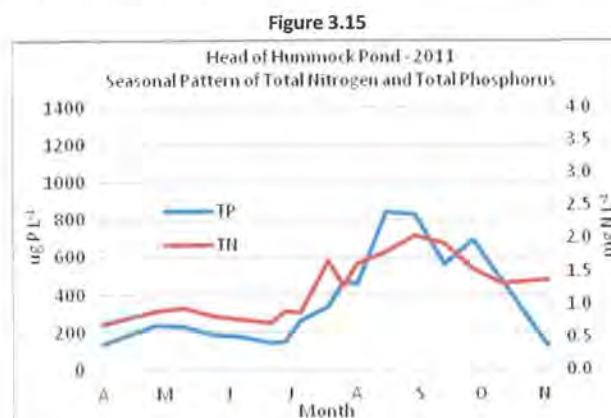
Taking into account the physical, chemical and biological conditions measured in HHP during 2011, the likely source of high mid-summer TP concentrations is the persistent 'bloom' conditions coupled with the decomposition of organic matter in the lower waters resulting in the development of anoxic conditions and mobilization of TP from the bottom sediments.

There were 13 sampling dates during 2011 when grab water samples were collected just above the bottom sediments in addition to the integrated water samples from the surface of HHP down to several feet off of the bottom. Both samples were analyzed for TP and the results are shown in Figure 3.14.



The samples collected near the bottom of HHP generally had TP concentrations similar to the upper waters early and late in the season and higher TP concentrations than the upper waters during the period from July through mid-October when high rates of productivity were occurring in HHP (Figure 3.14). Higher concentrations of TP would be expected in this lower pond region as a result of decomposition of organic matter and the mobilization of phosphorus from the bottom sediments during periods of anoxia (low dissolved oxygen concentrations).

Figure 3.15 shows the 2011 seasonal pattern of TN and TP in HHP. In spite of differences in the relative concentrations of the two nutrients, there was good agreement between overall pattern (rise and fall) as the 2011 season progressed from spring through summer and into fall.



The consistent agreement between TN and TP and the absence of any wild fluctuations in the concentration of either nutrient during the entire sampling period suggests a stable pond ecosystem with the emphasis focused solely on productivity.

3.1.4 Phytoplankton

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

The 2011 phytoplankton collections began following ice-out and provide an accurate evaluation of the community since a complete picture of the seasonal transitions were documented during the sampling period. A total of 17 samples were collected during 2011 as compared with 15 samples collected during 2010 and 8 samples collected during 2009. Under ideal circumstances, several more years of monitoring would be required before the HHP phytoplankton community could be characterized accurately. The unique nature of individual growing seasons in a body of water such as HHP is described later as the community dynamics are presented and discussed.

The 2011 HHP phytoplankton community exhibited several important features that characterize the general water quality of the pond. These features may be summarized as follows

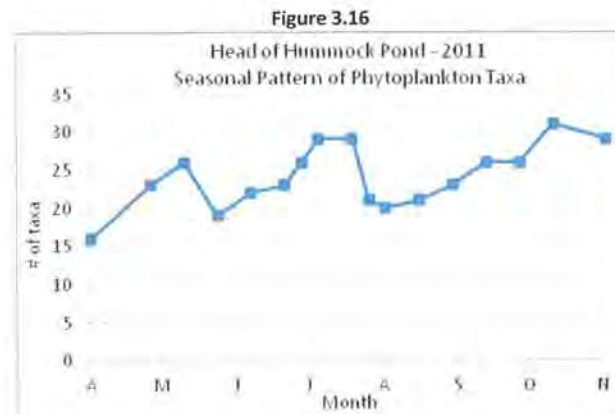
- There was a seasonal succession of phytoplankton groups starting early in 2011,
- *Density* and *biomass* exhibited distinct seasonal patterns during 2011,
- There was a seasonality of chlorophyll *a* concentrations in HHP during 2011,
- Intense Cyanophyte blooms occurred during 2011 and the prevalent species was *Chroococcus limneticus*,
- The Cyanophyte toxin, microcystin, was detected in some 2011 samples submitted for analysis.
- The phytoplankton community characteristics, both individually and collectively, observed during 2011 reflect high productivity and continued poor water quality.

Description of the assemblage. There were 67 taxa identified in the 2011 phytoplankton samples; all of the major algal groups were represented (Table 3.1).

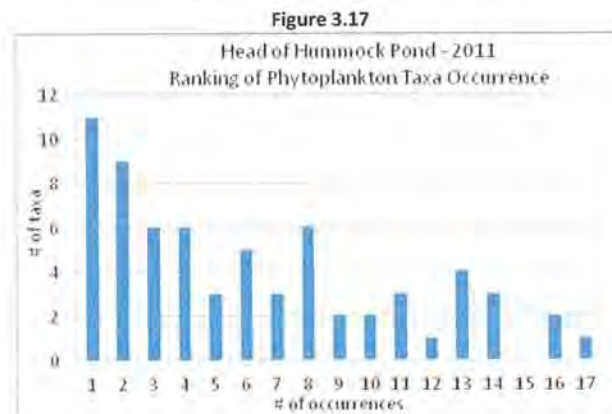
Table 3.1

Cyanophyta	Chlorophyta	Chrysophyta (Bacillariophyceae)
<i>Anabaena flos aquae</i>	<i>Pandorina morum</i>	<i>Hippodonta</i> sp.
<i>A. spiroides</i>	<i>Pediastrum duplex</i>	<i>Navicula</i> spp.
<i>Aphanocapsa elachista</i>	<i>Pyramimonas tetrarhyncus</i>	<i>Nitzschia</i> sp.
<i>Chroococcus limneticus</i>	<i>Quadrigula lacustris</i>	<i>Planothidium</i> sp.
<i>C. turgidus</i>	<i>Scenedesmus abundans</i>	<i>Rhoicosphenia curvata</i>
<i>Gloeocapsa rupestris</i>	<i>S. bijuga</i>	<i>Stauroneis</i> sp.
<i>Merismopedia glauca</i>	<i>S. quadricauda</i>	<i>Stephanodisus</i> sp.
<i>Microcystis incerta</i>	<i>Selenastrum minutum</i>	<i>Surirella</i> sp.
Chloromonadophyta	<i>Sphaerocystis Schroeteri</i>	<i>Synedra acus</i>
<i>Gonyastomum semen</i>	<i>Staurastrum natator</i> var. <i>crassum</i>	<i>S. fulgens</i>
Chlorophyta	<i>Tetraedron minimum</i>	<i>S. ulna</i>
<i>Ankistrodesmus falcatus</i>	<i>Xanthidium</i> sp.	<i>Thalassiosira</i> sp.
<i>Closterium</i> sp.	Chrysophyta (Bacillariophyceae)	Chrysophyta (Chrysophyceae)
<i>Coelastrum cambricum</i>	<i>Achnanthes</i> sp.	<i>Mallomonas</i> sp.
<i>Cosmarium</i> spp.	<i>Achnanthes</i> sp.	<i>Ochromonas</i> sp.
<i>Crucigenia quadrata</i>	<i>Aulacoseria granulata</i>	Euglenophyta
<i>Dictyosphaerium ehrenbergianum</i>	<i>Cocconeis</i> sp.	<i>Euglena</i> sp.
<i>Eudarina elegans</i>	<i>Cyclotella</i> sp.	<i>Peranema</i> sp.
<i>Elakatothrix gelatinosa</i>	<i>Cymbella</i> sp.	<i>Phacus</i> sp.
<i>Kirchneriella lunaris</i>	<i>Eunotia</i> sp.	<i>Trachelomonas</i> spp.
<i>Lagerheimia ciliata</i>	<i>Fragilaria islandica</i>	Pyrrhophyta (Cryptophyceae)
<i>L. quadriseta</i>	<i>Gomphonema constrictum</i>	<i>Cryptomonas ovata</i>
<i>Oocystis borgei</i>	<i>G. lanceolatum</i>	Pyrrhophyta (Dinophyceae)
<i>O. pusilla</i>	<i>G. truncatum</i>	<i>Peridinium cinctum</i>
<i>O. solitaria</i>	<i>Gyrosigma</i> sp.	

The total number of taxa in the phytoplankton community fluctuated between high values of 25-31 and low values of 16-20 throughout the study period (Figure 3.16). The total phytoplankton taxa in the community exhibited a pattern of peaks and troughs during the summer with an overall increase from the low value of 16 taxa on April 8th to the high value of 31 taxa on October 18th. Community richness averaged 24.1 (± 4.1) taxa for the entire 2011 sampling period, which was about 30 percent of the total taxa identified in the 2011 pond assemblage.



The occurrence of each phytoplankton taxon in the 2011 samples was ranked to determine how many times the taxon occurred in the 17 samples. The results of this ranking are presented in Figure 3.17.



Most taxa occurred once, or a few times, while a few taxa occurred in more than one-half of the samples (Figure 3.16). Eleven (11) taxa, or about 15 percent of the total (67), occurred only on a single sampling date, and 49 taxa (about 75 percent of total) occurred in less than one-half of the samples collected. Only 1 taxon occurred on all 17 sampling dates.

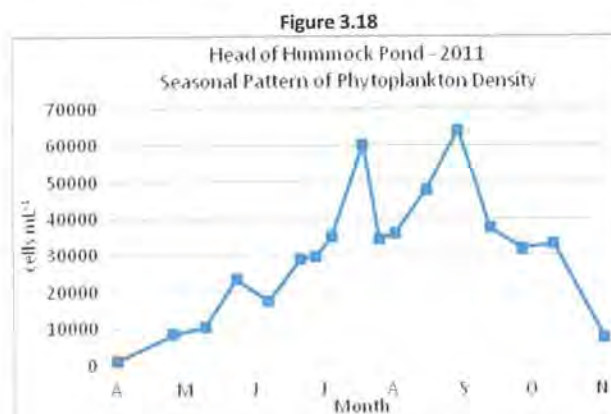
Table 3.2 lists the phytoplankton taxa that occurred most frequently in the 2010 samples and some characteristics for each taxon including cell biomass, seasonality, and number of times the taxon was dominant in the community out of 17 sampling dates. As a group, Cyanobacteria were the most frequent density and biomass dominants in the community. Three (3) species of Cyanophytes were community density dominants a total of 21 times, and community biomass dominants a total of 11 times. Only 11 other non-Cyanophyte taxa were either density or biomass dominants in the community during the entire 2011 season.

Table 3.2

Major Group	Cell Biomass	Number of times the taxa			2011
Taxon-species	(μm^3)	Occurred	BM dominant	DN Dominant	Seasonality
Cyanobacteria (Cyanophyta)					
<i>Anabaena spiroides</i>	308.0	8	4	5	summer-early fall
<i>Chroococcus limneticus</i>	381.5	11	7	7	summer-fall
<i>Chroococcus turgidus</i>	381.5	8	0	0	summer-early fall
<i>Microcystis incerta</i>	3.0	10	0	9	summer-fall
Chlorophyta					
<i>Lagerheimia quadriseta</i>	343.3	8	0	0	late spring-early summer-fall
<i>Oocystis borgei</i>	518.0	12	1	0	all year
<i>O. pusilla</i>	135.0	11	0	2	spring-early summer-fall
<i>Pediastrum duplex</i>	8000.0	14	7	1	all year
<i>Scenedesmus quadricauda</i>	100.0	16	2	6	all year
<i>Sphaerocystis schroeteri</i>	775.0	10	8	7	spring-early summer-fall
<i>Tetraedron minimum</i>	30.0	13	0	0	all year
Bacillariophyta					
<i>Cocconeis</i> sp.	500.0	13	0	0	all year
<i>Cyclotella</i> sp.	268.0	17	2	3	all year
<i>Fragilaria islandica</i>	289.4	9	0	0	all year
<i>Navicula</i> spp.	350.0	16	1	1	all year
<i>Nitzschia</i> sp.	190.0	13	1	1	all year
<i>Planothidium</i> sp.	80.0	14	0	0	all year
<i>Stephanodisus</i> sp.	2000.0	9	0	0	all year (sporadic)
<i>Synedra acus</i>	350.0	11	1	1	all year (sporadic)
<i>S. fulgens</i>	350.0	8	0	0	spring-summer-early fall
Euglenophyta					
<i>Trachelomonas</i> spp.	1144.5	13	1	1	all year
Pyrrophyta					
<i>Cryptomonas ovata</i>	3890.7	14	5	0	all year

BM = biomass; DN = density; * = biomass unknown

Density. The 2011 density of phytoplankton in the pond ranged between 1,103 cells mL^{-1} and 63,883 cells mL^{-1} , and averaged 31,045 cells mL^{-1} for the entire period. Figure 3.18 presents the 2011 seasonal pattern of phytoplankton cell density and shows that three (3) separate peaks occurred.

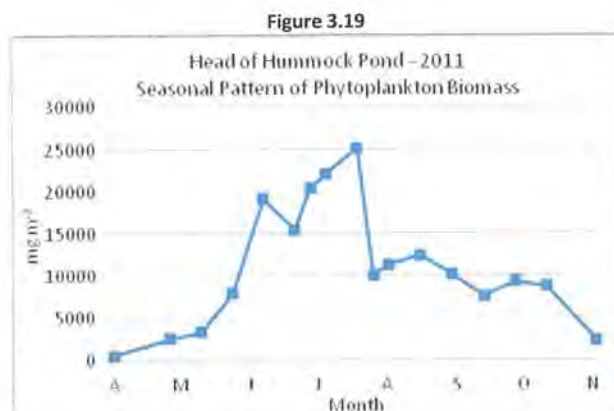


The first peak was on May 31st following the closure of Hummock Pond after the spring opening to the Atlantic Ocean. The second peak occurred on July 26th and was the second highest density recorded during 2011. The highest density occurred on September 6th and community values declined thereafter throughout the remainder of the 2011 season (Figure 3.18).

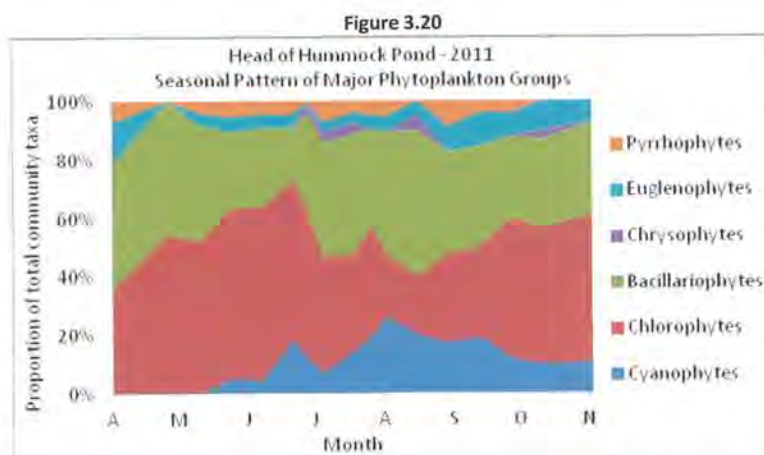
Biomass. Cell biovolume was used as the indicator to evaluate phytoplankton taxon biomass, or productivity, since cell counts and conversion into density does not necessarily account for the significant size difference among various phytoplankton taxa. The ambiguous nature of density as a community descriptor is evident when viewing the cell biomass listed in Table 3.2 and noting the difference between the size of, for example, *Pediastrum duplex*

cells and other phytoplankton listed in the table. Differences in relative biomass (the size of individual cells) explain how small numbers of cells can make a taxon a dominant member in the phytoplankton community.

During 2011, phytoplankton community biomass ranged from 504 mg m^{-3} to $25,160 \text{ mg m}^{-3}$, and averaged $11,044 \text{ mg m}^{-3}$ for the entire study period. The 2011 seasonal pattern of phytoplankton biomass exhibited a single major peak which occurred near the end of July and is shown in Figure 3.19.



Seasonality and associations. The extended period of sampling from early April through early November 2011 revealed a pattern of seasonal succession of various phytoplankton groups, and also patterns of density and biomass that were quite similar to each other. Figure 3.20 is a basic look at the 2011 phytoplankton community dynamics as the seasons progressed from spring through fall; it summarizes the proportion of the total community represented by the different phytoplankton groups.



Chlorophytes, Bacillariophytes, Euglenophytes and Pyrriophytes were present all year and their proportions in the community composition varied according to the season (Figure 3.20). Cyanophytes were not detected in the community until late spring-early summer, and the Chrysophytes only occurred during the mid-summer and late fall period, being absent during the remainder of the year (Figure 3.20).

Phytoplankton density (Figure 3.21) and biomass (Figure 3.22) present the 2011 community dynamics in slightly different perspectives. While both community variables portray an accurate seasonal pattern of succession, the biomass summary is a more accurate and realistic representation of the instantaneous community conditions since size of the individual cells is considered instead of cell density. In terms of seasonal succession, the Euglenophytes,

Bacillariophytes, Cryptophytes, Chrysophytes and Chlorophytes dominated at various times during spring and early summer and then there was a transition to total dominance by Cyanophytes from about mid-June through the remainder of the study period.

Figure 3.21

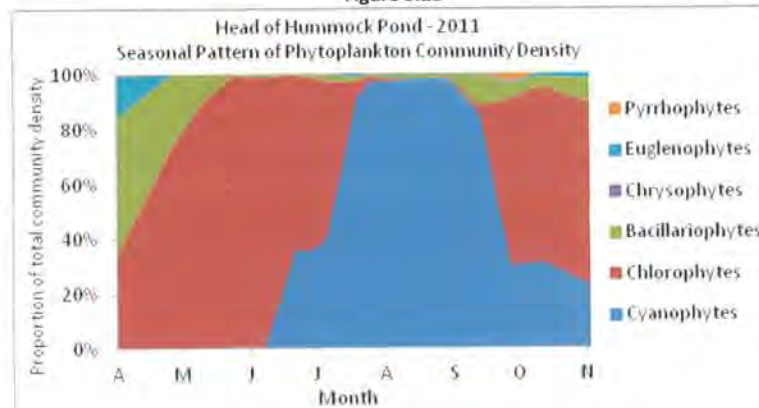
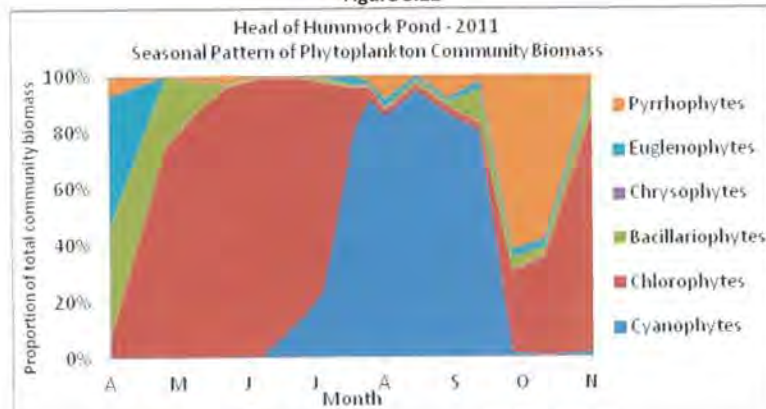


Figure 3.22



Dominance. Usually only 2 or 3 phytoplankton taxa were dominant in the HHP community during 2011 (Table 3.3). The most frequent dominant taxa were *Sphaerocystis Schroeteri* (occurred on 8 dates), *Chroococcus limneticus* (7), *Pediastrum duplex* (6) and *Coelastrum cambricum* (5). The succession of the spring and early summer community is marked by the changeable nature of the dominant taxa among sampling dates with green algae and cold-water forms (Cryptophytes, Chrysophytes) making up the major proportion of the biomass and then green algae dominating until the cyanophytes appeared in early July (Table 3.3). There were 5 dates in August and September where 2 taxa dominated >85% the community biomass and *Chroococcus limnerticus* always was one of the taxa. The late fall saw a change back to cold-water forms and Cyanophytes no longer were dominant in the community.

Diversity. Seasonal phytoplankton diversity in HHP was measured using the Shannon-Wiener function² which calculates diversity, [H], using number of taxa and the portion of individuals among the taxa on each sampling date. An increase in either factor will increase the value of the diversity index.

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.

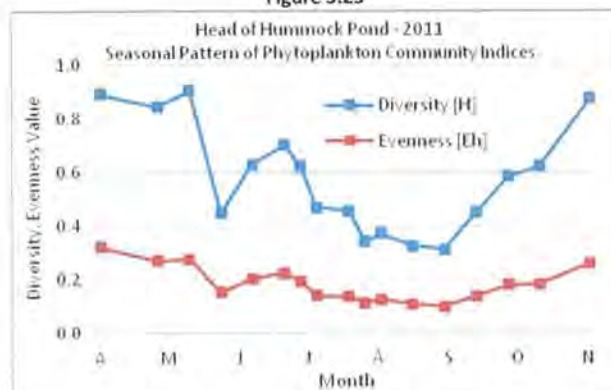
Table 3.3

Sampling Date	Biomass Rank	Taxon (Major Group)	% of Total Biomass
04/08/11	1	<i>Trachelomonas</i> spp. (Euglenophyta)	33
	2	<i>Cyclotella</i> sp. (Chrysophyta)	16
	3	<i>Euglena</i> sp. (Cryptophyta)	12
	4	<i>Gyrosigma</i> sp. (Chrysophyta)	10
05/03/11	1	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	34
	2	<i>Cyclotella</i> sp. (Chrysophyta)	21
	3	<i>Coelastrum cambricum</i> (Chlorophyta)	18
05/17/11	1	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	42
	2	<i>Coelastrum cambricum</i> (Chlorophyta)	12
	3	<i>Scenedesmus quadricauda</i> (Chlorophyta)	12
05/31/11	1	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	70
	2	<i>Scenedesmus quadricauda</i> (Chlorophyta)	19
06/14/11	1	<i>Pediastrum duplex</i> (Chlorophyta)	36
	2	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	33
	3	<i>Eudorina elegans</i> (Chlorophyta)	22
06/28/11	1	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	54
	2	<i>Pediastrum duplex</i> (Chlorophyta)	12
	3	<i>Eudorina elegans</i> (Chlorophyta)	11
07/05/11	1	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	55
	2	<i>Pediastrum duplex</i> (Chlorophyta)	17
	3	<i>Anabaena spiroides</i> (Cyanophyta)	15
07/12/11	1	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	64
	2	<i>Chroococcus limneticus</i> (Cyanophyta)	24
	3	<i>Pediastrum duplex</i> (Chlorophyta)	7
07/26/11	1	<i>Chroococcus limneticus</i> (Cyanophyta)	75
	2	<i>Sphaerocystis Schroeteri</i> (Chlorophyta)	7
	3	<i>Pediastrum duplex</i> (Chlorophyta)	6
08/02/11	1	<i>Chroococcus limneticus</i> (Cyanophyta)	83
	2	<i>Anabaena spiroides</i> (Cyanophyta)	6
08/09/11	1	<i>Chroococcus limneticus</i> (Cyanophyta)	80
	2	<i>Cryptomonas ovata</i> (Cryptophyta)	8
08/23/11	1	<i>Chroococcus limneticus</i> (Cyanophyta)	80
	2	<i>Anabaena spiroides</i> (Cyanophyta)	13
09/06/11	1	<i>Chroococcus limneticus</i> (Cyanophyta)	85
	2	<i>Cryptomonas ovata</i> (Cryptophyta)	7
09/20/10	1	<i>Chroococcus limneticus</i> (Cyanophyta)	77
	2	<i>Nitzschia</i> sp. (Chrysophyta)	9
10/04/11	1	<i>Cryptomonas ovata</i> (Cryptophyta)	62
	2	<i>Pyramimonas tetrahynchus</i> (Chlorophyta)	18
	3	<i>Coelastrum cambricum</i> (Chlorophyta)	7
10/18/11	1	<i>Cryptomonas ovata</i> (Cryptophyta)	58
	2	<i>Pyramimonas tetrahynchus</i> (Chlorophyta)	17
	3	<i>Coelastrum cambricum</i> (Chlorophyta)	13
11/9/11	1	<i>Coelastrum cambricum</i> (Chlorophyta)	34
	2	<i>Pediastrum duplex</i> (Chlorophyta)	28
	3	<i>Staurastrum natator</i> var. <i>crassum</i> (Chlorophyta)	12

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 allocation on a sampling date. The next step in the process was to calculate equitability, [**E_H**], 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).

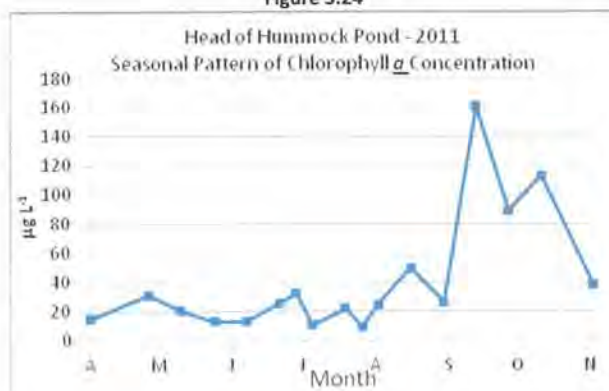
Community diversity [**H**] and equitability, or evenness, [**E_H**] during 2011 are presented in Figure 3.23. Diversity ranged between values of 0.90 and 0.31. Diversity was highest at the beginning and end of the 2011 season, with widely fluctuating, low values during the late spring, summer and early fall. The lowest values, [**H**] less than 0.4, occurred between August 2nd and September 6th when the community was totally dominated by the Cyanophytes (> than ~ 90 percent of total community density and biomass). Evenness values ranged between 0.10 and 0.32, and the seasonal pattern of evenness [**E_H**] essentially was the same as the diversity pattern (Figure 3.23).

Figure 3.23



Chlorophyll *a*. The chlorophyll *a* samples collected on 17 sampling dates in 2011 averaged $40.4 \mu\text{g L}^{-1}$, and ranged from $9.0 \mu\text{g L}^{-1}$ to $160.2 \mu\text{g L}^{-1}$. The average mid-summer concentration for 12 sampling dates when the pond water temperature $\geq 18^\circ\text{C}$ was $39.3 \mu\text{g L}^{-1}$. Chlorophyll *a* concentrations were low-to-moderate from April through September 6th, then increased by a factor of 6 to $160.2 \mu\text{g L}^{-1}$ on September 20th and declined thereafter through the remainder of the season (Figure 3.24).

Figure 3.24



There was no clear correlation (relationship) between chlorophyll *a* concentration and phytoplankton community density during 2011. Neither was there a good relationship between chlorophyll *a* and phytoplankton community biomass during 2011 although some correlation started to appear at the end of the season.

The HHP algal associations documented in 2011 provide some additional important information about the general trophic 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, 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 enhanced trophic (productivity) of the HHP ecosystem; the complete dominance of the Cyanophytes during mid-summer and early fall indicates eutrophic conditions.

SUNY-ESF report on cyanophyte toxins.

The following material was provided by the State University of New York, College of Environmental Science and Forestry where the 2011 Cyanophyte filtered samples were received and analyzed for toxins.

The results for all Cyanophyte toxins are summarized in Table 3.4.

Table 3.4

Sample Date	Microcystin by PPIA			ATX	CYL	BMAA
	ug/L	c.v.	n	ug/L	ug/L	ug/L
5/17/2011	<0.07		1	<0.11	<0.03	<0.09
5/17/2011	<0.06		1	<0.12	<0.04	<0.10
6/28/2011	<0.06		1	<0.09	<0.03	<0.08
6/28/2011	<0.06		1	<0.09	<0.03	<0.08
7/5/2011	<0.06		1	<0.09	<0.01	<0.08
7/26/2011	0.66	0.09	2	<0.44	<0.04	<0.32
8/23/2011	1.11	0.39	2	<0.26	<0.03	<0.36
8/23/2011	1.43	0.18	2	<0.26	<0.03	<0.36
9/20/2011	0.16	0.11	2	<0.12	<0.02	<0.12
10/18/2011	0.18	0.01	2	<0.77	<0.11	-

PPIA (protein phosphatase inhibition assay), ATX (Anatoxin-A), CYL (cylindrospermopsin and variants), BMAA (beta methyl amino alanine)

Of the five (5) samples in which microcystins were detected by PPIA, only two (2) samples were near the World Health Organization threshold for drinking water of 1 µg microcystins per L. All samples were well below the MA Department of Public Health threshold for recreational contact of 10 µg/L microcystins. None of the samples submitted during 2011 tested positive for the other common Cyanophyte toxins anatoxin-a, cylindrospermopsins, or BMAA.

3.1.5 Trophic status

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

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

- Oligotrophic – usually large and deep water bodies with rocky or sandy shorelines, low phosphorus enrichment, limited rooted plant growth, low algal growth and adequate dissolved oxygen throughout the water column.
- Mesotrophic – an intermediate category with characteristics between the 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) commonly is used to characterize the trophic status (overall health) of a water body (Carlson, 1977). Since they tend to correlate, the three independent variables most often used to calculate the Carlson index include chlorophyll pigments, total phosphorus and Secchi depth (water clarity). Individual TSI values are calculated from the following equations:

- Total phosphorus TSI (TSIP) = $14.42 * [\ln(TP \text{ average})] + 4.15$
- Chlorophyll a TSI (TSIC) = $9.81 * [\ln(Chlorophyll \ a \ average)] + 30.5$
- Secchi disk TSI (TSIS) = $60 - (14.41 * [\ln(Secchi \ average)])$

Of these three variables, chlorophyll probably will yield the most accurate index since it is the most accurate predictor of biomass in the ecosystem. This was found to be the case in HHP during 2010, but was not the case in 2011. Phosphorus may be a more accurate predictor of the summer trophic status of a water body than chlorophyll if the measurements also are made during the winter months, which did not occur in this study. Secchi depth probably is the least accurate predictor but also is the most affordable and easiest measure to obtain since it is a subjective visual determination.

Table 3.5 presents the relationships among Trophic Index (TI), chlorophyll ($\mu\text{g L}^{-1}$), phosphorus ($\mu\text{g L}^{-1}$), Secchi depth (meters), and Trophic Class (after Carlson, 1996):

Table 3.5

Trophic Index	Chlorophyll ($\mu\text{g L}^{-1}$)	TP ($\mu\text{g L}^{-1}$)	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 2011 to calculate the Carlson TSI using all three variables. However, instead of using all of the data collected during the period of study, only the summer values were used when the average water column temperature was 18°C or greater. This temperature restriction lowered the number of sampling dates from 17 to 12, and included the period from May 31st through October 4th.

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 mid-summer chlorophyll *a* = $39.3 \mu\text{g/L}$

Chlorophyll *a* TSI = $9.81 * [\ln (39.3)] + 30.6$

TSI = $(9.81)(3.7) + 30.6$

TSI = 66.9

Total phosphorus

Average mid-summer total phosphorus = $424.0 \mu\text{g/L}$

Total phosphorus TSI = $14.42 * [\ln (424.0)] + 4.15$

TSI = $(14.42)(6.0) + 4.15$

TSI = 90.7

Secchi depth

Average mid-summer Secchi depth = 0.71 m

Secchi TSI = $60 - [14.41 * \ln (0.71)]$

TSI = $60 - (14.41)(-0.34)$

TSI = 64.9

Chlorophyll *a* was unequivocal in placing HHP within the eutrophic category. Secchi depth being a subjective reading, is not as robust a calculator, and also provided a eutrophic classification. The results for TP placed HHP in the hyper-eutrophic range. Given that total phosphorus results were available for the upper and lower levels of the water column during 2011, the TSI index for this variable probably would be considerably higher if we were able to factor in the average of the summer readings for the 2 zones of the water column.

3.2 Literature Cited

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

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

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

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

MA Department of Public Health AND World Health Organization Citation.

http://www.mass.gov/Eeohhs2/docs/dph/environmental/exposure/protocol_cyanobacteria.pdf

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

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

Chapter 4

A Comparison of 2009, 2010 and 2011 Water Quality

4.0 Introduction.

This chapter compares the HHP water quality data collected during 2009, 2010 and 2011. Having several years of water quality data for a lake or pond provides the opportunity to compare datasets and determine whether certain characteristics are consistent from one year to the next and whether trends are developing. Although three successive years of data are not sufficient to determine long-term water quality trends, there is inherent value in examining the data to see where similarities and differences may occur.

4.1 Presentation of Results

A basic method for evaluating different sets of annual water quality data is to compare mean, or average, values for certain parameters collected each year. In the case of the HHP water quality data collected by this investigator, there was a 4-month (late June to late October) dataset collected during 2009 and 8-month (April-November) datasets collected during 2010 and 2011. There were 8 sampling visits to HHP in 2009, 16 sampling visits in 2010, and 17 sampling visits in 2011. The 2010 and 2011 datasets are twice as extensive as the 2009 dataset which can bias the results of the data analysis. In order to compensate for the different durations of the 2009, 2010 and 2011 studies, the 2010 and 2011 datasets have been summarized in two different formats: (1) to represent the entire sampling period (April-November) and (2) to represent the same 4-month period (late June-late October) that was monitored in 2009.

4.2 Comparison of 2009, 2010 and 2011 Data

In the following material, data from similar 4-month periods (late June to late October) are reviewed when comparing the 2009 data with the 2010 and 2011 data. In addition, the 2010 and 2011 datasets are compared to each other since the duration of both programs was almost identical.

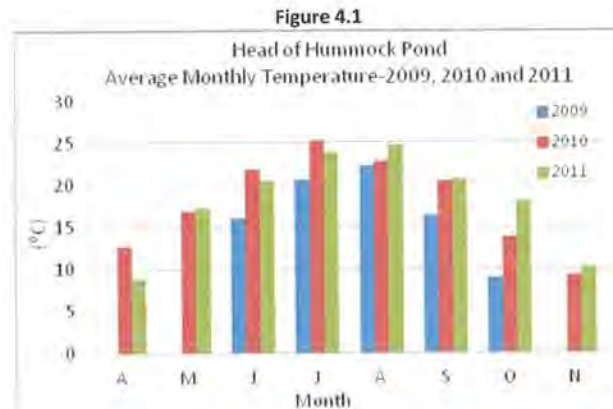
4.2.1 Physical characteristics

A summary of HHP physical and chemical data collected during 2009, 2010 and 2011 are presented in Table 4.1.

AVERAGE FOR THE ENTIRE SAMPLING PERIOD									
	Secchi (m)	TP ($\mu\text{g L}^{-1}$)	NO ₃ (mg L^{-1})	NH ₄ (mg L^{-1})	NO ₃ +NH ₄ (mg L^{-1})	TN (mg L^{-1})	Org N (mg L^{-1})	spC ($\mu\text{S cm}^{-1}$)	pH (su)
2009	0.84	491	0.07	0.17	0.24	1.28	1.09	2668	8.25
2010	0.87	278	0.08	0.26	0.34	2.00	1.66	6379	8.27
2011	0.76	370	0.03	0.28	0.31	1.24	0.93	1737	8.40
AVERAGE FOR SIMILAR 4- MONTH SAMPLING PERIODS									
	Secchi (m)	TP ($\mu\text{g L}^{-1}$)	NO ₃ (mg L^{-1})	NH ₄ (mg L^{-1})	NO ₃ +NH ₄ (mg L^{-1})	TN (mg L^{-1})	Org N (mg L^{-1})	spC ($\mu\text{S cm}^{-1}$)	pH (su)
2009	0.84	491	0.07	0.17	0.24	1.28	1.09	2668	8.25
2010	0.69	386	0.11	0.37	0.48	2.30	1.82	6142	8.70
2011	0.66	473	0.03	0.34	0.36	1.42	1.06	1774	9.03

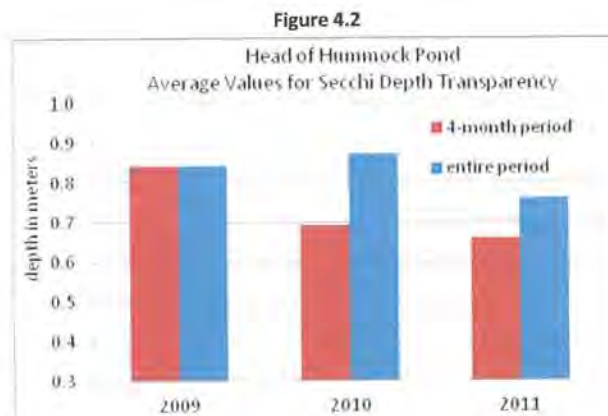
Certain data compared in the following sections of this chapter also are summarized in figures. The summary of biological data is presented later in this chapter.

Thermal cycle. Figure 4.1 is a summary of the average monthly water column temperature profiles recorded in HHP during 2009, 2010 and 2011.



HHP warmed up earlier in the season (June and July) during 2010 than in either 2009 or 2011; the average temperature during August, September and October 2010 was warmer than 2009 and August, September and October 2011 was warmer than either of the two previous years (Figure 4.1). This sizeable difference in average water column temperature would extend the duration of the growing season during 2010 and 2011, which would directly affect the water quality of the pond through increased robustness of the phytoplankton community.

Transparency. A comparison of 4-month transparency data for 2009, 2010 and 2011 indicates that algal blooms, the primary factor affecting water transparency in HHP, were most intense during 2011, with an average Secchi depth of 0.66 m compared with 0.69 m in 2010 and 0.84 m in 2009 (Figure 4.2).



The lowest average water transparency for the three-year monitoring period was recorded during 2011 (annual average = 0.76 m) and was influenced by the occurrence of Cyanophyte blooms from late June through mid-October. The 2010 transparency values were similar to 2009 conditions when the annual averages were 0.87 and 0.84 m, respectively (Table 4.1).

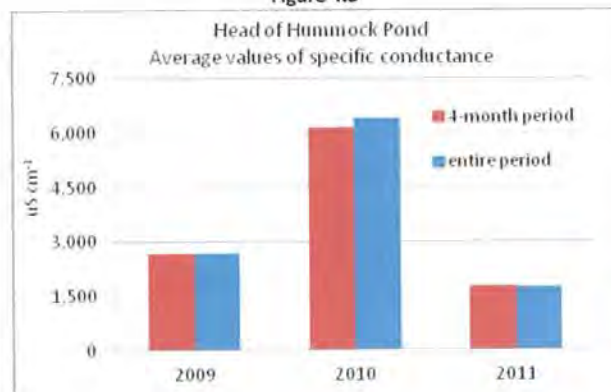
4.2.2 Chemical characteristics

Specific conductance and pH. Conductance levels in HHP during 2011 were the lowest recorded during the three-year monitoring period, regardless of whether average values for the entire season or the similar 4-month datasets were compared (Table 4.1 and Figure 4.3).

Since the annual spring and fall openings of Hummock Pond to the Atlantic Ocean are the only significant inputs of salt-water to Hummock and HHP each year, the low 2011 values resulted from very brief opening periods during

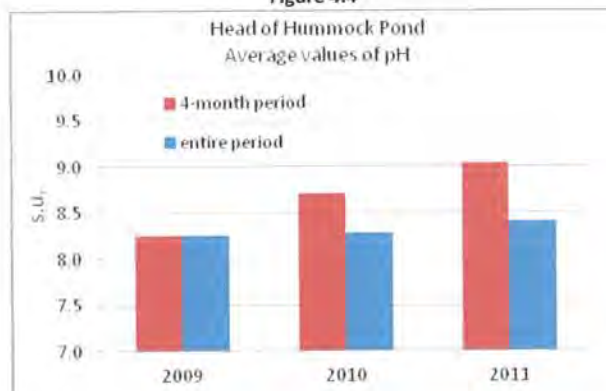
the spring and fall of 2011, when water exchange between the pond and ocean lasted only 3 days and 1 day, respectively, which greatly minimized the amount of salt-water intrusion.

Figure 4.3



The average pH values were similar during 2009-2011, regardless of which dataset was considered (Figure 4.4).

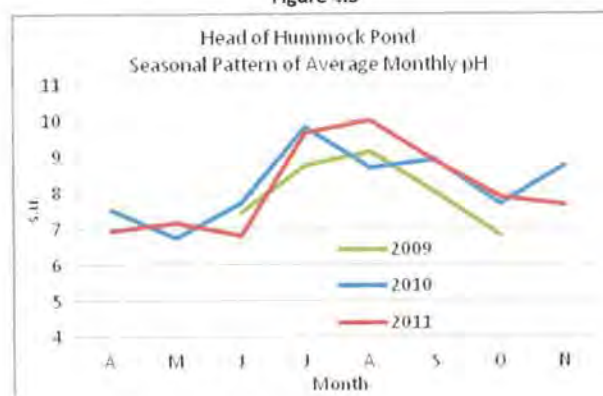
Figure 4.4



pH levels in excess of 9.0 were measured on different dates during both 2009 and 2010, and the 4-month (July-October) average pH in HHP during 2011 was 9.03. Levels in excess of 9.0 were measured on 7 occasions in 2011, and readings in excess of 10.0 were measured on three sampling dates in 2011.

The seasonal progression of average monthly pH values in HHP during 2009-2011 is shown in Figure 4.5.

Figure 4.5



The same pattern was exhibited each year, with values early in the season being low (around 7.0–7.5 s.u.) and then increasing in late June-July and remaining high until late August-early September and declining thereafter.

The reader should be aware, however, that all of the values recorded in HHP are exceptionally high and have a profound effect on the biological community in HHP. These high pH values result from phytoplankton bloom conditions in the pond which are removing carbon dioxide during photosynthesis and increasing the pH to levels where some water column constituents, e.g. ammonia, become toxic to organisms such as zooplankton and fish. These conditions can drastically alter the food web dynamics of the pond.

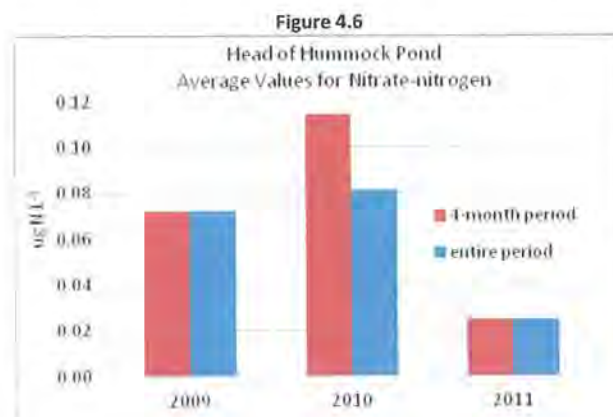
Dissolved oxygen concentration and percent saturation. The patterns of oxygen concentration and saturation during 2009, 2010 and 2011 were similar and characterize a water body that contains very high levels of algal productivity. The upper region of the water column usually was either near-saturation or super-saturated with dissolved oxygen, while the concentration and saturation characteristics of the lower waters would vary based upon the pattern and extent of surface winds blowing across the pond surface.

During extended periods with no wind and no mixing of the water column from the pond surface down to the bottom, the volume of pond water adjacent to the bottom becomes deprived of oxygen (termed 'hypoxia') and may become almost totally devoid of oxygen (termed 'anoxia') as organic material settling down from the upper levels of the pond undergoes decomposition and utilizes dissolved oxygen in the process. These conditions of extremely low dissolved oxygen provide conditions suitable for the mobilization of plant nutrients bound in the sediment to be released into the water column.

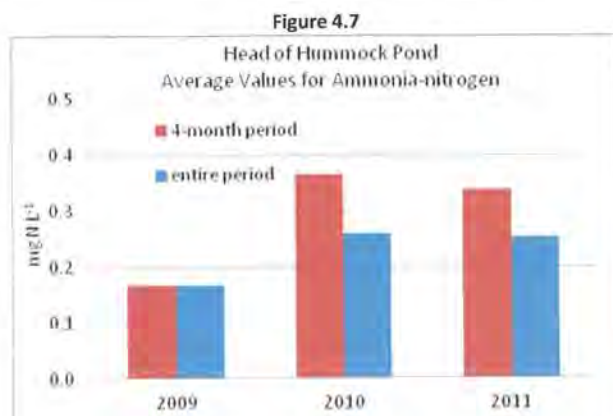
During extended periods of wind of sufficient velocity across the surface of the pond, the entire volume of water in the pond is set in motion and the pond will eventually 'mix' from the surface to the bottom, thus distributing the mobilized nutrients into the water column and back into the cycle of pond productivity. This process of bound nutrients being released back into the water column also is termed 'internal loading'.

4.2.3 Plant Nutrients

Nitrogen. The average nitrate-nitrogen concentrations in HHP were about the same (0.07 mg N L^{-1}) during similar 4-month periods in 2009 and 2010 (Figure 4.5), but the average concentration for the entire 2010 sampling period was considerably higher at 0.11 mg N L^{-1} (Table 4.1 and Figure 4.6). Nitrate-nitrogen during 2011 was substantially lower (average = 0.03 mg N L^{-1}) and just at the laboratory level of detection for the entire season except for a single elevated reading in November.

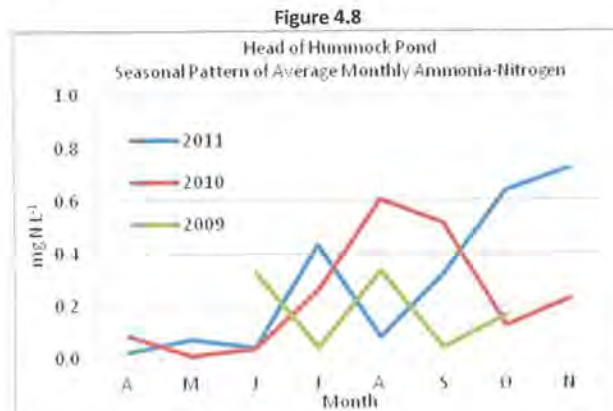


The average ammonia-nitrogen values were similar in 2010 and 2011 regardless of whether the 4-month period or entire sampling season were considered (Table 4.1 and Figure 4.7), and about 50 percent higher than the average values observed in 2009.



As explained in Chapter 3, most of the mid-summer ammonia-nitrogen in HHP probably is in the form of NH_4OH and toxic to biological growth as a result of extremely high pH levels occurring in the pond at that time. The average pH during comparable 4-month periods was higher in 2011 (9.0) than in 2010 (8.7) or 2009 (8.3), which could explain the greater amount of ammonia-nitrogen in the water rendered unusable due to toxicity.

The seasonal progression of average monthly ammonia-nitrogen values observed in HHP during 2009, 2010 and 2011 is presented graphically in Figure 4.8.

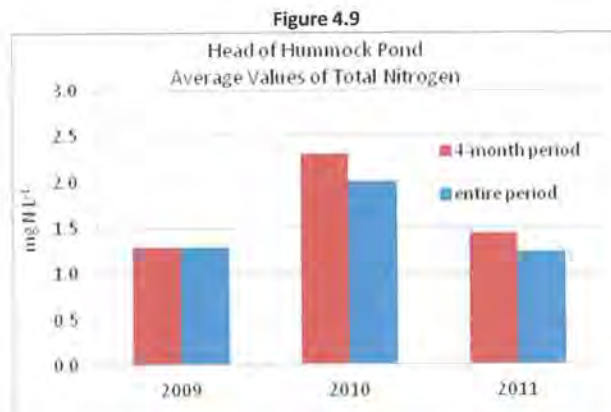


Each seasonal pattern of ammonia-nitrogen concentration is different. During 2009, the shortest period of monitoring, the concentration fluctuated during the entire season, ranging between average monthly values of ~ 0.040 – $0.330 \text{ mg N L}^{-1}$. During 2010, the average monthly concentration remained low until July, then peaked in August and September, and then decreased. In 2011, the concentration was low from April through June, exhibited a peak in July, declined in August before exhibiting a second, higher peak late in the season (Figure 4.8).

The different patterns of average monthly ammonia-nitrogen concentrations in HHP during the past 3 years of monitoring probably are due to short-term changes in productivity and nutrient cycling within the pond ecosystem. At certain times, the pH of the system is low enough to make $\text{NH}_4\text{-OH}$ non-toxic and thus ambient concentrations of $\text{NH}_4\text{-OH}$ are available for use (uptake) in the nitrogen cycle dynamics of the pond. At other times,

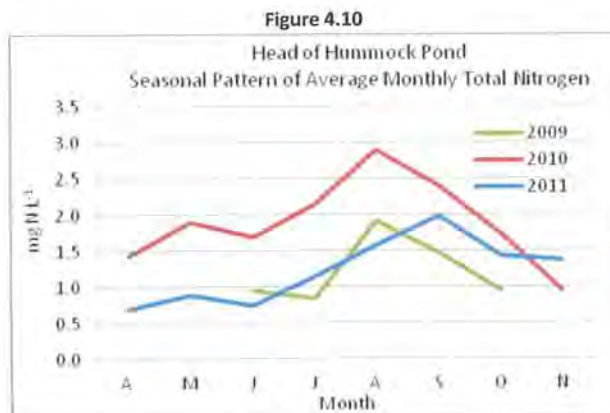
the pH of the pond becomes very high and renders NH_4OH toxic, whereby large concentrations build up in the system and are unusable in the cycle of productivity.

The 2011 average values for total nitrogen (TN) were similar to 2009 average values, both for the 4-month period and the entire year (Table 4.1 and Figure 4.9).



The average values for 2010 stand out as the highest concentrations for the 3-year period (Figure 4.9). The high TN values in HHP during all three years indicate very high pond productivity as substantiated by the phytoplankton community biomass and chlorophyll *a* concentrations documented during each growing season.

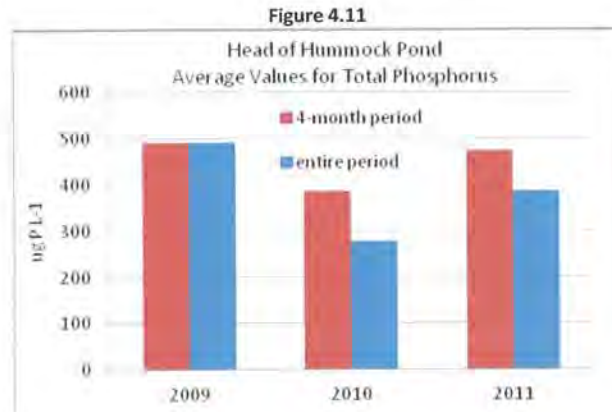
The seasonal progression of average monthly total nitrogen values observed in HHP during 2009, 2010 and 2011 is presented graphically in Figure 4.10.



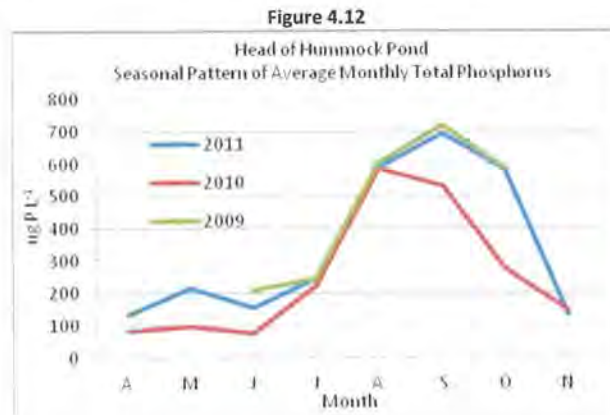
All of the seasonal patterns were essentially the same. Average concentrations early in the season were low after ice-out. Concentrations started to rise almost immediately thereafter and mid-summer peaks occurred either during August (2009, 2010) or in September (2011) and then declined during the remainder of the period.

Phosphorus. Total phosphorus (TP) averaged $491 \mu\text{g P L}^{-1}$ during 2009, $278 \mu\text{g P L}^{-1}$ during 2010, and $370 \mu\text{g P L}^{-1}$ during 2011 (Table 4.1 and Figure 4.11).

When the 4-month period between late June and late October is considered, the same pattern of total phosphorus concentrations is maintained, i.e., 2009 was the highest ($491 \mu\text{g P L}^{-1}$), followed by 2011 ($473 \mu\text{g P L}^{-1}$) and 2010 ($386 \mu\text{g P L}^{-1}$). Any of these average total phosphorus values is considered extremely high and indicative of very poor mid-summer water quality.



The seasonal pattern of average total phosphorus values in HHP during 2009, 2010, and 2011 is presented in Figure 4.12. There is considerable agreement and overlap among the patterns exhibited during the three years. The primary difference in the patterns is the lower average concentration documented during August 2010 and the lower values in September and October of that same year.



Total phosphorus likely is added to the water column at irregular intervals through internal loading and the combined effect of surface wind with the cycle of total phosphorus/dissolved oxygen dynamics that is occurring near the pond bottom during the mid-summer period of growth and productivity.

4.2.4 Phytoplankton

The phytoplankton data collected during 2009, 2010 and 2011 are discussed in this section. The 2010 and 2011 phytoplankton data have been summarized to reflect (1) the entire 8-month sampling season and (2) just the 4-month sampling season that is similar to the sampling period in 2009 (Table 4.2).

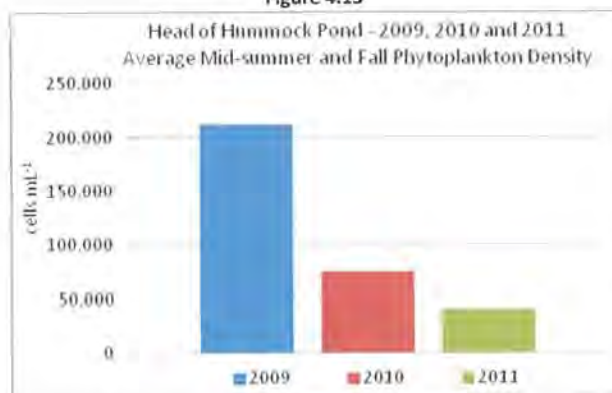
Table 4.2

Category	ENTIRE SEASON			4-MONTH PERIOD		
	2009	2010	2011	2009	2010	2011
Avg. Chl. a ($\mu\text{g mL}^{-1}$)	39.8	65.5	40.4	39.8	90.2	50.8
Avg. # taxa	25.1	19.9	24.1	25.1	19.7	25.0
Avg. Density (cells mL^{-1})	211134	54653	29759	211134	74083	39795
Avg. Biomass (mg m^{-3})	6696	9609	11044	6696	11502	13838
Avg. Diversity (H)	0.750	0.461	0.578	0.750	0.398	0.476
Avg. Evenness (E_H)	0.236	0.155	0.183	0.236	0.134	0.148

Total assemblage. There were 55 different taxa in the 2009 HHP phytoplankton assemblage, 60 taxa in the 2010 assemblage, and 67 taxa in the 2011 assemblage. A total of 32 taxa were common to all three assemblages. Some of the new taxa identified in the 2010 and 2011 assemblages occurred during the spring and early summer, which were not sampled during 2009. The 2009 assemblage contained an average of 25 taxa for the eight sampling dates (Table 4.2). The assemblages that occurred during 2010 and 2011 contained an average of about 20 taxa and 25 taxa, respectively, regardless of whether the entire sampling period or the similar 4-month period was considered. None of these assemblage characteristics are particularly helpful in describing differences among the communities described in HHP during the three-year period.

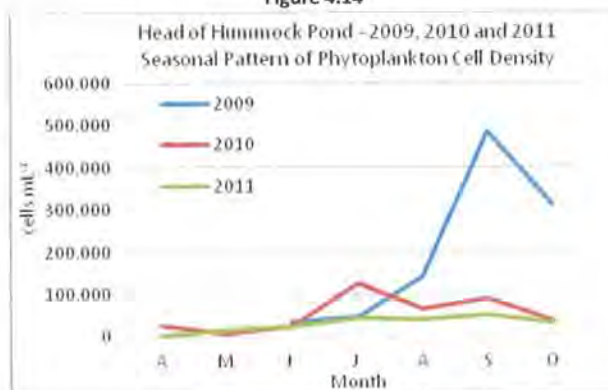
Density. This quantifier of the phytoplankton assemblage provides the first evidence of significant differences between the 2009, 2010 and 2011 communities (Table 4.2 and Figure 4.13). The 4-month average density was 211,134 cells mL⁻¹ in 2009 compared with 74,083 cells mL⁻¹ in 2010 and 39,795 cells mL⁻¹ in 2011. This is a substantial difference between 2009 and the densities documented in 2010 and 2011. The 2010 average density was about 35 percent of 2009 levels and the 2011 average density was about 20 percent of the 2009 average density levels.

Figure 4.13



The seasonal pattern of phytoplankton cell density presented in Figure 4.14 also highlights the considerable density difference among the three consecutive years that the HHP community has been monitored.

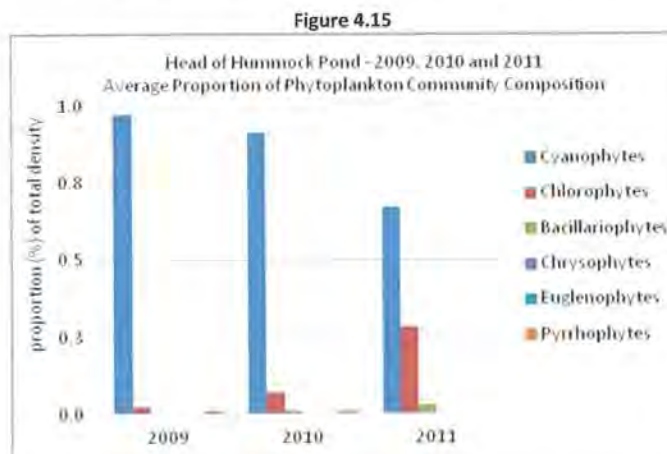
Figure 4.14



The assemblage starts out with low densities each year following ice-out and the breaching of Hummock Pond with the Atlantic Ocean, and then community density increases to maximum levels during mid-summer and fall before declining toward the end of each season. The sudden shock of sea-water and its high salt content following the

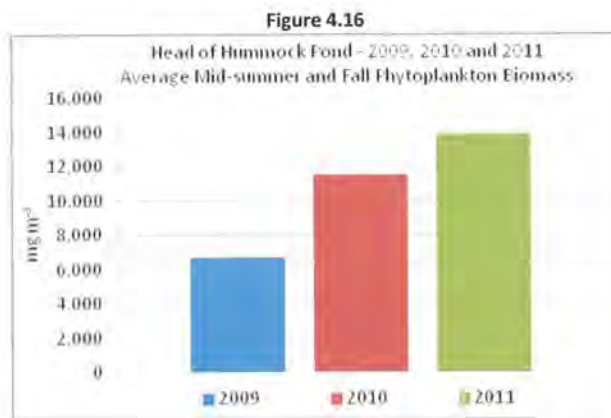
spring breaching of Hummock Pond probably has more control over the density of phytoplankton in HHP at that time than any other environmental factor beside temperature, which regulates cell growth rate.

An examination of the major phytoplankton groups that make up the HHP community during the period 2009-2011 and the relative proportion of these groups in the community composition provide some interesting results and present another trend in density that occurred during the period. Figure 4.15 summarizes this community composition and density information for similar 4-month period in 2009, 2010 and 2011.



As shown in Figure 4.15, the importance of Cyanophytes in the phytoplankton community declined during the three-year period, from 97 percent in 2009 to 91 percent in 2010 and 67 percent in 2011. At the same time, the proportion (importance) of Chlorophytes (green algae) in the community increased from 2 percent in 2009 to 7 percent in 2010 and to 28 percent in 2011. Continued monitoring of HHP during the next several years will determine whether this community composition trend continues or whether it was some sort of short-term anomaly and had no basis as a trend.

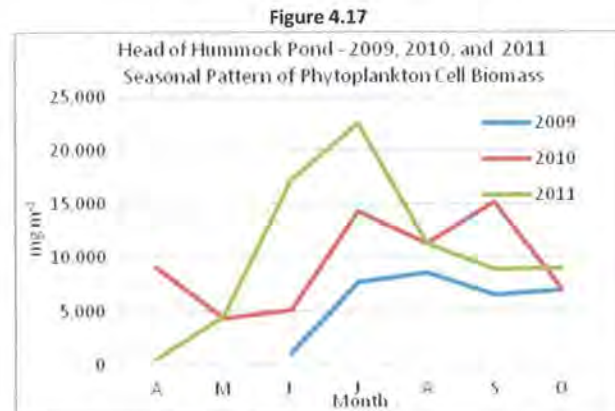
Biomass. This quantifier of the phytoplankton community reveals some differences among the HHP 2009, 2010 and 2011 assemblages and also highlights another definite trend with the three years of data collected to date. Whereas the average density of the phytoplankton community has been decreasing since 2009, the average biomass of the community has been increasing during the same time period (Figure 4.16).



The average community biomass during similar 4-month periods was 6696 mg m³ in 2009, 11,502 mg m³ during 2010 and 13,838 mg m³ in 2011. Thus, it would appear that the trend during the past three years in the HHP

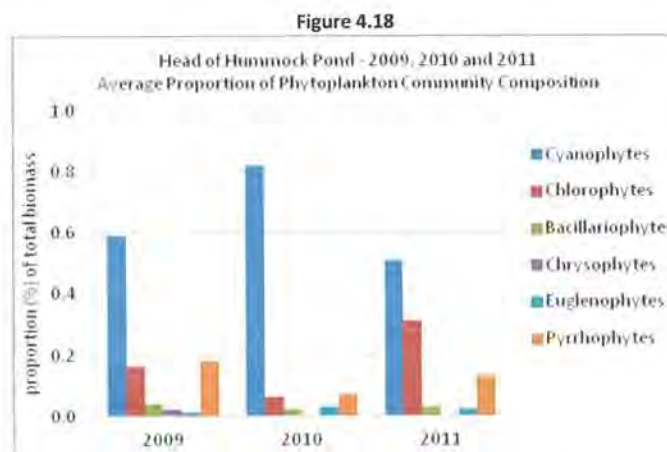
phytoplankton community has been a reduction in the total cell density and concurrent increase in the average biomass of taxa that make up the community matrix. It remains to be determined whether either of these trends will continue into the future or whether they are short-term phenomena.

The seasonal pattern of phytoplankton biomass, presented in Figure 4.17, also highlights this considerable biomass difference among the three consecutive years that the community has been monitored.



In spite of large differences in relative biomass among years, the seasonal progression of community biomass is similar each year, with low biomass early in the season following ice-out and the breaching of Hummock Pond with the Atlantic Ocean, and maximum biomass occurring during the mid-summer and early fall, and then declining.

As discussed in the density section earlier, an examination of the major phytoplankton groups that make up the HHP community during the period 2009-2011 and the relative proportion of these groups in the community composition provide some interesting results regarding the biomass patterns that occurred. Figure 4.18 summarizes this community composition and biomass information for similar 4-month periods during 2009-2011.



A comparison of Figures 4.15 and 4.18 emphasizes the disparity between cell density and biomass when evaluating HHP phytoplankton community dynamics. Only four major groups, Cyanophytes, Chlorophytes, Bacillariophytes and Pyrrophytes, are shown on the density composition graph (Figure 4.15). It can be concluded that only 4 of 6 major algal groups are involved in the community dynamics in HHP, with the major groups being Cyanophytes and Chlorophytes, and the Bacillariophytes and Pyrrophytes having only very minor roles.

The biomass composition graph (Figure 4.18) presents a totally different picture of the mid-summer and fall phytoplankton community and emphasizes that cell size (mass) is an important factor that must be considered when evaluating the role of individual groups and their taxa in the seasonal dynamics. According to Figure 4.18, all six major phytoplankton groups have played important roles in the mid-summer and fall community dynamics of HHP at different time during the past three years, and the Cyanophytes, Chlorophytes, and Pyrrhophytes have been the most frequent dominants.

Seasonality. The associations documented in the HHP phytoplankton community during 2010 and 2011 provide important information about the seasonal development of community dynamics and the general trophic of the pond. There were no spring data collected during 2009 which limited the community evaluation to mid-summer and fall. Following the spring opening of Hummock Pond to the Atlantic Ocean in 2010 and 2011, the taxa that became established in HHP were cold-water forms that would be expected to dominate as the pond started warming. Important early taxa were included in the Euglenophytes, Cryptophytes, Chrysophytes, Bacillariophytes (diatoms), and Chlorophytes, and the density and biomass of these taxa varied during the spring and early summer each year. Diatoms and cryptomonads are adapted to cold-water environments. The Cyanophytes were not detected in the HHP community until mid-June of both years. The appearance of greens (Chlorophytes) and Cyanophytes during the warmest period of the year is a situation typical of mesotrophic-to-eutrophic conditions.

Dominance. Different taxa have dominated the HHP phytoplankton community during the mid-summer and fall of 2009, 2010 and 2011. In fact, there is very little consistency and agreement among the dominant taxa identified during these three years. Community dominance is summarized in Table 4.3. This lack of community consistency from one year to the next is not totally understood, but may be due to the spring breaching of Hummock Pond to the Atlantic Ocean and the intrusion of seas-water which 'shocks' most, if not all, phytoplankton taxa in the seed bank and levels the playing field until the most aggressive and adapted species can take over (make this better).

Table 4.3

2009 Community Dominants	2010 Community Dominants	2011 Community Dominants
Taxa (Group)	Taxa (Group)	Taxa (Group)
	<i>Anabaena elenkinii</i> (Cyanophyte)	
<i>Anabaena flos-aqua</i> (Cyanophyte)		
<i>Anabaena spiroides</i> (Cyanophyte)	<i>Anabaena spiroides</i> (Cyanophyte)	<i>Anabaena spiroides</i> (Cyanophyte)
<i>Chroococcus limneticus</i> (Cyanophyte)		<i>Chroococcus limneticus</i> (Cyanophyte)
<i>Microcystis aeruginosa</i> (Cyanophyte)		
<i>Microcystis incerta</i> (Cyanophyte)		
<i>Ankistrodesmus falcatus</i> (Chlorophyte)		
<i>Closterium</i> spp. (Chlorophyte)		
<i>Coelastrum cambricum</i> (Chlorophyte)		<i>Coelastrum cambricum</i> (Chlorophyte)
<i>Eudorina elegans</i> (Chlorophyte)		<i>Eudorina elegans</i> (Chlorophyte)
<i>Pandorina morum</i> (Chlorophyte)	<i>Pandorina morum</i> (Chlorophyte)	
<i>Pediastrum duplex</i> (Chlorophyte)	<i>Pediastrum duplex</i> (Chlorophyte)	<i>Pediastrum duplex</i> (Chlorophyte)
	<i>Pyramimonas tetrarhynchus</i> (Chlorophyte)	<i>Pyramimonas tetrarhynchus</i> (Chlorophyte)
<i>Quadrigula lacustris</i> (Chlorophyte)		
<i>Sphaerocystis Schroeteri</i> (Chlorophyte)		<i>Sphaerocystis Schroeteri</i> (Chlorophyte)
		<i>Nitzschia</i> sp. (Chrysophyte)
<i>Stephanodiscus</i> sp. (Chrysophyte)	<i>Stephanodiscus</i> sp. (Chrysophyte)	
	<i>Trachelomonas</i> spp. (Euglenophyte)	
<i>Cryptomonas ovata</i> (Pyrrhophyte)	<i>Cryptomonas ovata</i> (Pyrrhophyte)	<i>Cryptomonas ovata</i> (Pyrrhophyte)
	<i>Rhodomonas</i> sp. (Pyrrhophyte)	
<i>Peridinium cinctum</i> (Pyrrhophyte)		

Diversity. Phytoplankton community diversity increased slightly when samples collected during the spring and early summer of 2010 and 2011 were included in the data analysis instead of just using the 4-month dataset from late June through October (Table 4.3). The 4-month value for [H] was 0.398 in 2010 and 0.476 in 2011, while the [H] values for the expanded season were 0.461 and 0.578 for 2010 and 2011, respectively. These slight increases are due to the increased number of taxa that were important in the phytoplankton community during the spring

and early summer of 2010 and 2011 but not as important during mid-summer and fall. In spite of this increased diversity that was detected from the extended sampling, the overall average diversity values for 2010 and 2011 were substantially lower than the value of 0.750 for [H] in 2009.

Chlorophyll *a*. The 2011 summer and fall average chlorophyll *a* concentration ($50.8 \mu\text{g L}^{-1}$) was only about one-half of the 2010 average concentration for the same period ($90.2 \mu\text{g L}^{-1}$), but greater than the average concentration measured in 2009 ($39.8 \mu\text{g L}^{-1}$) (Table 4.2).

4.2.5 Trophic status

As shown in Table 4.4 below, there were only slight differences among the TSI indices calculated for 2009, 2010 and 2011 using the chlorophyll *a*, total phosphorus and Secchi depth transparency data for each sampling period.

Table 4.4

Sampling	Trophic State Index (TSI) Based Upon		
	Chlorophyll <i>a</i>	Total Phosphorus	Secchi Depth
2009	67.4 (E)	93.4 (HE)	63.2 (E)
2010	73.3 (HE)	88.6 (HE)	62.1 (E)
2011	66.6 (E)	91.4 (HE)	64.9 (E)

The subtleties of the exact placement by individual trophic state indicators among the years being compared really is inconsequential when it comes to the overall water quality of HHP. The pond is well within the range of eutrophy for each of the indicators under consideration and, in some cases, the conditions elevate the condition to hyper-eutrophy, which is an accelerated state of eutrophication. The bottom line is that the pond has very poor water quality regardless of which criteria are used to make the evaluation.

4.3 Summary

The comparison of three consecutive years of water quality data from HHP revealed certain similarities and differences that were summarized in this chapter. The plant nutrients, nitrogen and phosphorus, exhibited some variation among the years. The highest average TN concentration occurred in 2010, followed by the 2011 and 2009 average concentrations. As for TP, the average concentration in 2009 remained the highest measured to date, followed closely by 2011 and 2010 a distant third. These relative differences in the plant nutrient data in HHP during 2009, 2010 and 2011 are insignificant, however, in terms of the overall water quality of the pond, which was very poor during all three consecutive growing cycles.

An important finding was the significant difference in the 2011 phytoplankton community when compared with the communities from the previous two years. Once again, the taxa that were dominant during 2011, almost without exception, were different than the dominant taxa in 2010 and 2009. One consistent feature among the three years was the existence of a major Cyanophyte bloom from mid-summer through the fall, although the dominant Cyanophyte taxa were different during each of the three years.

Poor water quality continues to be documented in HHP with each successive growing season. While some sort of remediation seems necessary to improve water quality in the pond, a better understanding of internal and external nitrogen and phosphorus dynamics would aid in the selection of alternatives to address high nutrient conditions. We need to increase our present level of knowledge with regard to (1) the pond bottom sediments and the availability/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.

Sutherland, J.W. 2011. Head of Hummock Pond. The 2010 Water Quality Program. A Summary of Physical, Chemical and Biological Monitoring. 51 pp. + Appendix.

Chapter 5

A Review of Historical and Current Water Quality Data

5.0 Introduction.

Water quality data collected from HHP during the previous decade was identified, summarized and reviewed in a previous report to describe overall water quality during the period and identify water quality trends, if they existed (Sutherland, 2011). The 2011 data collected from HHP will be summarized, presented and discussed here and compared with all previous water quality data in the context of trends that may be occurring in HHP.

5.1 Analysis and Summary of Historical Data

HHP water quality data first appeared in a Hummock Pond report by Knoecklein (2006) where 2004 and 2005 data were discussed. Subsequently, Conant (2007, 2008) collected samples and information from a station on HHP during 2006 and 2007. Table 5.1 provides a summary of all known water quality data collected from HHP.

Table 5.1

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
2011	17 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 including nitrate-nitrogen, ammonia-nitrogen and total nitrogen); chl a (chlorophyll a); MC (microcystin neurotoxin).			

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 year since this is the 'growing season' and represents the period of most concern for pond water quality. In view of the variety of sampling conditions, the period of late June through October was selected for water quality data comparisons among the various investigators to standardize the data, starting with 2005. The 2004 data reported by Knoecklein 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, 2010 and 2011 HHP 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 that were collected each year. In some instances, plotting the seasonal pattern of analyte concentration provides important insights regarding the productivity cycle in the pond. Both of these factors were 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. The samples collected from HHP during 2004-2007 were grab samples, which are collected from a specific water depth and, as such, represent the water chemistry only at the depth from which the sample was taken. In contrast to this sampling technique, the samples collected during 2009-2011 are integrated samples which represent a composite of the water chemistry from the pond surface down to a lower depth just above the bottom sediment of the pond. Grab samples can provide misleading chemistry results since the depth at which samples are taken often can be biased with high concentrations of phytoplankton located at a particular level of the water column where light conditions are optimal for photosynthesis during the daytime 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

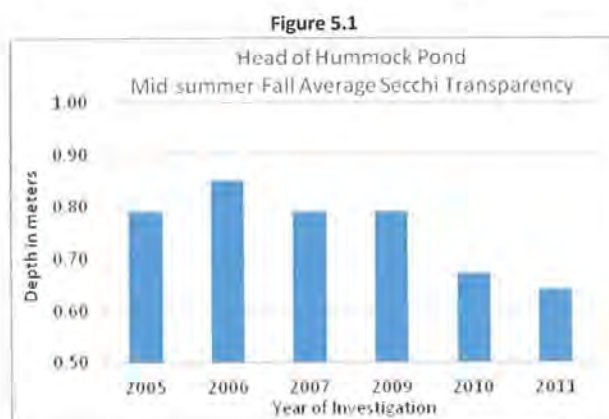
It was encouraging to discover that several different years of HHP water quality data were available from the previous decade that could be compared with the three consecutive years of data collected on HHP since 2009. In many situations, lakes and ponds have no historical database available and considerable time, effort and money must be expended to collect enough data to evaluate water quality over time with any degree of certainty. Having data for a period of one year for a lake or pond certainly is not sufficient to make an accurate evaluation of water quality since any year can produce in anomalous conditions as a result of environmental perturbations and other factors. In the case of HHP, there appears to be a sufficient amount of reliable data to allow meaningful interpretation of historical water quality as it relates to current conditions.

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 late June-October.

Year	2005	2006	2007	2009	2010	2011
Average transparency (m ⁻¹)	0.79	0.85	0.79	0.79	0.67	0.64

The average transparency in HHP 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 long (Figure 5.1).



Based upon average transparency values during the past six years and the relationship between phytoplankton community biomass and water column transparency revealed during two of the past three years of study, it appears that algal blooms, probably Cyanophytes, have been prevalent in HHP since data collection began in 2005. In fact, Knoecklein (2006) reported collecting a sample from HHP in 2005 that contained *Anabaena* and *Microcystis* spp. at densities of 90,000 cells mL⁻¹ although the sample date was not mentioned. The same report mentioned that blooms densities of Cyanophytes were observed in HHP during August, September and October 2005.

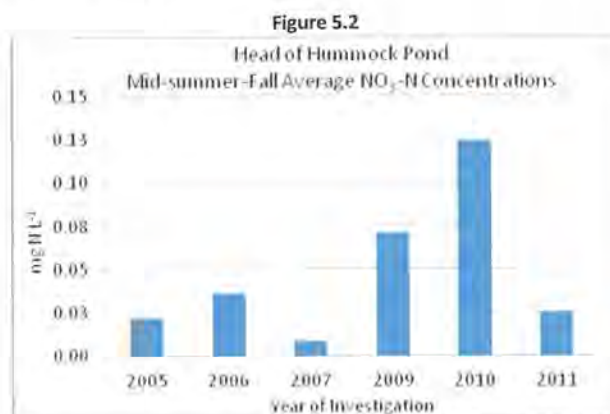
5.2.2 Plant Nutrients

Author's Note: In some cases, the earlier investigators used different units when reporting HHP nutrient concentrations. Although the choice of units for reporting concentrations in the literature is not entirely arbitrary, it may be a matter of preference for certain individuals regardless of the exact protocol. In the following discussion, the author has continued to report nutrient concentrations according to the procedure followed earlier in this report and in previous reports. For matters of comparison in the discussion that follows, the conversions of concentrations are, for example: 20 µg/L = 0.02 mg/L = 20 ppb.

Nitrogen. The average **nitrate-nitrogen** ($\text{NO}_3\text{-N}$) data available for HHP during the late June-October period are summarized below.

Year	2005	2006	2007	2009	2010	2011
Average $\text{NO}_3\text{-N}$ (mg N L^{-1})	0.02	0.04	0.01	0.07	0.12	0.03

Knoecklein (2006) reported that most nitrate/nitrite samples collected from HHP during 2004-2005 were below the detection limit of 20 ppb (0.02 mg N L^{-1}). Conant (2007) reported an average nitrate-nitrogen concentration of 0.04 mg N L^{-1} in 2006 HHP samples and an average concentration of 0.01 mg N L^{-1} during 2007. The average nitrate concentrations in HHP during 2009, 2010 and 2011 have fluctuated but are consistent with the levels reported by Knoecklein and Conant (Figure 5.2); nitrate-nitrogen averaged 0.07 mg N L^{-1} for 2009, 0.12 mg N L^{-1} for 2010 and 0.03 mg N L^{-1} for the 4-month period during 2011.



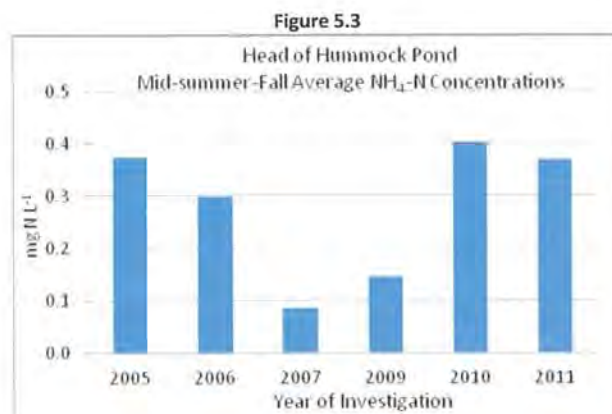
Low, or undetectable, nitrate-nitrogen levels often occur during mid-summer and indicate that available nitrogen in the form of nitrate is being consumed by phytoplankton uptake as soon as it is available in the water column. There does not appear to be any trend occurring in HHP with average nitrate nitrogen concentrations during the mid-summer and fall. With the exception of 2009 and 2010 (Figure 5.2), all of the other average values have been low during the period of high productivity.

The average **ammonia-nitrogen** ($\text{NH}_4\text{-N}$) concentrations reported for HHP during the late June-October period are summarized below.

Year	2005	2006	2007	2009	2010	2011
Average $\text{NH}_4\text{-N}$ (mg N L^{-1})	0.37	0.30	0.09	0.14	0.40	0.37

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).

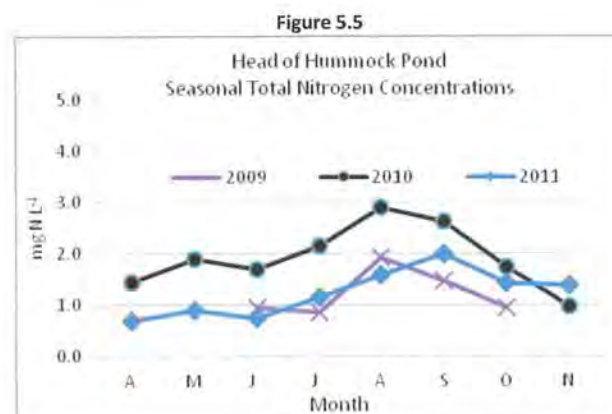
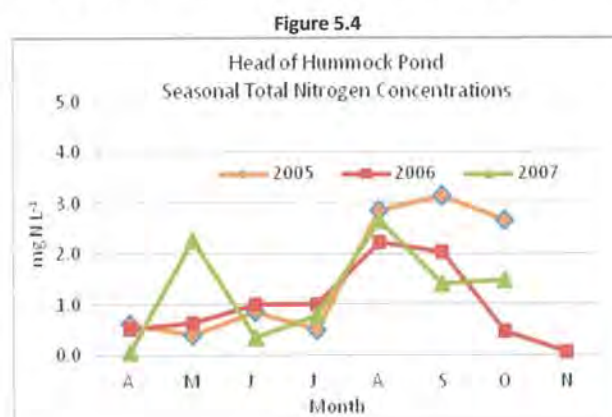
The 2009-2011 data indicate that the ammonia-nitrogen concentration in HHP is directly related to pH. Unfortunately, there are corresponding pH and ammonia-nitrogen data from only these last three years to test this hypothesis. High pH would increase the amounts of ammonia-nitrogen in the form of NH_4OH , which is toxic to biological growth. The average water column pH during similar 4-month periods was higher in 2010 (8.70) than in 2009 (8.25), which explains the greater amount of ammonia-nitrogen in the water column (0.40 versus 0.14 mg N L^{-1}) unusable as a result of toxic conditions. The highest average mid-summer and fall pH occurred during 2011 (9.03) and the ammonia-nitrogen concentration was 0.37 mg N L^{-1} , which was slightly less than the 2010 value.



A summary of annual average **total nitrogen (TN)** concentrations for HHP data available during the late June-October period are presented below.

Year	2005	2006	2007	2009	2010	2011
Average TN (mg N L^{-1})	2.28	1.43	1.58	1.33	2.36	1.49

The monthly pattern of TN concentrations in HHP has been constructed from previous (2005, 2006 and 2007) and current (2009, 2010 and 2011) data in Figure 5.4 and Figure 5.5, respectively.



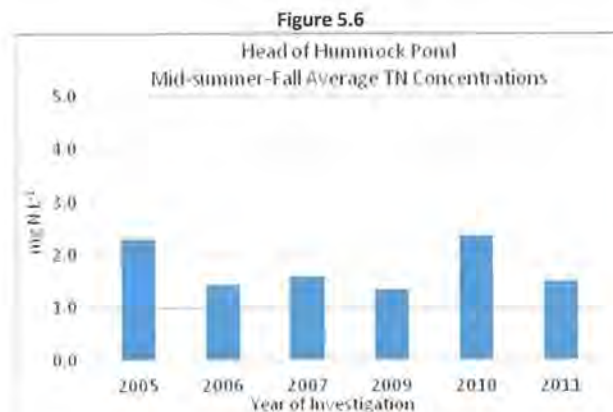
During 2005 and 2006, TN concentrations were low during spring and early summer and then increased to a mid-summer and early fall peak (Figure 5.4). This pattern was partially exhibited during 2009, even though there were no spring and early summer data collected (Figure 5.5). The 2011 data exhibited a pattern similar to 2009 except

that the TN peak occurred in September instead of August. The 2006 pattern was bi-modal, with peaks in the spring and again in the mid-summer. The 2010 pattern was noteworthy and different, starting in April with a high average TN concentration ($\approx 1.5 \text{ mg N L}^{-1}$) which continued to increase to $\approx 3.0 \text{ mg N L}^{-1}$ TN in August and then declined.

Knoecklein (2006) reported an average total nitrogen (TN) concentration of 1.47 mg N L^{-1} in HHP from eight monthly samples collected in 2005; however, the July, August, September and October samples were 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 (Figure 5.4); 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 (Figure 5.4) was most similar to the 2009 and 2010 results (Figure 5.5), with the highest values occurring during mid-summer and the lower values during spring and fall. His 2007 pattern of TN was similar to the pattern reported by Knoecklein for 2005 when TN values remained high through the fall period.

The average values reported for 2005 (Knoecklein 2006) and 2010 (Sutherland, 2011), 2.28 mg N L^{-1} and 2.36 mg N L^{-1} , respectively, are the highest reported values from the TN data available. Although the values for 2006, 2007, 2009 and 2011 are lower than the 2005 and 2010 values, they are considered to be high TN levels for freshwater and estuarine systems world-wide. Figure 5.6 summarizes the average 4-month TN concentrations, standardized for the period late June through October for 2005, 2006, 2007, 2009, 2010 and 2011.

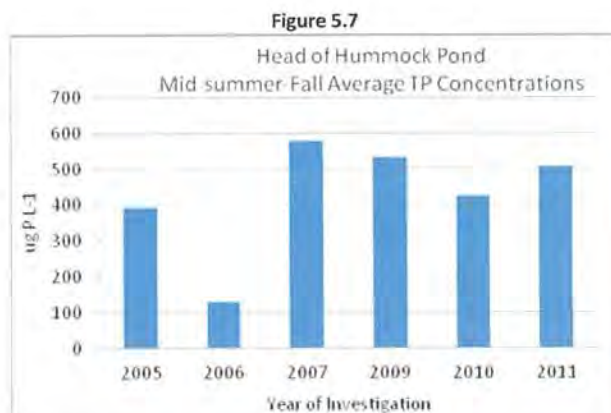


The annual average TN values in HHP exhibit considerable fluctuation; TN values have been high since 2004 and probably for a much longer period of time, although there are no earlier data to confirm this belief. The high TN values documented in HHP during the past decade emphasize the nutrient-rich condition 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, annual precipitation patterns, and some basic understanding of the hydrologic cycle of the pond.

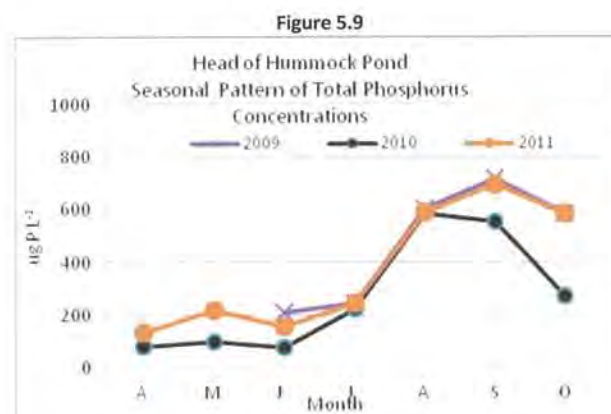
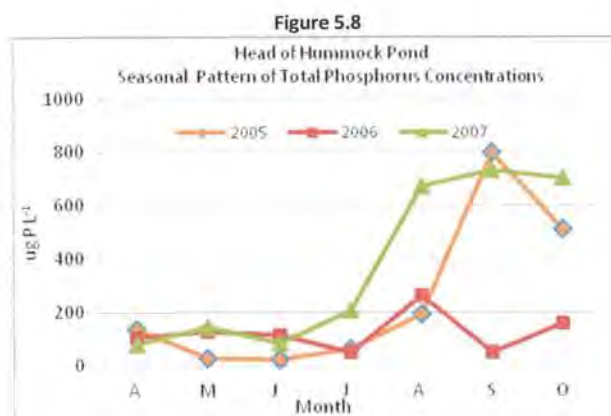
Phosphorus. The average **total phosphorus** (TP) concentrations for HHP data are presented below. These values represent comparable 4-month averages for the sets of data available.

Year	2005	2006	2007	2009	2010	2011
Average TP ($\mu\text{g P L}^{-1}$)	392	156	578	531	424	506

The highest 4-month average values occurred during 2007 and 2009, 578 and 531 $\mu\text{g P L}^{-1}$, respectively. Although the average values for the other years are lower, there still should be cause for concern since all of these average TP values are indicative of very poor water quality. There has not been any pattern in the average TP concentration since 2005 (Figure 5.7).



The monthly pattern of average total phosphorus (TP) concentrations in HHP has been constructed from previous and current data. Figure 5.8 presents the average monthly concentrations of TP data for 2005, 2006 and 2007. The average monthly concentrations of TP data for 2009, 2010 and 2011 are summarized in Figure 5.9



The seasonal TP 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 Figures 5.8 and 5.9 is the early seasonal increase in TP concentrations during 2007, 2009, 2010 and 2011. 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 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 assumption.

A worst case scenario concerning TP concentrations in HHP appear to have occurred in 2004. Only 2 collections 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, the values of TP recorded in HHP during August and September 2004 were $1230 \mu\text{g P L}^{-1}$ and $2200 \mu\text{g P L}^{-1}$, respectively (average value= $1715 \mu\text{g P L}^{-1}$), the highest values reported to date.

5.2.3 Phytoplankton

The first comprehensive collection of phytoplankton data from HHP occurred during 2009 and continued during 2010 and 2011. Although there is no extensive record of this important biological component within the HHP ecosystem, the water quality record since 2004 indicates that Cyanobacteria blooms have been a common occurrence in the pond at least since the early 2000s. Knoecklein (2006) reports a single phytoplankton sample collected from HHP during a bloom observed in August, September and October in 2005, but does not identify 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 three seasons (2009-2011).

5.2.4 Trophic status

A *Trophic Status Index* (TSI) could be calculated only for the Secchi depth and TP data since there were no chlorophyll *a* data collected prior to 2009. As shown below in Table 5.2, there were only slight differences among the TSI indices calculated for either the 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.

Table 5.2

Sampling Period	Trophic State Index (TSI) Based Upon	
	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)
2011	91.4 (HE)	64.9 (E)

It is worth noting that the TP TSI value calculated from the 2011 data (91.4) was the second highest value, and tied with 2007, since the data record began in 2005. In addition, the Secchi TSI value from the 2011 data (64.9) is the

highest value to date, and is close to the threshold value (70) that would place the HHP Secchi TSI value in the hyper-eutrophic category.

5.3 Summary

After three consecutive years of monitoring, the water quality at HHP continues to be extremely poor. 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. The likely source of nutrient contamination to HHP is (1) internal cycling of phosphorus from the bottom sediments, as well as some nitrogen cycling from the same source, and (2) groundwater flow from the surrounding watershed which also contributes both important plant nutrients nitrogen and phosphorus. Another potential source of contamination 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 nutrients depending upon water level, water flow, wind dynamics, and other factors.

5.4 Literature Cited

- Knoecklein, G. 2006. Hummock Pond 2005 Monitoring Report. Prepared for Nantucket Marine and Coastal Resource Department. Northeast Aquatic Research, LLC. 54 pp.
- Conant, K.L. 2008. Hummock Pond Annual Report 2007. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.
- Conant, K.L. 2007. Hummock Pond Annual Report 2006. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.
- 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.
- Sutherland, J.W. 2011. Head of Hummock Pond. The 2010 Water Quality Program. A Summary of Physical, Chemical and Biological Monitoring. 51 pp. + Appendix.

6.0 2011 Project Summary

The investigation of HHP continued during 2011 to determine if the poor water quality conditions documented in 2009 and 2010 would continue, particularly the blooms of Cyanophytes that dominated the phytoplankton community during the mid-summer and fall each previous year. In addition to high levels of the plant nutrients, phosphorus and nitrogen, measured in the water column through the mid-summer and fall of 2009 and 2010, a notable finding during 2010 was the presence of several species of Cyanophytes that have been linked to the production of algal neurotoxins, substances that can be harmful to humans, pets, farm animals and wildlife. The neurotoxin, microcystin, was detected in HHP samples collected from the pond during much of the 2010 mid-summer and fall.

The 2011 sampling program on HHP was similar to the 2010 sampling program and included almost the entire ice-free period, from early April until mid-November, thus documenting the seasonal progression of water quality in the pond for a third consecutive growing cycle. HHP was sampled at about bi-weekly intervals. Samples were collected for physical, chemical and biological parameters including temperature, dissolved oxygen, nutrient chemistry, chlorophyll *a*, and phytoplankton community composition; the same parameters sampled during 2009 and 2010. In addition, a special study of the neurotoxin, microcystin, was continued in 2011. This substance, if detected, would indicate the presence of neurotoxin-producing Cyanophytes in the pond.

As reported during the previous two years, HHP continued to exhibit elevated levels of total phosphorus and total nitrogen during 2011, validating the 'eutrophic' status attached to this body of water by earlier investigations (Conant, 2007, 2008; Knoecklein, 2006) and by the recent results from 2009 and 2010. If the pond's inventory of historical data is included in the trophic state analysis along with the 2009-2011 information, it reveals that HHP has been in a eutrophic-to-hyper-eutrophic condition at least since 2004, and probably for longer, although this premise cannot be proved with any certainty.

The 2011 growing season in HHP was more extensive than either of the previous two years (2009, 2010) based upon a higher average temperature of the water column for an extended period of time. A threshold temperature of 18°C was used for the comparison. During 2009, the average water column temperature was greater than 18°C only during July and August, whereas in 2010, the average water column temperature was greater than 18°C during June, July, August and September. During 2011, the period of average water column temperature in excess of 18°C was 5 months, June through October, which means an extended period of time for the development and manifestation of water quality conditions in the pond.

The 2011 phytoplankton community in HHP did not respond to these extended, warmer conditions entirely as expected. The mid-summer and fall standing crop, estimated from chlorophyll *a* concentration, was about one-half (50 percent) of the 2010 average concentration. Furthermore, the average density of the 2011 community was about one-half (50 percent) of the 2010 average density and less than 20 percent of the average density reported during 2009. In spite of these reductions in standing crop and density, the average biomass of the 2011 phytoplankton community was the highest reported during the three-year period, which may indicate a shift in the community from single-celled organisms to chain-like, multi-celled, taxa including many well-known Cyanophyte species that form blooms.

With regard to the plant nutrients in HHP, a comparison of similar 4-month sampling periods from 2009-2011 reveals the following decreasing order for average TP concentration: 2009 > 2011 > 2010. The same evaluation for

TN yields the following decreasing order: 2010 > 2011 > 2009. Chlorophyll *a* results for the three-year period can be ranked as: 2010 > 2011 > 2009. There are no apparent trends developing when evaluating these recent data or when these data are combined with the earlier data-sets and evaluated.

In spite of having sufficient recent and historical nutrient data for HHP, certain 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 NLC provided funding during 2011 to install a series of groundwater wells in the HHP watershed around the perimeter of the pond so that data could be collected that would provide information for item #2 above. The information that was collected has been summarized in a separate interim report.

The phytoplankton community documented during the spring and early summer of 2011 was diverse and exhibited a 'typical' seasonal succession of cold-water to warm-water forms that would be expected to occur in a pond of this type. Some forms identified early in the season were considered salt-tolerant and likely were remnants from the period of the opening of Hummock Pond to the Atlantic Ocean to flush the pond and introduce sea-water.

About 50 percent of the phytoplankton taxa identified in HHP during 2009-2011 were common to all three years of the study. The most noteworthy feature of the three consecutive phytoplankton communities was the unique nature of the dominant forms during each year; only three dominant taxa were common to all three years.

For the second year in a row, Cyanophytes were absent from the entire spring phytoplankton assemblage and first appeared in samples collected during mid-to-late June. The total dominance of the Cyanophytes from that point in time through the remainder of the sampling season 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 2011, all major groups except the Cyanophytes were scarce during the mid-summer and through the month of September, regardless of whether cell density or biomass is considered in the evaluation.

A total of 13 different Cyanophyte species have been identified in the phytoplankton samples collected from HHP during the past three years and are summarized in Table 6.1 below.

Table 6.1

2011	2010	2009
<i>Anabaena flos aquae</i>		<i>Anabaena flos aquae</i>
<i>A. spiroides</i>	<i>A. spiroides</i>	<i>A. spiroides</i>
	<i>Anabaenopsis elenkinii</i>	
		<i>Aphanizomenon flos-aquae</i>
<i>Aphanocapsa elachista</i>	<i>Aphanocapsa elachista</i>	
<i>Chroococcus limneticus</i>		<i>Chroococcus limneticus</i>
<i>C. turgidus</i>		
		<i>Coelosphaerium naegelianum</i>
<i>Gloeocapsa rupestris</i>	<i>Gloeocapsa rupestris</i>	
<i>Merismopedia glauca</i>		
		<i>Merismopedia punctata</i>
		<i>Microcystis aeruginosa</i>
<i>Microcystis incerta</i>	<i>Microcystis incerta</i>	<i>Microcystis incerta</i>

Only two Cyanophyte species, *Anabaena spiroides* and *Microcystis incerta*, were identified in the assemblage during all three years. There were four species that were identified in at least two of the three assemblages. A total of seven other species were identified in only a single community assemblage.

The Cyanophyte toxin, microcystin (MC), was detected in five (5) samples submitted for analysis during 2011. Only two (2) samples were near the World Health Organization threshold for drinking water of 1 µg microcystins per L. All samples were well below the MA Department of Public Health threshold for recreational contact of 10 µg/L

microcystins. We do not know which Cyanophyte species was (were) producing this neurotoxin. Special studies would have to be conducted to isolate the species responsible and the Cyanophyte assemblage is quite variable each year as far as the species present and the dominant forms.

Cyanophytes 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 cyanobacterial population can have a toxic potential in the aquatic ecosystem in which it is located.

6.1 Discussion

Earlier 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 three years have confirmed the results from the earlier work that HHP suffers from a nutrient enrichment involving both TP and TN. In addition to plant nutrient data, the recent intensive sampling of the pond has documented the occurrence of extensive Cyanophyte blooms and the presence of species that produce potentially-harmful toxins, including the neurotoxin microcystin.

Potential sources of nutrients to HHP were discussed by Knoecklein (2006). The total HHP groundwater drainage basin is about 191 acres, 16 acres of which include the surface area of the pond. Most of the remaining 176 acres of groundwater drainage, about 135 acres, flows toward Maxey Pond (9.5 acres) and Waqutuquaib Pond (≈ 8.2 acres). The direct contributory watershed for HHP, therefore, is relatively small (41 acres) and 6 or fewer homes are within the watershed divide that contributes directly to the pond.

There are certain questions that should be considered in the development of any long-term remediation plan for HHP, including the following:

- (1) Within the watershed that is contributory to HHP, to what extent are homes a source of external loading of nutrients directly from wastewater treatment systems to the pond via groundwater flow and discharge (allochthonous source), or
- (2) To what extent is HHP mobilizing forms of nitrogen internally (autochthonous source), and particularly during the mid-summer growing period when massive quantities of algal cells and other organic material is settling to the lower levels of the pond, accumulating on the bottom sediment and decomposing under anoxic conditions.
- (3) To what extent does a sizeable wetland along the southeast and southwest shoreline of HHP serve as a 'source' and 'sink' for phosphorus, nitrogen and other contaminants.

The dynamic of the nitrogen cycle in HHP very likely is some combination of the three factors listed above, with the external influence driven by patterns of precipitation and the flow of groundwater into the pond, and the internal influence controlled by alternating conditions of oxygen availability in the bottom sediments and the effect on nitrogen cycling dynamics in the sediments.

A recommendation in the 2010 HHP Water Quality Report was the installation of groundwater wells in the HHP watershed to collect data that would answer the question regarding external nutrient inputs to the pond. This recommendation was implemented during 2011 with funding provided by the NLC. Three groundwater wells were installed around the perimeter of HHP and were monitored for water quality from late spring through the fall. The results from this effort are presented in a separate interim report.

Another recommendation in the 2010 HHP Water Quality Report was the installation of equipment and collection of data to evaluate the hydrologic (water) cycle of HHP. This recommendation also was implemented during 2011 with funding provided by the NLC. A continuous water level recording device was installed along the shoreline of the pond and has been collecting data since mid-summer. The results from this effort will be summarized in a separate interim report.

The water quality results from 2009-2011 suggest that a significant amount of phosphorus is remobilized within HHP (autochthonous source) during the summer months, based upon the oxygen depleted zone near the bottom and the extremely high TP concentrations measured in the lower waters during most of the mid-summer and fall. However, it also is likely that some amount of phosphorus is entering the pond ecosystem via the external groundwater route.

The development of Cyanophyte blooms that dominate the entire mid-summer and fall phytoplankton assemblage is problematic and cause for concern. As a group, Cyanophytes are ubiquitous, occurring in almost every habitat, and their presence in small numbers in the phytoplankton assemblage of aquatic ecosystems is part of a natural process. When present in large numbers as with 'bloom' conditions, however, Cyanophytes can induce physical, chemical and biological changes in the aquatic environment in which they occur and eventually effect negative changes to the ecosystem which may require some direct remedial action to reverse or overcome. This is the current situation in HHP and apparently has been occurring for some time. The water quality of the pond has gone beyond the point where it is able to correct its own problems. Some sort of remedial action is required.

Intense concentrations (blooms) of Cyanophytes in the water column decrease transparency, thereby reducing the depth of the photic zone (area where incident light is sufficient to allow photosynthesis to occur) and the volume of water (area of the pond) that supports other photosynthetic organisms. In addition, high concentrations of Cyanophytes in the water column result in high rates of cell die-off which settles to the bottom and causes oxygen depletion within the system through decomposition of the dead plant material. This process of 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 overall oxygen saturation temporarily and transports mobilized nutrients into the upper levels of the pond for metabolism by phytoplankton. The release of nutrients into the water exacerbates the cycle by encouraging increased primary productivity in an already over-productive and stressed system.

By the time a dense Cyanophyte mat is seen floating on the surface of the pond, the cells already have affected the aquatic ecosystem in which they are located and, under certain conditions, can pose health and safety issues for users of the water body. Algal 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. An example of this condition in HHP is shown in Figure 6.1, a shoreline photograph taken on July 1st 2011.

In some instances, the dead, lysed cells are Cyanophytes that can produce cyanotoxins. In addition to being toxic and dangerous to animals, such as cattle, dogs and cats, cyanotoxins also should be considered a public safety risk to the extent that contact and consumption by humans be avoided in the pond water and 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 mid-summer events documented during the past three years, the Cyanophyte problem 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 mid-summer pond

ecosystem. The logical focus of any remedial action should be the reduction and/or inactivation of phosphorus and nitrogen in the aquatic ecosystem.

Figure 6.1



6.2 Conclusions

HHP is a body of water with very high mid-summer concentrations of total phosphorus, total nitrogen and chlorophyll *a* that are cause for concern and require remedial action. Whether the pond is 'eutrophic' or 'hyper-eutrophic' is irrelevant. The water quality is very poor and requires attention.

The high levels of total phosphorus measured in HHP during the growing season probably are generated within the system, resulting from the high 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 mid-summer and fall concentrations of chlorophyll *a* and greatly reduced transparencies measured in HHP during 2009-2011 reflect the extensive bloom conditions of Cyanophytes in the ecosystem.

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 mechanisms probably explains what actually is occurring.

There has been considerable variation in the Cyanophyte species assemblage identified in HHP during the past three years and the dominant Cyanophytes species have been different each year. The major Cyanophytes identified in HHP during 2010 were quite different from the 2009 assemblage in which 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 2010 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 collected from HHP since 2004, the bottom line in terms of water quality is (1) severe nutrient enrichment problems and (2) annual Cyanophyte 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 during 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 assertion is not supported with any data.

6.3 Recommendations

- (1) Head of Hummock Pond requires continued scientific investigation directed toward a series of water quality issues that have been manifested for part of the past decade, including high nutrient enrichment and extended blooms of Cyanophytes that, on different occasions, produce neurotoxins and pose a public safety threat for recreational users of the pond and local residents.
- (2) The Nantucket Land Council, Inc. (NLC) should continue to implement a short-term action plan toward water quality management and remediation for HHP and also for Hummock Pond, two separate but connected bodies of water that both require attention. The NLC has sponsored the previous three years of investigation on HHP and has a strong vision toward stewardship and environmental management on Nantucket Island.
- (3) The 2011 HHP water quality monitoring program should be extended through 2012 to continue documenting water quality issues on the pond and the response of pond water quality to any remediation activities that might be implemented during 2012.
- (4) Continue to monitor groundwater in the HHP watershed during 2012 according to the plan and protocol implemented in 2011.
- (5) Continue to sample the water quality of Hummock Pond and Head of Hummock Pond before and after the bi-annual spring and fall openings to the Atlantic Ocean in order to evaluate the effect of that flushing event on pond water quality.
- (6) Continue to collect samples in HHP during the mid-summer and fall for the analysis of the Cyanophyte neurotoxin, microcystin.
- (7) Continue to maintain surveillance 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

Conant, K.L. 2008. Hummock Pond Annual Report – 2007. Prepared for Marine and Coastal Resource Department, Nantucket, MA. 13 pp. + appendices.

Conant, K.L. 2007. Hummock Pond Annual Report 2006. Prepared for Marine and Coastal Resource Department, 34 Washington Street, Nantucket, MA 02554. 13 pp. + appendices.

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

MA Department of Public Health AND World Health Organization Citation.

http://www.mass.gov/Eeohhs2/docs/dph/environmental/exposure/protocol_cyanobacteria.pdf

Sutherland, J.W. 2011. *Head of Hummock Pond. The 2010 Water Quality Program. A Summary of Physical, Chemical and Biological Monitoring.* 51 pp. + Appendix.

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

Head of Hummock Pond
The 2011 Water Quality Program

Appendix

Materials Referenced in the Report

Head of Hummock Pond Field Sheet
Chain of Custody Form
2011 Temperature Profile Data
2011 Dissolved Oxygen Saturation Profile Data

**HEAD OF HUMMOCK POND
2011 WATER QUALITY SAMPLING**

STATION # _____	DATE _____	TIME START _____	TIME STOP _____
CONDITIONS _____			
TOTAL DEPTH _____	WATER COLOR _____	LAT _____	
SECCHI DEPTH _____	TEAM INITIALS _____	LONG _____	
COMMENTS _____			

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

SAMPLE #	SAMPLE DEPTH	COMMENTS

OTHER _____

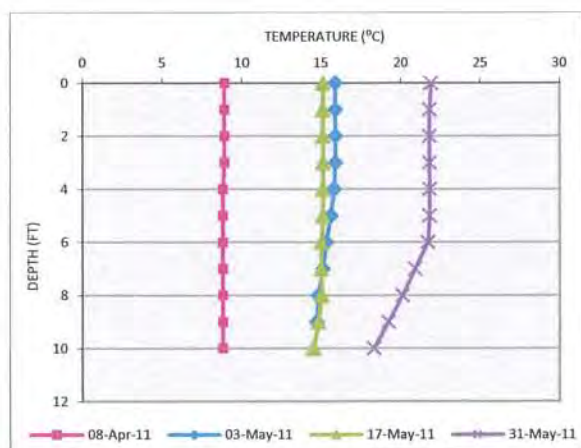
CHAIN OF CUSTODY RECORD

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

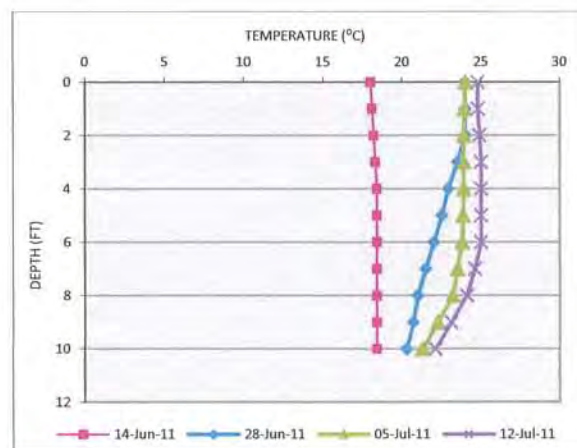
CUSTODY OF SAMPLES

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

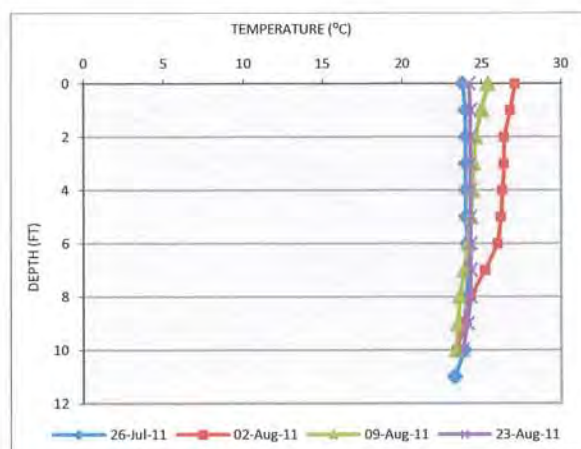
A series of graphs displaying the temperature profile data collected on 17 different dates during 2011 at the Station #4 permanent marker buoy on HHP. Data from several different dates are included on each graph. The scale of temperature (in °C) is across the top, or X-axis, of the graph; the Y-axis 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 of the pond.



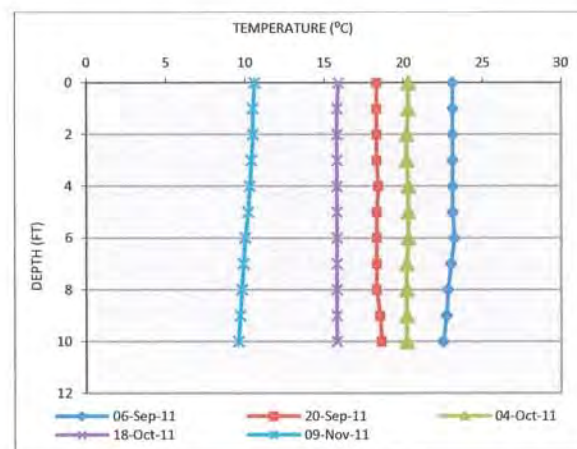
A



B

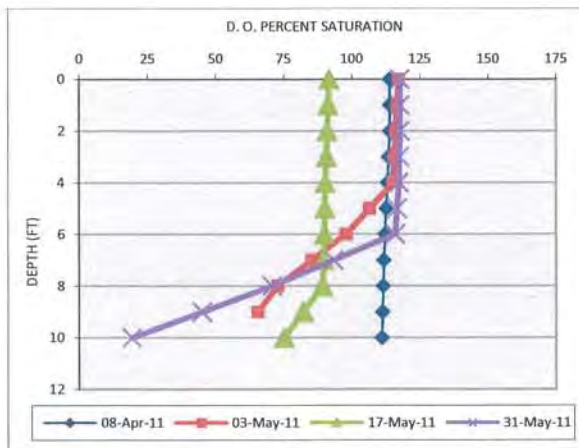


C

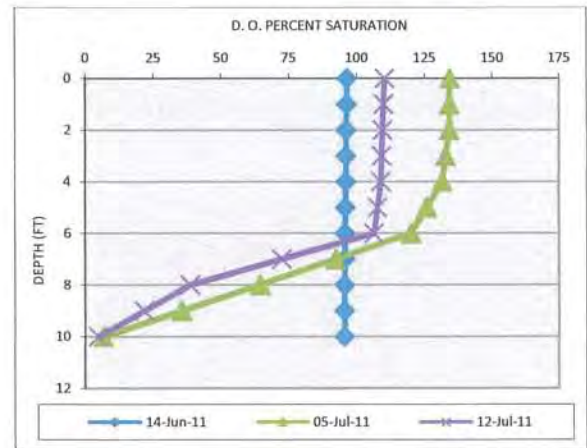


D

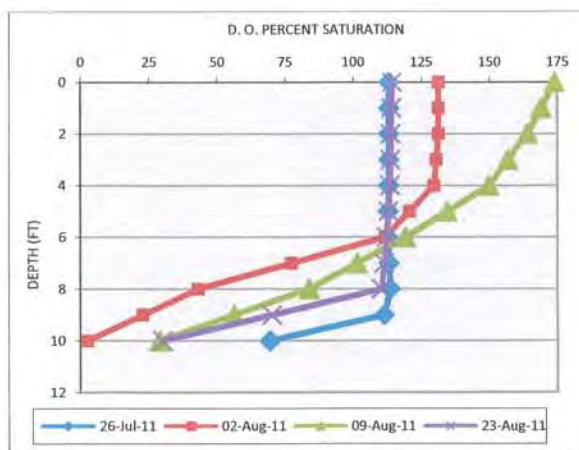
A series of graphs displaying the dissolved oxygen percent saturation profile data collected on 19 different dates during 2010 at the permanent marker buoy on HHP. Data from several different dates are included on each graph. The scale of dissolved oxygen percent saturation is across the top, X-axis, 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 of the pond.



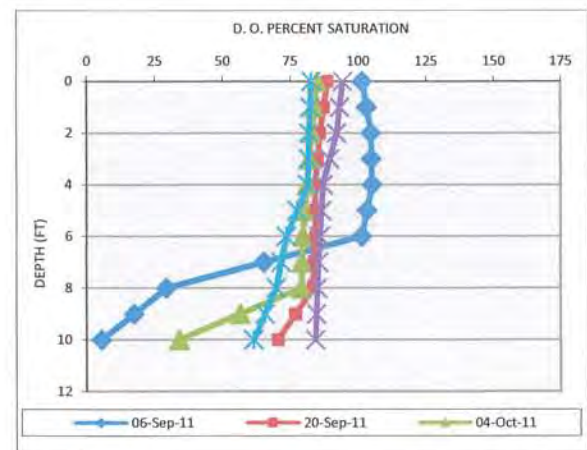
A



B



C



D