Coastal Plain Pond Water Quality and Mercury Content of Biota of the Long Island Central Pine Barrens and Mashomack Preserve:

Effects of Atmospheric Deposition and Human Development

Final Report

January 2015

Report Number 15-01

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Core Values:

Objectivity, integrity, public service, partnership, and innovation.

Coastal Plain Pond Water Quality and Mercury Content of Biota of the Long Island Central Pine Barrens and Mashomack Preserve: Effects of Atmospheric Deposition and Human Development

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

and

The Nature Conservancy on Long Island

Cold Spring Harbor, NY

Prepared by:

U.S. Geological Survey

Troy, NY

G.B. Lawrence
J. Siemion

and

Biodiversity Research Institute

Portland, ME

O. Lane

NYSERDA Report 15-01 NYSERDA Contracts 28431 and 25929 January 2015

Notice

This report was prepared by U.S. Geological Survey and The Biodiversity Research Institute in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority and The Nature Conservancy on Long Island (hereafter the "Sponsors"). The opinions expressed in this report do not necessarily reflect those of the Sponsors or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, the Sponsors, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. The Sponsors, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of the reports that they write, in compliance with NYSERDA's policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Preferred Citation

New York State Research and Development Authority (NYSERDA). 2015. "Coastal Plain Pond Water Quality and Mercury Content of Biota of the Long Island Central Pine Barrens and Mashomack Preserve: Effects of Atmospheric Deposition and Human Development," NYSERDA Report 15-01. Prepared by U.S. Geological Survey and Biodiversity Research Institute. nyserda.ny.gov/publications

Acknowledgments

This work was performed with financial support from The Nature Conservancy (TNC), the New York State Energy Research and Development Authority, and the U.S. Geological Survey (USGS). Special thanks to Marilyn Jordan (TNC) for her valuable assistance with all phases of this project and Mike Scheibel and Mike Laspia (TNC) for help with the Mashomack sites. We are grateful to Derek Rogers and other TNC staff and interns for field assistance with bird capture and invertebrate collections in the Pine Barrens. Many thanks to Sam Edmonds from BRI for his assistance with the project. We also thank John Colman (USGS) and Irene Fisher (USGS) for helpful reviews of the manuscript.

Table of Contents

List of Figures

List of Tables

List of Photos

Summary

Pine barrens are considered an imperiled ecosystem in the northeastern U.S. The Suffolk County Pine Barrens, once the second largest in the Northeast, were substantially reduced and fragmented by development during the 20th century. The coastal plain ponds being considered in this study occur in central Suffolk County within the Long Island Central Pine Barrens region. This highly unique natural environment, embedded with forests and woodlands, resulted from its glacial origins and a land use history that predates European colonization. Included in this study was The Nature Conservancy's Mashomack Preserve, located on Shelter Island between Peconic Bay and Gardiner's Bay. There are no freshwater ponds in the Mashomack Preserve, but this area was included with the Central Pine Barrens investigation, because Shelter Island has a similar geologic and land-use history that has resulted in a similarly unique low-nutrient forest and woodland ecosystem with extremely coarse-textured soils.

The development encroaching on the Central Pine Barrens poses the risk of nutrient enrichment (eutrophication) through the addition of nutrients in drainage waters. Furthermore, Long Island is subject to atmospheric deposition of pollutants that include nutrients such as nitrogen. In the absence of anthropogenic inputs, nitrogen is highly limiting to plant growth in pine barrens ecosystems. Coupled with the possibility of nutrient enrichment, the Long Island study sites are subject to the atmospheric deposition of nitrogen and sulfur as acid-forming pollutants and mercury (Hg), which is toxic to biota. Acidic deposition can (1) lower the pH of soil and surface waters, (2) decrease the naturally low biotic availability of nutrient cations such as calcium and magnesium, and (3) increase mobility of harmful forms of aluminum in the soil, which can lead to deleterious effects on aquatic and terrestrial biota. Furthermore, atmospherically deposited mercury (Hg) and its toxic organic form methylmercury (MeHg) biomagnifies up food webs and can be an important stressor to wildlife populations. Acidic environments can potentially be sites of elevated Hg methlylation.

At the request of The Nature Conservancy on Long Island (TNC), the potential biogeochemical impacts of atmospheric deposition and surrounding land use on six coastal plain ponds within the Central Pine Barrens Region of Long Island were evaluated through selected measurements of surface waters, soil water, and soils, which can be used with data from ongoing monitoring of groundwater in this area. The Nature Conservancy's Mashomack Preserve on Shelter Island in Peconic Bay was included in this study to enable assessment of impacts of atmospheric deposition on a Long Island forest outside of the Central Pine Barrens, and to inform conservation management of the Preserve. Soil and soil water chemistry were evaluated at three locations within the Mashomack Preserve.

In addition to assessments of acidic deposition effects, exposure of breeding birds and their invertebrate food sources in the Central Pine Barrens and Mashomack Preserve was evaluated because of possible enhancement of Hg methylation by acidification. Documented low pH and fluctuating water levels of the Pine Barrens ponds, factors known to accelerate mercury methylation in freshwater systems, increase the risk of bioavailable Hg entering the food web. This research links water and soil chemistry data with biotic Hg data, and adds to the understanding of the spatial extent of Hg contamination on Long Island.

Soils at all study sites were coarse textured, and as a result, excessively drained. Cation-exchange capacity was low, as were exchangeable concentrations of mineral nutrients (calcium [Ca], magnesium [Mg], and potassium [K]). Soils were acidic at all sites, ranging from pH 3.8 to 4.7 in deioinized water extracts of the uppermost mineral horizons. Collection and incubation of upper mineral soils did not result in increases in nitrate (NO_3^-) concentrations in soil water extracts, which indicated that the forest ecosystem was strongly nitrogen limited. In general, soils were acidic and nutrient-poor, with poor water-holding capacity, which is typical of soils that have developed on deep sand deposits.

Pond chemistry was strongly related to hydrologic controls. Three of the ponds intersected groundwater, and therefore were relatively well acid-buffered with pH values between 5.8 and 6.9. Although soil minerals at all the study sites were extremely low in Ca and weathered slowly, the extended residence time of groundwater enabled effective acid neutralization. The most acidic pond had little or no interaction with groundwater, and without a watershed due to flat terrain, collected little precipitation other than that which fell directly on the pond. Therefore, this pond was prone to becoming dry during periods with little precipitation. Acidity in this pond was due to a combination of natural organic acids derived from decomposing plant material and acidic deposition, which resulted in pH values less than 5.0. Two other ponds also had limited groundwater interaction, but these ponds collected event water either from shallow soil flow paths or upstream surface flow. As a result, these ponds were somewhat acidic, with pH values as low as 5.2.

A total of 242 songbirds representing 28 species were captured for collection of blood samples. Differences in blood Hg were found among sites, but in general blood Hg concentrations were below the known effect level of 0.7 ppm for songbirds . The following species were found to be suitable indicators of mercury exposure and include Carolina Wren, Common Yellowthroat, Red-winged Blackbird, Red-eyed Vireo and Pine Warbler. Concentrations of MeHg in invertebrates varied widely from 1 ng g^{-1} (or ppb) dry wt. in praying mantis from Block Pond to 322 ng g^{-1} in Tetragnathidae (spider) from Sandy Pond West. When invertebrate data were grouped by pond, considerable variation in MeHg as a percentage of total Hg was observed, ranging from approximately 25% near Bellows Pond to nearly 100% near Third Pond. An inverse correlation between blood Hg and concentrations of Ca, Mg, and K, as well as base saturation suggests greater uptake of Hg by biota at sites where mineral nutrients were least available in the upper soil. The inverse correlation between base saturation and Hg in blood is consistent with other studies that have indicated increased Hg in biota in acidic ecosystems. However, it is unclear if the ponds are providing conditions needed for strong methylation or if the uptake is occurring through some terrestrial process. The Hg concentrations measured in the spiders, which do not have an aquatic stage in their life cycle, suggest this possibility.

Results indicate that acidic deposition was not likely to have substantially reduced the acid-neutralization capacity of these soils, which is naturally very low. Because of the extremely low cation-exchange capacity, the storage of available soil Ca was also very low, even in the absence of acidic deposition. Therefore, acidic deposition was not likely to have lowered Ca availability a great deal. Furthermore, Ca availability was supplemented by seasalt deposition, that provides a consistent, albeit small input of Ca. The three different hydrologic settings that were observed in study ponds are likely to be common in the coastal plain ponds of eastern Long Island, although there may be other hydrologic settings not encountered in this study. In combination, the factors of soils, hydrologic pathways, and atmospheric deposition of Ca resulted in conditions that ameliorated acidification, although moderate decreases in pH in some ponds were likely to have been caused by acidic deposition. Furthermore, the low concentrations of Hg in bird blood in the species living near the ponds suggested that neither chemical processes within the ponds nor in the adjacent forests and woodlands were playing a large role in making Hg available to the food chain.

1 Introduction

Pine barrens are considered an imperiled ecosystem in the northeastern U.S. The Suffolk County Pine Barrens, once the second largest in the Northeast, were substantially reduced and fragmented by development during the 20th Century (Kurczewski and Boyle 2000). To protect the remaining pine barrens ecosystem, the New York State Long Island Pine Barrens Protection Act was passed in 1993 and the Central Pine Barrens Joint Planning and Policy Commission was formed (http://pb.state.ny.us).

The coastal plain ponds (New York Natural Heritage Program Conservation Guide for Coastal Plain Ponds, http://www.acris.nynhp.org/guide.php?id=9889) being considered in this study are in central Suffolk County within the Long Island Central Pine Barrens region, embedded with forests and woodlands. The primary tree species are pitch pine (*Pinus rigida* Mill.) and tree oaks including black (*Quercus velutina* Lam.) white (*Quercus alba* L.) and scarlet (*Quercus coccinia* Muench). Typical soils are excessively drained, coarse-textured, and low in nutrients. This highly unique natural environment is of glacial origin and a land-use history that predates European colonization (Jordan et al. 2003). The study ponds lie in the sandy outwash plains that formed south of the recessional Roanoke Point Moraine, (Bennington 2003), often referred to as an extension of the Harbor Hill Moraine.

Included in this study was The Nature Conservancy's Mashomack Preserve, located on Shelter Island between Peconic Bay and Gardiner's Bay. Shelter Island was created by recessional deposits of the Ronkonkoma Moraine and therefore has extremely coarse-textured, low nutrient soils similar to the Central Pine Barrens. There are no freshwater ponds in the Mashomack Preserve, but an assessment of atmospheric deposition effects on soils was conducted in parallel with the Central Pine Barrens investigation. Mashomack forests are composed of a diverse mix of tree species including the same species of oaks as in the Central Pine Barrens but with an equal abundance of red maple (*Acer rubrum* L.) plus some pignut hickory (*Carya glabra* Miller), American beech (*Fagus grandifolia* Ehrh.), and other species.

Because pine barren ecosystems develop on mineral-poor sand deposits, endemic plant and animal species are adapted to naturally oligotrophic (low nutrient) conditions. The development encroaching on the Central Pine Barrens poses the risk of nutrient enrichment (eutrophication) through the addition of nutrients in drainage waters. Furthermore, Long Island is subject to atmospheric deposition of pollutants that include nutrients such as nitrogen (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=NY96&net=NTN). In the absence of anthropogenic inputs, nitrogen is highly limiting to plant growth in pine barrens ecosystems (Morgan and Good 1988, Rice et al. 2004). Coupled with the possibility of nutrient enrichment, the Long Island study sites are subject to the atmospheric deposition of nitrogen and sulfur as acid-forming pollutants and mercury (Hg), which is toxic to biota. Although acidic deposition includes nitrogen, and therefore increases nitrogen availability, it can also (1) lower the pH of soil and surface waters, (2) decrease the naturally low biotic availability of nutrient cations such as calcium and magnesium, and (3) increase mobility of harmful forms of aluminum in the soil, which can lead to deleterious effects on aquatic and terrestrial biota (Driscoll et al. 2001).

Atmospheric deposition on Long Island also includes Hg, which is toxic in the form of methylmercury (MeHg). Once Hg enters the food web, it biomagnifies and can be a major stressor to wildlife populations (Wolfe et al. 1988). Acidic environments can potentially be sites of elevated Hg methlylation (Driscoll et al. 2007). Historically, investigations on mercury contamination have focused on freshwater aquatic ecosystems such as lakes and rivers and its impact on upper trophic level consumers (e.g., predatory fish and piscivorous birds). Although some studies have highlighted Hg and MeHg exposure in terrestrial biota (Driscoll et al. 2007), little is known about the pathways for contaminant transfer or about the thresholds for toxicity in terrestrial biota (Rimmer et al. 2010).

1.1 Acidic Deposition and Human Development Effects

Research on effects of acidic deposition on pine barrens in Long Island is limited to Greller et al. (1990), who found a significant decrease in pH of A horizon soil in an undisturbed forest on an estate in Mill Neck, Nassau County, Long Island between 1922 and 1985. They also documented a dramatic shift in flora from acid-intolerant plant species to acidophilic species during this time period. These changes do not prove, but are consistent with, acidification from precipitation. No other Long Island studies of effects of acidic deposition, or changes in acidity of soils or waters over time, are known.

A few studies done in pine barrens ecosystems in New Jersey suggest that some increase in acidity of surface waters has resulted from acidic deposition. Johnson (1979) found that average annual pH decreases of 0.2 to 0.5 units in two streams in the New Jersey Pine Barrens were significantly correlated ($p < 0.05$) with decreases in precipitation pH that occurred over that same period. However, both increases and decreases in stream pH in the New Jersey Pine Barrens were identified during the 1960s and 1970s, a period when acidic deposition was likely to be near its maximum (Husar et al. 1991) and large-scale forest fires occurred. The short-term effect of fires would be an increase in pH over several years (Boerner and Forman 1982), which could accentuate decreases in pH in the subsequent record, or possibly obscure a pH decrease for several years immediately following a fire (Morgan 1984). Therefore, the interactions of acidic deposition and fires complicate interpretations of trends in stream chemistry. The same complications apply to the Long Island Central Pine Barrens in which numerous major wildfires occurred over the last two centuries (Kurczewski and Boyle 2000, Jordan et al. 2003).

Effects of acidic deposition on surface water chemistry in pine barrens were also assessed in a reconstruction of pH over the past 12,000 years from diatom stratigraphy in sediments of a Cape Cod kettle pond. Results indicated that the pond had become more acidic during the 20th century, but that similar levels of acidity had occasionally occurred in past centuries, possibly from changes in vegetation, fire history and climate (Winkler 1988). Additional research in the New Jersey Pine Barrens linked elevated concentrations of aluminum in streams to atmospherically deposited sulfuric acid, although organic acids, naturally produced by decomposing organic matter, were also identified as an important factor (Turner et al. 1985).

The relative effects on biogeochemical processes, of acidic deposition, versus effects from residential and agricultural land use were specifically addressed in the New Jersey Pine Barrens in the study of Morgan and Good (1988). Results showed that areas not affected by development had surface waters that were extremely dilute, to the degree that calcium inputs from precipitation exceeded watershed outputs, an indication of little or no contribution of calcium from mineral weathering in the soil. However, in the watersheds affected by development, watershed outputs of calcium did exceed inputs, a result directly attributed to human inputs from agriculture in the disturbed portions of the watersheds (Morgan and Good 1988). In both developed and undeveloped watersheds, the forest ecosystems were highly efficient at retaining atmospherically deposited nitrate and ammonium, with outputs nearly undetectable.

1.2 Mercury Contamination Studies on Long Island

Recent Hg exposure studies in coastal wetlands and tidal marshes of Long Island, New York, have shown that saltmarsh sparrows (*Ammodramus caudacutus*) accumulate potentially harmful Hg levels in their blood (Lane et al. 2011a, Lane et al. 2011b). In 2011, over 90% of all adult sparrows sampled from three islands off Hempstead, Pine Neck Preserve in East Quogue, and Accabonac Harbor in East Hampton had blood Hg concentrations exceeding 1.0 micrograms per gram (µg/g) wet weight (ww) with several individuals reaching 2.3 µg/g ww (NYSERDA 2011). Current estimates of Hg effect concentrations resulting in impairment of 20% of the population (EC_{20}[1]) for songbirds range from 0.63 µg/g ww in tree swallows (Jackson 2011) to 1.2 µg/g ww in Carolina Wrens (Jackson et al. 2011). Garbage incinerators located in Hempstead and Babylon on Long Island have been identified as major point sources of Hg and are likely contributing to Hg deposition on Long Island, according to a NYPIRG news release from December 21, 2011 (http://www.nypirg.org/media/releases/enviro/2011.12.21_NYPIRG_Honeywell_News_Release.pdf).

Mercury pollution represents an emerging stressor especially for aquatic low pH ecosystems and requires urgent attention to better understand the processes and spatial extent of contamination. In addition, understanding how climate change and rising temperature will affect acid deposition and, ultimately, Hg bioaccumulation in the food chain is vital.

1.3 Objectives

At the request of The Nature Conservancy on Long Island (TNC), a project was developed to evaluate the potential biogeochemical impacts of atmospheric deposition and surrounding land use on six coastal plain ponds within the Central Pine Barrens Region of Long Island through selected measurements of surface waters, soil water, and soils, which can be used with data from ongoing monitoring of groundwater in this area. TNC's flagship Mashomack Preserve was included in the proposal at the request of TNC to enable assessment of impacts of atmospheric deposition on a Long Island forest outside of the Central Pine Barrens, and to inform conservation management of the Preserve. Soil and soil water chemistry were evaluated at three locations within the Mashomack Preserve.

To assess Hg exposure to birds breeding in the Central Pine Barrens and Mashomack Preserve, a biotic component was added to the TNC/USGS study conducted by the Biodiversity Research Institute (BRI). Documented low pH and fluctuating water levels of the Pine Barrens ponds, factors known to accelerate mercury methylation in freshwater systems, might be increasing bioavailable Hg concentrations in the food web.

---

[1] EC_{20} stands for the effective concentration at which 20% of a wildlife population is adversely affected by a contaminant. The EC_{20} for Hg in songbirds is based on published results by Jackson et al. (2011). Adverse effects were defined as 20% nest success, which is the probability of fledging at least one young.

This research links water and soil chemistry data with biotic Hg data and adds to the understanding of the spatial extent of Hg contamination on Long Island. This work will assist with the design and development of protocols for long-term Hg and acid deposition monitoring. Long Island has been proposed as one of 20 long-term, intensive Hg monitoring sites for the U.S. Environmental Protection Agency sponsored National Mercury Monitoring Network (Merc-Net) (Negra and Lambert 2008).

The objective of this study was to address the following questions pertaining to acidification, nutrient enrichment, and Hg contamination of biota.

1.3.1 Acidification

- Is “acid rain” reducing coastal plain pond water pH and buffering capacity in the present, or are such impacts likely in the future?
- If atmospheric deposition is reducing pond water pH, are there indirect impacts on other chemical constituents of pond water or sediment (e.g. increased solubility of aluminum (Al), release of phosphorus (P), Hg etc. from sediments)?
- To what extent does soil type on Long Island influence acidification from precipitation independent of land based anthropogenic inputs from development activities?
- Could expected climate change effects of increased temperature and precipitation (primarily in winter) alter the severity of acid rain impacts in the future?

1.3.2 Nutrient Enrichment

- Has nitrogen (N) availability to biota increased due to atmospheric deposition?
- What is the relative importance of atmospheric deposition of N to ponds versus anthropogenic inputs through groundwater?
- Are Ca and Mg from liming of cultivated landscapes and agricultural fields counteracting acidification of ponds from precipitation?
- Could climate change affect the amount of atmospheric nitrogen deposition in the future, and/or alter biological impacts (especially from invasive N fixing plant species)? (Predictions are for increased temperature, and some increased precipitation primarily in winter).

1.3.3 Mercury Contamination

- Are birds that are breeding in the Central Pine Barrens and Mashomack Preserve accumulating harmful levels of Hg?
- What are the Hg levels in invertebrates that serve as food for these birds?
- Are Hg concentrations in biota related to the chemical measurements of soils or pond water?

2 Study Site Description

Six ponds were selected to represent the range in water chemistry of the ponds that occur within the Pine Barrens core area (Figure 1). All of the ponds lie at low elevations (Table 1) between the Ronkonkoma Moraine to the south and the Roanoke Point Moraine to the north. These ponds have either a single inflowing tributary that drains an upstream pond, or no surface inflows. The two westernmost ponds, which we referred to as Sandy Pond West and Third Pond, are in the headwaters of the Peconic River (Figure 2). These ponds are extremely shallow; less than 1.0 meter (m) at the deepest point throughout most of the year, with the exception of one small depression in Third Pond where the water depth can approach 2 m. These ponds, which occur at the lowest elevations in the central region of the island, result from the intersection of the unconfined groundwater table with the land surface. Based on the flat terrain and extremely high infiltration and percolation rates of the sandy soils surrounding these ponds, they collect little or no drainage water from precipitation events.

The ponds referred to as Sandy Pond East and Block Pond are several hundred meters east of Third Pond (Figure 2). Block Pond flows into Sandy Pond East when water levels are sufficiently high. Sandy Pond East also receives upstream surface flow from several other ponds (including Third Pond) that flow through Sandy Pond in route to the Peconic River. These two ponds are also extremely shallow, and in the case of Sandy Pond East, likely included groundwater intersecting with the pond as well as inlet surface flow. However, this area has undergone past alterations of drainage patterns to support historical agriculture. Block Pond was artificially created to enable the seasonal flooding and draining needed for cranberry crops. Therefore, Block Pond is not directly connected to the aquifer throughout most of the year, relying on collection of water from precipitation events. As a result, Block Pond was prone to becoming dry during the study period.

Figure 1. Locations of the six study ponds in the Central Pine Barrens and three soil sampling locations on Shelter Island in The Nature Conservancy's Mashomack Preserve

Base from National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC

Table 1. Locations of pond centers, pond elevation, and number of pond samplings, and the three locations and elevations in the Mashomack Preserve where soil samples were collected once

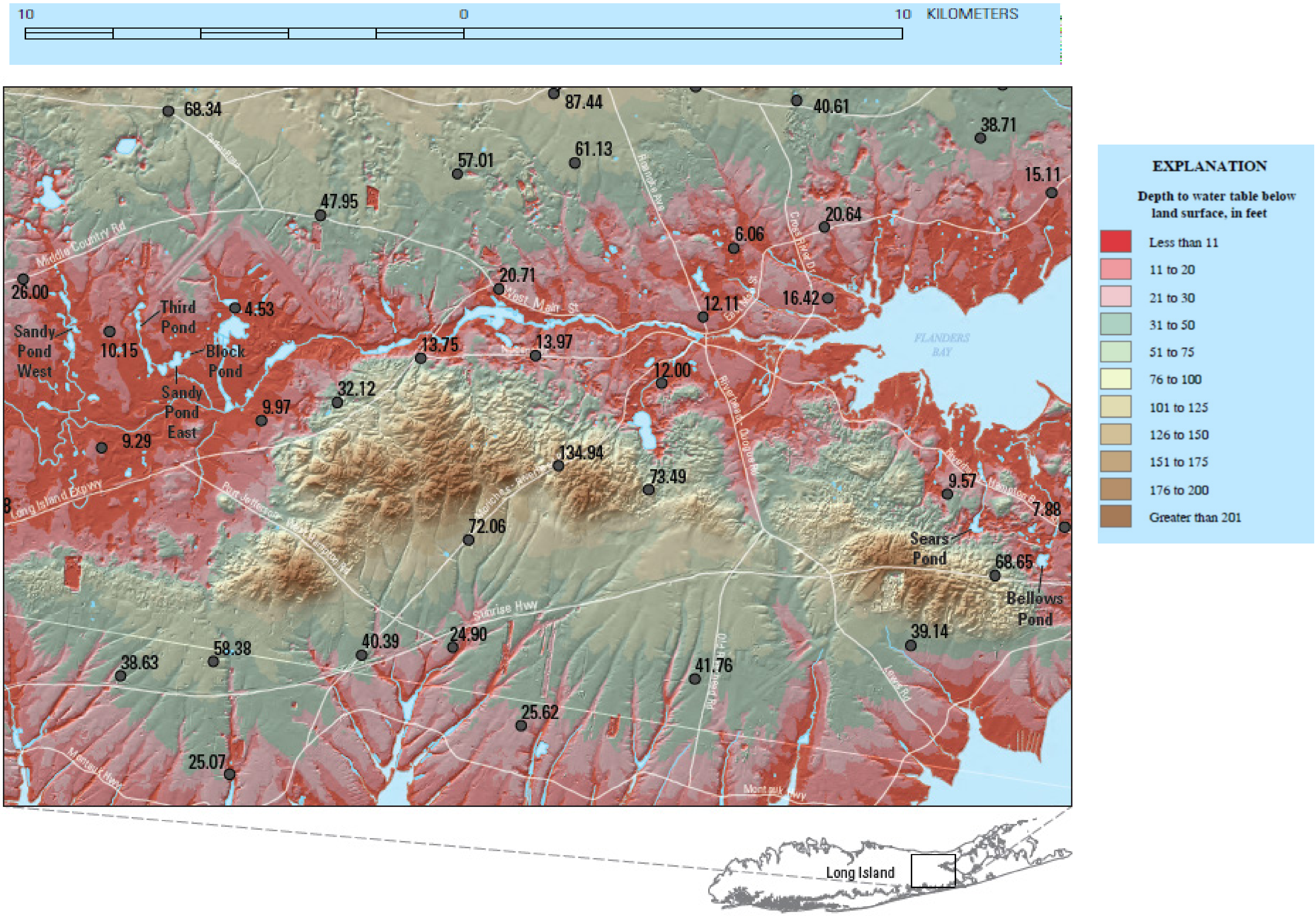
Pond Name	Latitude	Longitude	Elevation (m)	Number of samplings	Max. Pond Depth (m)
Bellows Pond	40.880146	-72.558937	3	6	4.3
Sears Pond	40.885521	-72.579082	3	7	1.8
Block Pond	40.894569	-72.804649	40	3	0.3
Sandy Pond East	40.892956	-72.807453	39	7	0.9
Third Pond	40.898958	-72.819421	14	7	0.9
Sandy Pond West	40.896151	-72.837373	12	7	1.2
Soil Sampling Site					
Mashomack 1	41.049083	-72.291944	18	--	--
Mashomack 2	41.060833	-72.295777	9	--	--
Mashomack 3	41.053638	-72.302166	9	--	--

Figure 2. Depth from land surface to water table of the study area for April-May 2010

Modified from Monti et al. 2013

This map depicts the depth to the water table beneath Long Island during April May 2010. A geographic information system was used to create a continuous surface of the water table using an iterative finite-difference interpolation technique with measurements from 349 observation wells, 16 streamgages, interpreted 10-foot (ft) contour intervals, and the coastline. The land surface or topography was downloaded from the National Map portal (http://nationalmap.gov), which represents the most currently available terrain representation as a 10-meter digital elevation model. The National Map terrain representation was combined with an additional land surface terrain model of Suffolk County, which was collected using LiDAR to produce a high accuracy three-dimensional land surface altitude model based on the geospatial product for coastal flood mapping. The continuous surface of the water-table altitude was adjusted for the vertical datum differences across Long Island. This surface was then subtracted from the topography at the same location. The results are shown as a depth to water table map. The general configuration of the depth to the water table reflects the topography data; however, because the map scales of the topography (1:24,000) and water-table altitude (1:125,000) differ, the horizontal accuracy of the depth to water table is 1:125,000 with a vertical error of ± 5 ft. Areas in which no water-level data were available for comparison are shown in gray; however, in areas along the south shore of Long Island, including marshes and the barrier island, the water-table altitude was assumed to be at National Geodetic Vertical Datum of 1929. Areas in which the depth to water table is shallow are shown in red and indicate areas where potential substructure flooding may occur.

Figure 2 continued



Sears Pond (Photo 1) and Bellows Pond, two kettle ponds located near Flanders Bay (Figure 2), were also sampled. Because these ponds lie in depressions formed from the melting of large ice chunks from retreating glaciers, they are somewhat deeper than the other ponds in the study, with maximum depths of approximately 2 to 3 m. Although these ponds are undoubtedly groundwater influenced, small hills surrounding the ponds suggest that they also receive drainage water during precipitation events.

Soils at each sampling location were coarse-textured sands and sandy loams that were excessively well drained. All sites had a surface litter layer (Oi horizon) that was underlain by an Oe horizon, 2-4 cm thick. Pits located in pine stands had an E horizon beneath the Oe horizon, whereas pits located in tree oak stands had A horizons underlying the Oe horizon. The pits located near the study ponds were in pine or mixed pine-oak stands that were in level terrain within about 90 m of the pond, with the exception of one pit located on a small hill approximately 10 m above Bellows Pond (Photo 2).

Photo 1. View of Sears Pond from shore

Photo by G. Lawrence, USGS

Photo 2. Mixed Pine-oak forest at the soil sampling location adjacent to Bellows Pond (seen in the background)

Photo by G. Lawrence, USGS

The three additional soil sites on Shelter Island within TNC Mashomack Preserve had excessively drained coarse-textured sands and sandy limes that were highly similar to the Central Pine Barrens sites. The sites were located on a hilltop (Mashomack 1), a midslope position (Mashomack 2) and a lower slope position (Mashomack 3). At each of the Shelter Island sites, mixed xeric oak species were the primary overstory vegetation in the vicinity of the pits. Each of these sites fell within what was referred to as the interior of the island by Abrams and Hayes (2008). This area has a history of logging and fire, but not agriculture, whereas the areas of the island closer to the ocean do have a land-use history that included plowing and pasture.

To assess Hg uptake by biota, birds and invertebrates were sampled in the immediate vicinity of the six ponds in forested areas as described (Table 2). Collections of birds and invertebrates were also made in the Mashomack Preserve on Shelter Island at two mixed hardwood sites similar to the soil sampling locations, plus one wetland riparian area.

Table 2. Sampling locations where birds and invertebrates were sampled to determine Hg concentrations

General Location	Site name	Latitude	Longitude
Mashnmack Preserve	Pine Swamp	41.057500	-72.320758
	Sanctuary	41.045445	-72.294040
	Section Six	41.051851	-72.300961
Pine barrens	Sandy Pond East	40.894565	-72.806055
	Sears Pond	40.886115	-72.577740
	Bellows Pond	40.878506	-72.558215
	Sandy Pond West	40.896500	-72.835829
	Third Pond	40.898148	-72.818765
	Block Pond	40.895578	-72.804258

3 Methods

3.1 Assessment of Acidification and Development Effects

Because most atmospheric deposition infiltrates the land surface before entering surface waters, possible acidification effects were evaluated in this study through soil measurements, as well as pond chemistry and characterization of hydrology. Analysis of pond water chemistry and the assessment of the local hydrology were also used to evaluate possible development effects. The pond and soil chemistry data were incorporated with available information on precipitation, acidic wet deposition (deposition falling as rain or snow), data from ongoing groundwater monitoring wells in the area, and previous data collected through Nature Conservancy programs.

3.1.1 Pond Water Sampling and Analysis

The six ponds in the selected watersheds were sampled to characterize seasonal variability over the 1-year period. Attempts were made to sample each pond at least six times in 2013 (April, May, July, September, October, and November). Third Pond was dry during the September sampling, and Block Pond was dry from July through November, although a sample was collected on an extra sampling date in December 2013. Four of the sites were also sampled in November 2012 during an initial field visit to verify selection of ponds. Pond water was collected at the approximate point of maximum depth, 1 m below the water surface. Temperature and dissolved oxygen profiles were taken during all of the 2013 samplings.

All pond samples were analyzed at the laboratory of the U.S. Geological Survey (USGS) New York Water Science Center for base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), inorganic acid anions (SO_4^{2-}, NO_3^{-}, Cl^{-}), total monomeric and organic monomeric Al, pH, acid-neutralizing capacity (ANC), specific conductance, dissolved organic carbon, and NH_4^{+} following standard operating procedures (SOPs) described at http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-A5Z-3.html. Sample processing for all analyses followed SOPs, with the exception of NH_4^{+}, for which subsamples for each pond were filtered on site. In addition, total recoverable phosphorus was analyzed at the USGS National Water Quality Laboratory, Denver, CO, following method code 2333 (http://nwql.cr.usgs.gov/usgs/catalog/index.cfm?a=bs&sa=l&sap=2333&uid=). Subsamples for total recoverable phosphorus analysis were processed and shipped overnight to the USGS Denver Laboratory within 24 hours of collection. Inorganic monomeric Al concentrations are calculated by subtracting organic monomeric Al concentrations from total monomeric Al concentrations.

3.1.2 Soil Sampling and Analysis

One soil pit was excavated in proximity to each of the six ponds, with the exception of Third Pond, where two soil pits were excavated, and Sandy Pond East and Block Pond, which were represented by a single pit. A single pit was also excavated at each of the three study locations on Shelter Island. Soil samples were collected from the faces of pits from the uppermost mineral soil horizon (either A or E), two-to-three depths from the B horizon, and from the C horizon, where it was found to exist. Approximately 1 kg of soil was collected from each horizon and placed in sealed plastic bags. Soil samples were air dried upon arrival at the USGS New York Water Science Center laboratory. Soil profiles were described from the pit faces according to Natural Resource Conservation Service (NRCS) protocols (Schoeneberger et al. 2002).

All soil analyses were run on air-dried samples that had passed through a 4 mm sieve (organic samples) or a 2 mm sieve (mineral samples). Moisture content of the air-dried samples was determined by oven drying at 65 ^{o}C for organic samples and 105 ^{o}C for mineral samples. Soil samples were analyzed for loss-on-ignition (LOI), pH (in 0.01 M $CaCl_2$, and deionized H_2O), exchangeable calcium, magnesium, potassium, sodium, (unbuffered 1 N NH_4Cl), exchangeable hydrogen (H^+) and aluminum (KCl extraction), and total C and N (C/N analyzer) following the methods of (Bailey et al. 2005). Cation exchange capacity (CEC) was calculated by summing the concentrations of exchangeable Ca, Mg, Na, K, H and Al.

3.1.3 Assessment of Soil Water Chemistry

Collection of soil water was attempted at each site using zero-tension lysimeters installed at an angle that was approximately 20° from the horizontal. The lysimeters consisted of 50-cm-long PVC tubes with a diameter of 5 cm, with 0.5 mm openings spaced 5 mm apart on the upper half the circumference of the tube, and sealed on one end. The tubes were inserted into the mineral horizon beneath the primary rooting zone at a depth of approximately 0.3 m. Two of these tubes were connected to a collection unit by tubing with an additional tube from the collection unit to the surface. Samples were pumped from the collection unit via peristaltic pump into 500 mL polyethylene bottles and stored on ice until arrival at the laboratory.

The lysimeter design, as previously described, has worked successfully elsewhere, but the soil texture of these sandy soils proved to be too coarse to sufficiently distribute flow through the soil for capture by the slotted tubes. Ten months after installation (February 2013), the lysimeters were excavated, modified by removing the top half of each tube, and reinserted into the original hole in the pit face, thereby minimizing further disturbance to the soil. For successful collection, sand above the tube needed to stabilize by moving downward to fill the tube and maintain flow continuity. This process occurs naturally as water moves through the soil. However, following lysimeter modification, precipitation was below the long-term monthly average for 7 of the ensuing 8 months, thereby slowing the stabilization process.

The lysimeters began to collect water in late fall 2013, but to avoid further delay in project implementation a soil water extraction approach was used to evaluate the availability of nitrogen retention in the rooting zone, which was the primary purpose of the soil lysimeters. In this approach, water extractable NO_3^- is measured upon sample collection, and then again after a 14-day incubation. A measureable increase in NO_3^- concentrations after incubation would indicate that nitrogen was not limiting to heterotrophic bacterial growth and that atmospheric deposition of nitrogen was causing eutrophication of this nitrogen-limited system. This water extraction is similar to the soil water expulsion method of Lawrence and David (1996), which added solution to moist soil under pressure to assess the chemistry of soil water held by soil particle surfaces. For the current study, approximately 500 mL of soil was collected from the uppermost 5 cm of mineral soil from three undisturbed locations within a few meters of each lysimeter installation. The soil sample was placed in a sealed plastic bag. Within 30 minutes of collection, a 20-mL subsample was removed from the 500-mL soil sample (after it was well mixed), then added to a bottle containing 100 mL of deionized water. The bottle was shaken for 30 seconds, after which a sample of extract was removed and passed through a glass fiber filter (nominal pore size 0.7 mm). The filtered extract and soil samples were stored on ice until arrival at the USGS New York Water Science Center laboratory where they were refrigerated at 4 °C. Percent dry weight was determined on a 20 mL sample of moist soil from each soil bag. Fourteen days after collection, the soil samples were removed from the refrigerator, mixed again, and extracted with deionized water following the same procedures. The filtered extract was analyzed for NO_3^- and NH_4^+ following the same method used for pond water samples.

3.2 Assessment of Mercury in Biota

3.2.1 Bird Capture and Sampling

Sample collection occurred in July 2012. Birds were captured in 12-m-long mistnets (Photo 3) with a use of playback song recordings to lure breeding birds into the nets. All birds were banded with a USGS aluminum band. Sex, age (adult or hatching year), and breeding status were determined for each bird. Females had a highly developed brood patch and males had an enlarged cloacal protuberance indicating breeding condition. All birds were released unharmed within 10-25 minutes of capture. Venipuncture of the cutaneous ulnar vein with a 27-gauge sterile disposable needle allowed collection of 50-70 microliters (µL) of whole blood into heparinized Mylar-wrapped tubes (Photo 4) for Hg and stable isotope analysis. The capillary tubes were sealed with Critocaps® stored in plastic vacutainers on ice for up to 6 hours before freezing at -17° C. (Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by NYSERDA.)

Photo 3. Capture site at Bellows Pond, 2012

Photo by Oksana Lane, BRI

Photo 4. Blood sample from a Blue Jay, 2012

Photo by Oksana Lane, BRI

Mercury concentrations in blood reflect recent dietary uptake. Samples were collected during the breeding period (July), and therefore reflect a bird's Hg exposure at the site where samples were collected. Tail feather Hg reflects body burden of Hg at the time of molt (Lane et al., 2011b). Many songbirds molt all feathers at the end of breeding season before migrating south. Tail feather Hg exposure reflects body burden of Hg from the previous year's breeding period or the wintering grounds.

Feather Hg from year-round residents (for example, Black-capped Chickadees, Blue Jays, possibly Carolina Wrens) reflect local Hg exposure. Feathers were placed in labeled, clean plastic bags, and refrigerated.

3.2.2 Invertebrate Prey Item Capture

During the summer breeding season, many target songbird species feed predominantly on invertebrates and larval insects. The field sampling effort targeted spiders, Dipterans (flies) and Odonates (dragon- and damselflies) because of their abundance and predatory feeding strategies. Invertebrate collection methods followed protocols outlined in Buck and Duron (2010) and included hand searching and opportunistic capture with aspirators and sweep nets. Individual invertebrate samples were stored in snap-cap centrifuge vials (1.5 mL), given a unique sample ID, and stored on ice while in the field. Upon returning from the field, sample fresh weights (±0.0001 g) were measured using an analytical balance and then all samples were stored frozen prior to being transported to BRI's Wildlife Mercury Research Laboratory (WMRL) for taxonomic identification. All individuals were identified to family level. Samples were then freeze-dried and re-weighed to obtain a dry weight. Dry weight measurements were calculated for each individual. For individuals with a dry weight <0.002 g, composite samples were made using individuals of the same taxonomic family, collected from the same sample location, and with a similar dry weight. Composited samples were homogenized using acid-rinsed stainless steel spatulas and sample splits were made for separate analyses (Hg/MeHg).

3.2.3 Laboratory Analysis

3.2.3.1 Avian Tissue Mercury Analysis

All blood and feather samples were analyzed for total Hg. Methylmercury (MeHg) was not measured because it has been shown that approximately 95% of total Hg in songbird blood is MeHg (Rimmer et al. 2005). Blood was analyzed as whole blood. All blood Hg concentrations are expressed in µg/g, wet weight (ww) and bird feather Hg in µg/g, fresh weight (fw). All blood and feather samples were analyzed at BRI's WMRL in Gorham, ME, using direct combustion/trapping atomic absorption (AA) method on a Milestone DMA 80. This approach has been incorporated by the U.S. Environmental Protection Agency (EPA) in EPA SW-846 Method 7473. Calibration utilized a blank and two calibration standards from the National Research Council of Canada (DORM-3 and DOLT-4); one for each of the two detector cells. Instrument response was evaluated immediately following calibration, and thereafter, following every 20 samples and at the end of each analytical run by running two certified reference materials and a check blank.

3.2.3.2 Invertebrate Total and Methylmercury Analyses

Invertebrates were analyzed for both total Hg and MeHg because the MeHg fraction of total Hg can vary substantially in invertebrates (Cristol et al. 2008). Dried samples were weighed accurately (±0.00001 g) into 15-mL vessels and digested with 1.75 mL of 4.57 M nitric acid for 12 h in a 60 ºC water bath (Hammerschmidt and Fitzgerald 2006). Digestates were analyzed for monomethylmercury (MeHg) by derivatization with sodium tetraethylborate and detection with flow-injection gas chromatographic atomic fluorescence spectrometry (Tseng et al. 2004). Analyses were calibrated with MeHg standards taken through the acid digestion procedure. All analyses of two standard reference materials from the National

Research Council of Canada (TORT-2 and DORM-3) were within the certified range, indicating little or no bias. Method detection limit for MeHg was about 3 ng/g for a 1-mg sample. Digestates used for MeHg analysis were oxidized with BrCl and analyzed for total Hg. The method is detailed and validated in Hammerschmidt and Fitzgerald (2006). Total Hg was determined after reduction with stannous chloride by dual-Au amalgamation cold-vapor atomic fluorescence spectrometry (Bloom and Fitzgerald 2007). Analyses were calibrated versus aqueous Hg(II) solutions traceable to the U.S. National Institute of Standards. Method detection limit for total Hg was approximately 20 ng/g for a 1-mg sample.

3.2.3.3 Stable Isotope Analyses

Stable isotope analyses (SI) for carbon and nitrogen ratios ($\delta^{13}C$ and $\delta^{15}N$) in bird blood were conducted at Boston University in Boston, MA. Blood samples were analyzed using automated continuous-flow isotope ratio mass spectrometry (Michener and Lajtha 2007). Using hematocrit tubes, blood was transferred into pre-weighed tin capsules. Assuming a content of 70% water, approximately 1.3 mg of blood (1.3 mL) was added to the capsules. All capsules were oven dried at 60˚C for 24 hours and then reweighed to get the dry mass. The capsules were then folded and compressed prior to analysis. The samples were combusted in a EuroVector Euro EA elemental analyzer. The combustion gases (N_2 and CO_2) were separated on a gas chromtagraph column, passed through a reference gas box and introduced into the GV Instruments IsoPrime isotope ratio mass spectrometer; water was removed using a magnesium perchlorate water trap. Ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ are reported as standard delta (δ) notation and are expressed as the relative per mil (‰) difference between the samples and international standards (Vienna Pee Dee Belemnite (V-PDB) carbonate and N_2 in air) as shown in Equation 1:

$$\delta X = (Rsample/ Rstandard-1) \times 1000 \ (‰) \qquad (1)$$

where:

- $X = {}^{13}C$ or ^{15}N
- $R = {}^{13}C/^{12}C$ or $^{15}N/^{14}N$

The sample isotope ratio is compared to a secondary gas standard, the isotope ratio of which was calibrated to international standards. For ^{13}C-VPDB, the gas was calibrated against NBS 20 (Solenhofen Limestone). The $^{15}N_{air}$ gas was calibrated against atmospheric N_2 and International Atomic Energy Agency (IAEA) standards N-1, N-2, and N-3 (all are ammonium sulfate standards).

3.2.4 Statistical Analyses

Factors were considered statistically significant at a probability level of less than 0.05. Data were aggregated by site. A Least Squares Means Model was used to identify factors influencing Hg concentrations in birds. All avian mercury results reflect total Hg concentrations based on wet weight in whole blood and fresh weight for feathers. Invertebrate results are reported as methylmercury and total Hg based on dry weight. Intra-specific variation in stable isotope concentrations ($\delta^{13}C$ and $\delta^{15}N$) across sites was analyzed using a one-way ANOVA followed by a post-hoc Tukey HSD test. Pearson's Product Moment correlations were used to explore relationships between stable isotope and Hg concentrations in birds.

4 Results

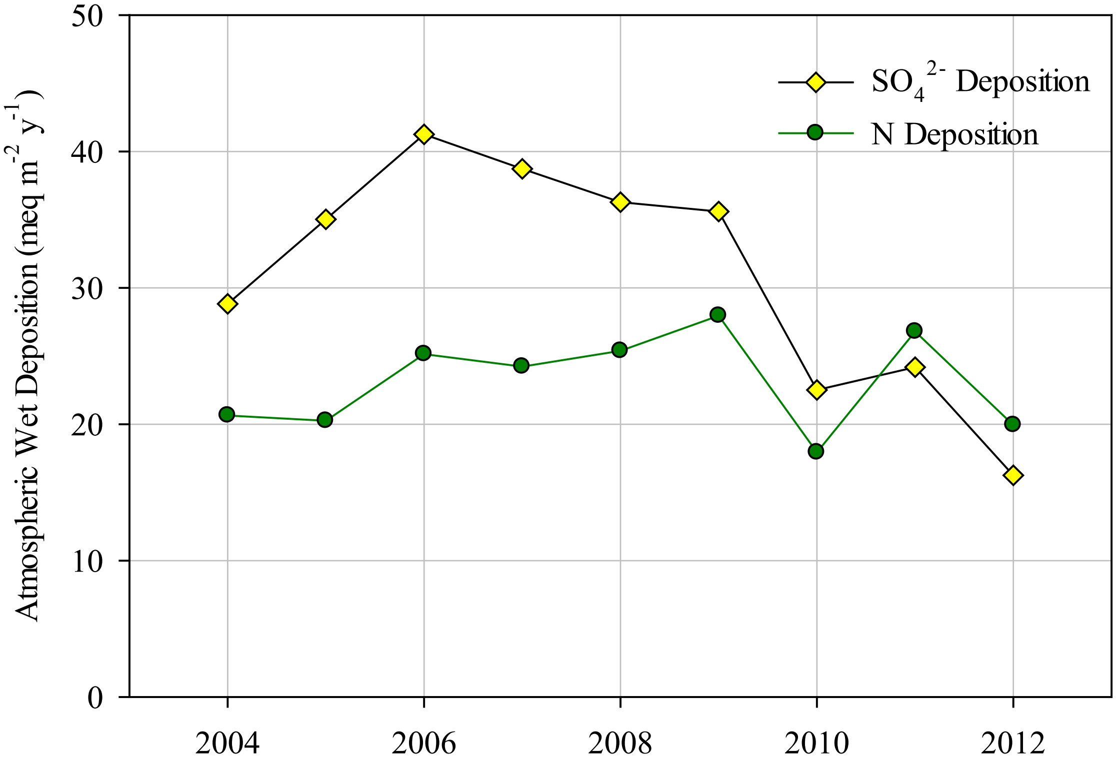
4.1 Atmospheric Deposition, Precipitation, and Groundwater

Atmospheric wet deposition is monitored by the National Atmospheric Deposition Program (NADP) site at Cedar Beach, Southold, NY, which is located approximately 7 km from the Mashomack sites and approximately 20 to 40 km from the study ponds (Figure 1). The record at this site is relatively brief, dating back to 2004 (http://nadp.sws.uiuc.edu/). Nevertheless, based on linear regression analysis (data were not found to be nonnormal) from 2004 to 2012, annual wet deposition of sulfur showed an overall decrease ($p = 0.05$) over this period (Figure 3). Deposition of nitrogen, however, showed no indication of a trend during the same period (Figure 3).

Figure 3. Wet deposition of SO_4^{2-} and NO_3^- plus NH_4^+ (N)

Measured in precipitation at the National Atmospheric Deposition Program (NADP) site at Cedar Beach, Southold, NY

(http://nadp.sws.uiuc.edu/)



Monthly average pH values ranged from approximately 4.6 to 5.4 during the 2 years that encompassed the study period (Figure 4), and concentrations of SO_4^{2-} ranged from approximately 10 to 40 mmol/L over this same period (Figure 4). Neither of these measurements showed seasonal patterns. Monthly average concentrations of NO_3^- and NH_4^+ in wet atmospheric deposition were similar, and concentration variations were highly correlated (Figure 5). Both measurements exhibited a wide range in values from approximately 5 to more than 35 mmol/L, and did not exhibit seasonal patterns.

Figure 4. Monthly average pH and concentrations of SO_4^{2-}

Measured in precipitation for water years (October-September) 2012-2013 at the National Atmospheric Deposition Program (NADP) site at Cedar Beach, Southold, NY

(http://nadp.sws.uiuc.edu/).

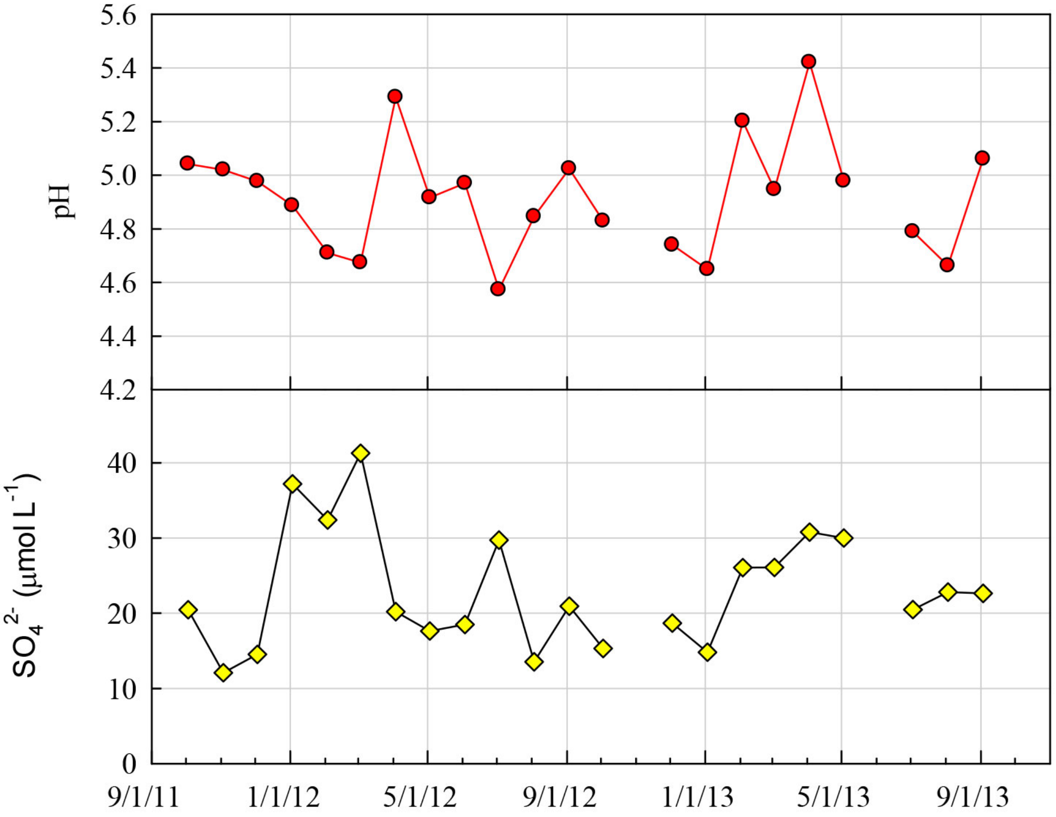
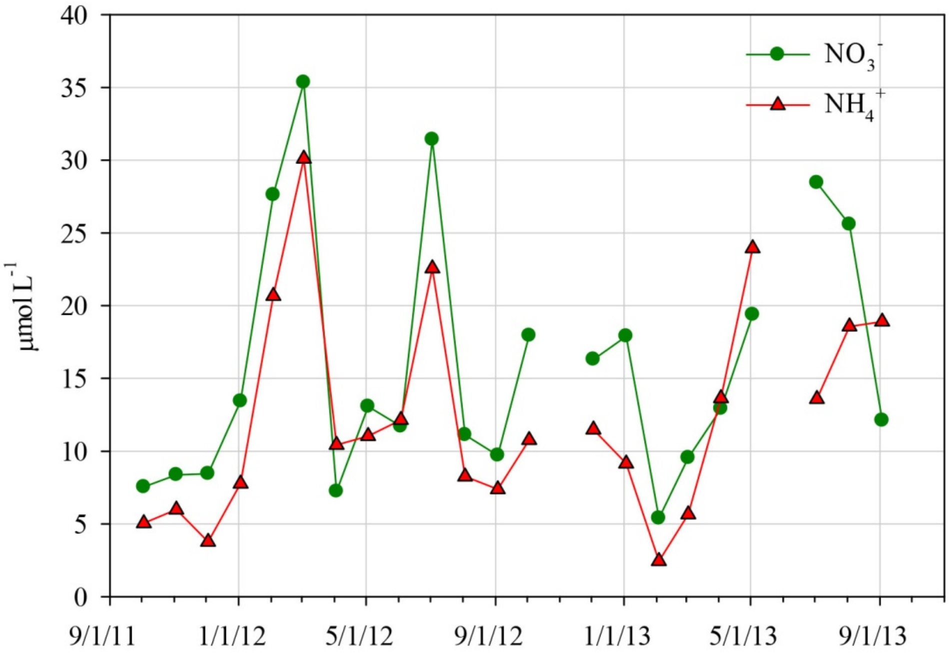


Figure 5. Monthly average NO_3^- and NH_4^+ concentrations

Measured in precipitation for water years (October-September) 2012-2013 at the National Atmospheric Deposition Program (NADP) site at Cedar Beach, Southold, NY

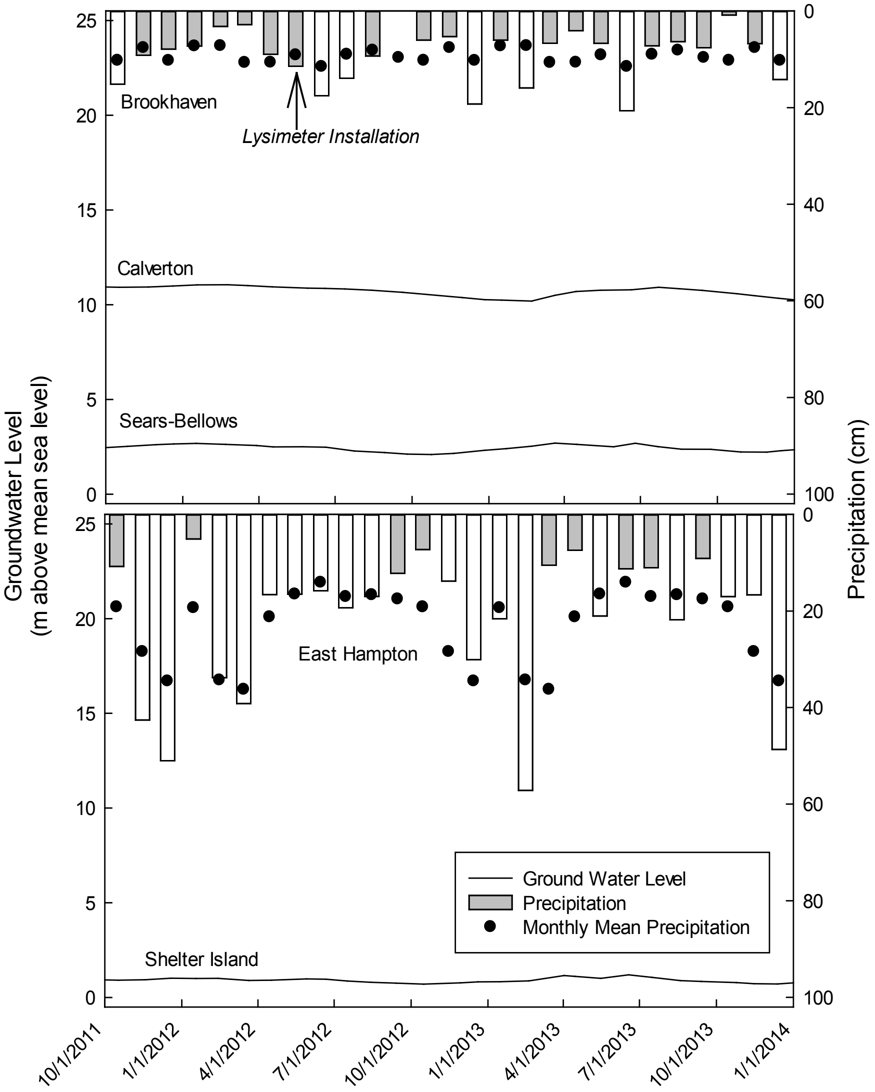
(http://nadp.sws.uiuc.edu/).



Annual precipitation during the study period averaged 240 cm at the East Hampton Airport, on the south fork of Long Island 11 km south-southeast of the Mashomack Preserve, and 156 cm at Brookhaven Airport (Figure 6), 20 km south-southwest of the Calverton Ponds (Sandy Pond East and Block Pond) and 25 km west of the Sears-Bellows Ponds area (http://climod.nrcc.cornell.edu/ accessed February 2014). Precipitation during 2012 was 5% less than the mean of the previous 14 years at Brookhaven Airport, and 17% less than the mean of the previous 11 years at East Hampton Airport. Similar decreases in precipitation compared to the long-term mean were measured at Brookhaven Airport during 2013, whereas the decrease at East Hampton Airport was half that of 2012. The precipitation deficit during 2012 occurred primarily during the fall season, whereas during 2013, the deficit was spread across all seasons. The mean annual air temperature during 2012 was 1.0 °C greater than the mean annual air temperature of the previous 15 years at Brookhaven Airport (11.3 °C), with the increase distributed throughout the year. Groundwater levels at wells near the Calverton Ponds, Sears and Bellows Ponds and Shelter Island showed little variability over the study period (Figure 6).

Figure 6. Monthly Total Precipitation

Upper panel: for water years (October-September) 2011-2012 (bars) and average values (closed circles) for the full record (1999-2012) at the National Weather Service Station, Brookhaven, NY, and groundwater levels in wells near the Sandy Pond East study pond, and the Sears-Bellows study ponds Lower panel: for water years 2011-2012 (bars) and average values over the full record (closed circles) at the National Weather Service Station, East Hampton Airport, NY, and groundwater levels in a well on Shelter Island near the Nature Conservancy's Mashomack Preserve



4.2 Soil Analyses

Soils at the nine sampled locations were generally similar in regard to their coarse texture and low rate of mineral weathering, which resulted in a low capacity for retention of water and nutrients. Some differences related to vegetation were evident. At the three Mashomack sites, and the site west of Third Pond, where the overstory was largely oak, the forest floor (Oi and Oe horizons) was underlain by an A horizon. At the other five sites, where pitch pine was an important component of the overstory, the A horizon was absent and the forest floor was underlain by a heavily-leached E horizon, which was more acidic, and had lower carbon content, cation-exchange capacity, and base saturation than the A horizons.

Pits 1 and 3 sampled in the Mashomack Preserve were in excessively drained, coarse-textured soils in the Entisol soil order. These soils are defined as recently deposited materials that exhibit little or no evidence of horizon development. They have a high quartz content with a low rate of mineral weathering. These locations were mapped by the National Resource Conservation Service (NRCS) as being loamy sands in the Plymouth soil series. Pit 2 in the Mashomack Preserve was in well-drained coarse textured soils in the Inceptisol soil order. These soils have minimal horizon development, but are more developed than Entisols. At this location, the soil was derived largely from slowly weathering granitic material and typically included rock fragments of approximately 5% of soil volume. This location was mapped by the NRCS as being a fine sandy loam in the Montauk soil series.

The pits sampled near Sears and Bellows Ponds were in excessively drained, coarse-textured soils in the Entisol soil order. Like the Mashomack Preserve Entisols, these soils exhibited little evidence of B horizon development, although each pit had well developed E and EB horizons (Photo 5). They also had a high quartz content with a low rate of mineral weathering. These locations were mapped by the NRCS as being sands in the Carver and Plymouth soil series.

The soils pits excavated on either side of Third Pond were both in the soil order Inceptisol, but the pit to the east of the pond was located in poorly drained silt loam in the Raynham series, whereas the pit to the west of the pond was in located in a well-drained loam in the Riverhead soil series. The soils in both of these locations were finer textured than in any of the other pits, but were similarly derived from slowly weathering granitic materials.

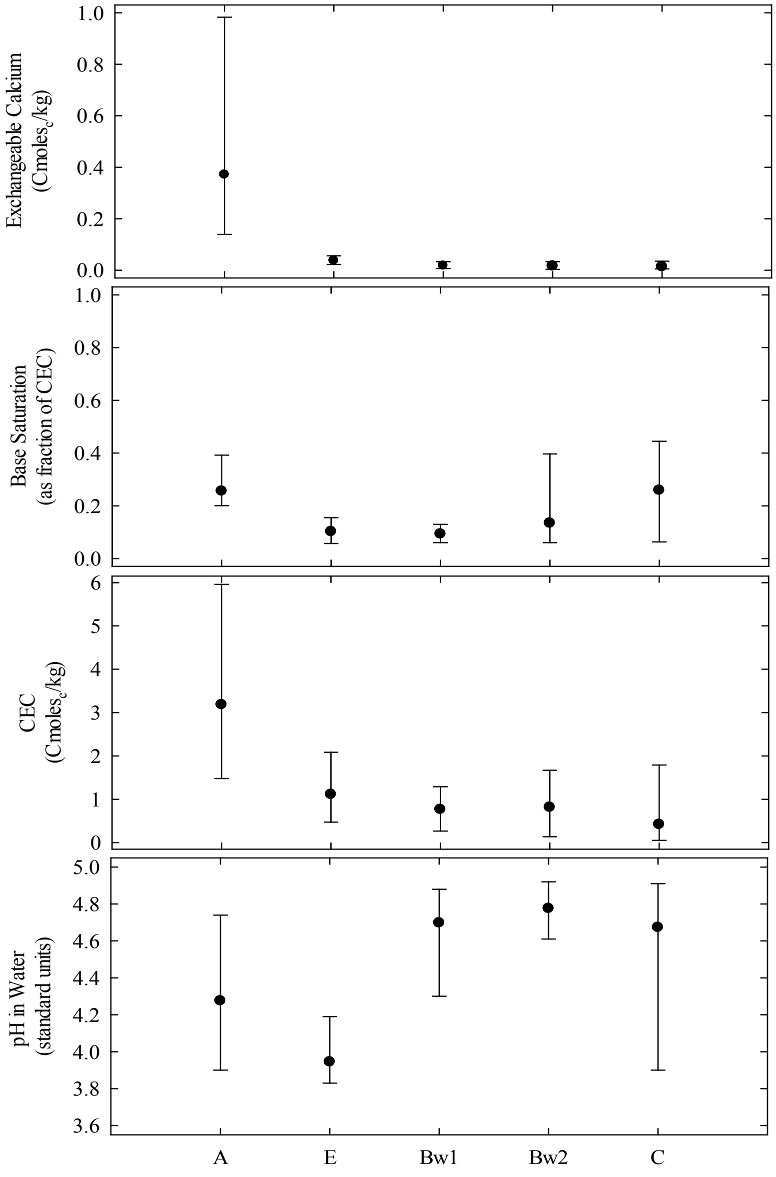
Photo 5. Profile of the soil pit excavated near Bellows Pond

The gray, heavily leached E horizon underlying the forest litter indicates forests where pitch pine is common.

The soil pits excavated near Sandy Pond East and Sandy Pond West were in loamy sands (soil order Entisol) in the Plymouth and Carver soil series, like the pits near Sears and Bellows Ponds. Predominate overstory vegetation had a consistent effect on upper soil horizination. The five sites in which pitch pine predominated had well-defined E horizons formed from leaching by organic acids derived from pine litter, whereas the four sites in which oak predominated all lacked an E horizon.

Variation in soil chemistry among the nine sampling locations was small, with the exception of the A horizon (Figure 7). All sites had extremely low CEC, typical of sandy-textured soils with low carbon content. The pit near Third Pond was a notable exception. This soil had a relatively high CEC and was in the Riverhead soil series, which was used extensively for agriculture in the area. Base saturation and concentrations of exchangeable Ca were extremely low below the A horizon in all pits. As a result, vegetation growing in these soils relied heavily on the O and A horizons at or near the surface for uptake of mineral nutrients. Mean values of deionized water extractable pH were less than 4.8 but higher than 3.8 for the nine sites. These soils would likely have been more acidic had CEC been higher.

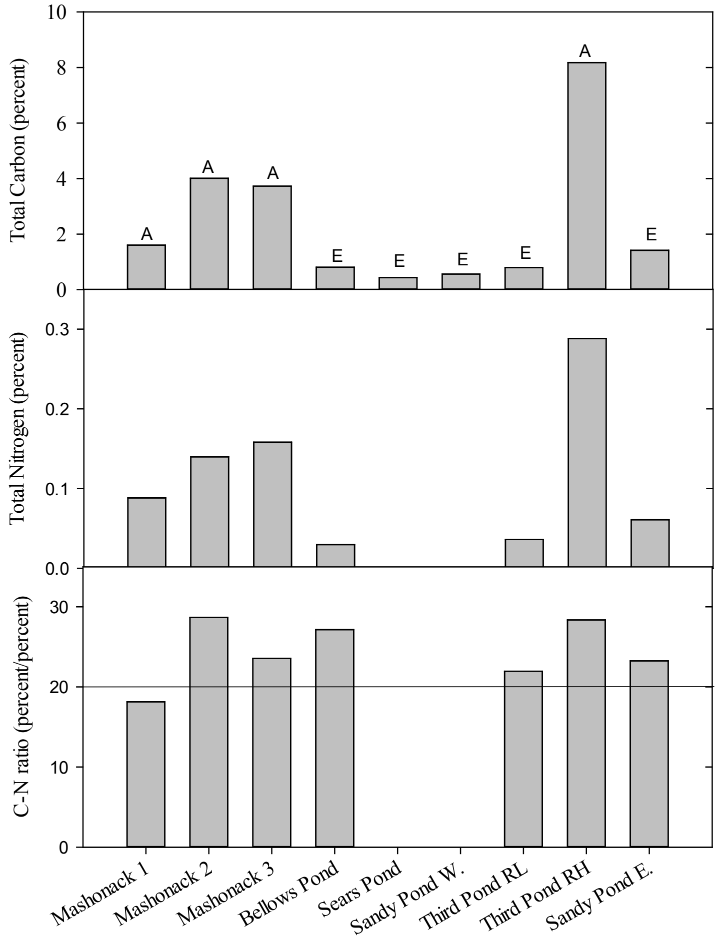
Figure 7. Concentrations of exchangeable calcium, base saturation, cation exchange capacity (CEC) and pH (deionized water extraction) averaged, by horizon, for the 9 soil sampling sites



Organic carbon and nitrogen contents of the uppermost mineral soil horizon varied considerably among the nine sampling locations (Figure 8). The three pits in the Mashomack Preserve had somewhat higher concentrations than the six other sites, but soils from all sites had low concentrations of carbon and low to undetectable concentrations of nitrogen. The one exception was the pit in the relatively fertile Riverhead soil near Third Pond, which had much higher concentrations than all other sites. Ratios of carbon to nitrogen were between 18 and 28 at the sites that had measureable nitrogen.

Figure 8. Concentrations of total carbon, total nitrogen, and total carbon to total nitrogen ratios in the upper most mineral soil horizon (A, or E, indicated in the top panel), at the 9 soil sampling locations

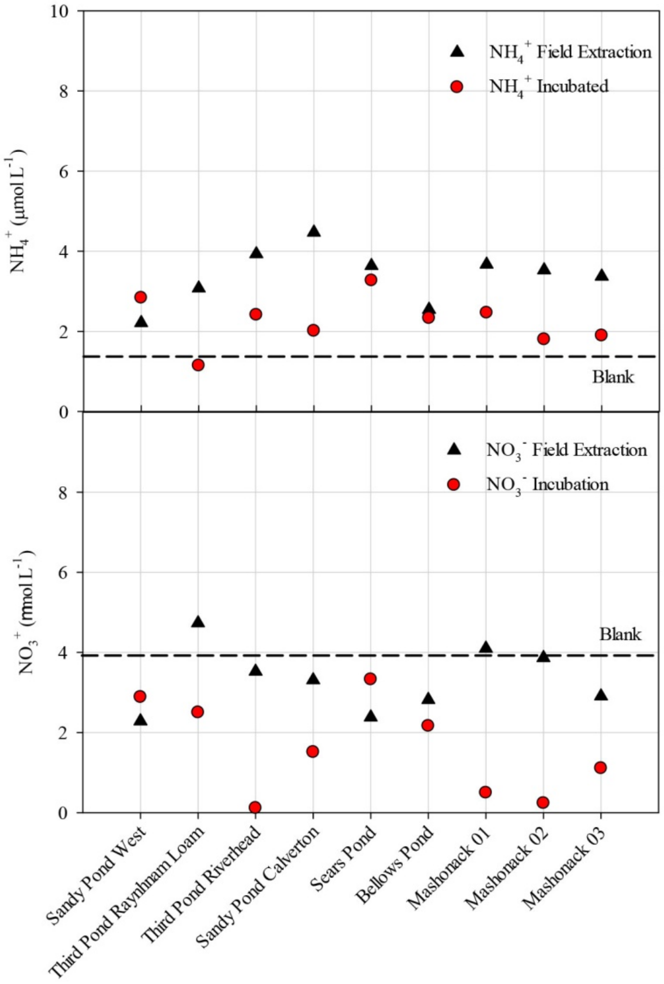
Total nitrogen values were below method detection at Sears Pond and Sandy Pond West.



Field extraction of NH_4^+ from the upper mineral soil (using deionized water) yielded concentrations that were below, or at one site, slightly above 4 millimoles per liter (mmol/ L; Figure 9). Extraction of this soil after incubation for 2 weeks resulted in similar or somewhat lower concentrations of ammonium (NH_4^+), which indicated some degree of net microbial uptake. Extraction of NO_3^- following the same method also indicated low concentrations in the field, and similar but somewhat lower concentrations after the 2-week incubation (Figure 9), which indicates that net nitrification did not occur. Net nitrification would indicate conversion of NH_4^+ to NO_3^- by autotrophic nitrifying bacteria, which would not occur unless NH_4^+ was in ample supply for heterotrophic bacteria. Overall, these results are consistent with what would be expected in a nitrogen-limited system. Incubation of a soil in which labile nitrogen had accumulated in excess of ecological demand (nitrogen saturation) would result in a clear increase in NO_3^- concentrations from nitrification (Aber et al. 2003, Ross et al. 2004). Values for all soil measurements are listed in Appendix A, and descriptions following NRCS procedures are listed in Appendix B.

Figure 9. Concentrations of NH_4^+ (upper panel) and NO_3^- (lower panel) in deionized water extractions immediately upon collection in the field (field extraction) and after a 2-week incubation (incubated)

Blank values are based on extractions done with the field extraction equipment and procedures, without soil. The blank value was not subtracted from the soil extractions, but was used to show that values from soil extractions were not substantially different from what you would obtain without soil.



4.3 Pond Water Quality

The six ponds exhibited similarly wide seasonal variations in water temperature (Figure 10), as would be expected in these shallow ponds. Maximum temperatures approached 30 °C in August, except in Block Pond, which was dry on the sampling date, and the Bellows Pond measurement that was taken within 1 m of the bottom, which did not reach 25 °C. The December measurement was less than 5 °C in each pond. Most of the dissolved oxygen measurements remained above 75% saturation throughout the sampling period for all ponds (Figure 10). The only measurements below 75% saturation were taken within 1 m of the bottom of Bellows Pond, and Sandy Pond East and Sandy Pond West during the October sampling. The relatively high oxygen saturation in all ponds through the sampling period reflects their shallow water columns. The high ratio of surface area to water volume of the ponds, with the possible exception of Bellows Pond (the deepest pond), enables ready mixing of atmospheric gases throughout the water column, limiting depletion of oxygen from decomposition processes within and just above sediments.

The acidity status of the ponds varied widely based on pH and acid-neutralizing capacity (ANC) measurements. Most pH measurements for Sears Pond, Sandy Pond East, and Sandy Pond West were well above 6.0, whereas values for Third Pond and Bellows Pond varied around pH 5.5 (Figure 11). Block Pond was extremely acidic with pH values at or near 4.5. Measurements of ANC were similarly distributed (Figure 12). Sears Pond and Sandy Pond East had the highest ANC, followed by Sandy Pond West. All three ponds had ANC values greater than 50 milliequivalents per liter (meq/L) for nearly all sample dates. In contrast, ANC measurements for Third Pond, Bellows Pond, and Block Pond were either slightly above or below 0.0 meq/L on all sample dates.

The distribution of Ca^{2+} concentrations among the ponds was generally similar to pH and ANC measurements (Figure 13). Higher values tended to occur in Sears Pond, Sandy Pond East, and Sandy Pond West, lower values tended to occur in Third Pond and Bellows Pond. The December measurement for Block Pond was much greater than the measurements in April and May. This difference probably reflects a concentration effect caused by evaporation as the pond dried up in late summer, then refilling just prior to sampling in December.

Figure 10. Water temperature and dissolved oxygen in the six ponds on each sampling date

Measurements in all ponds were taken 0.31 m from the bottom including Bellows Pond (deep). A measurement 0.31 m from the surface (shallow) was also collected in Bellows Pond.

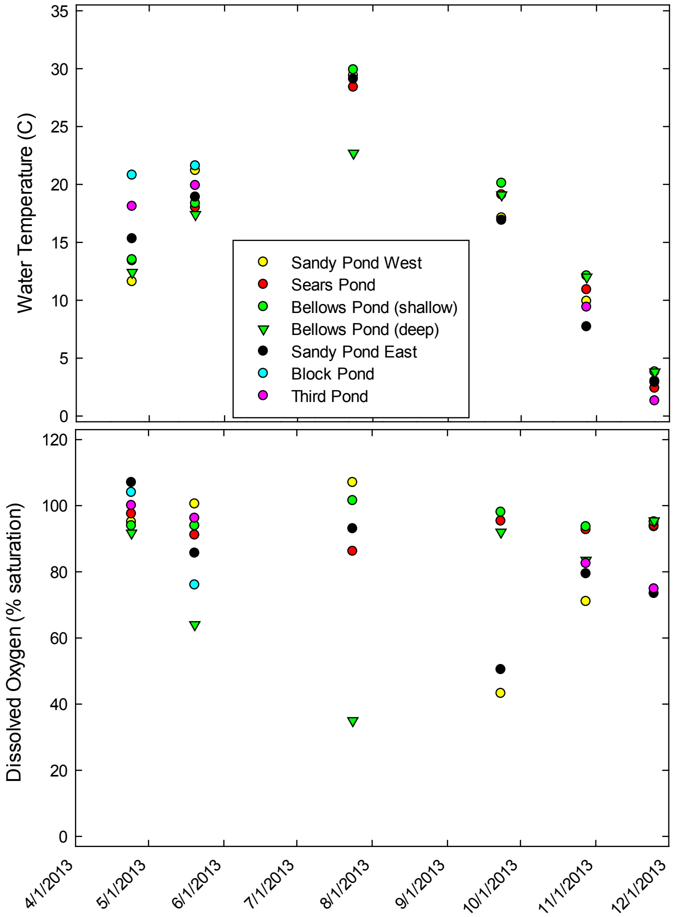


Figure 11. Measurements of pH for each water sample collected in the six ponds during the study period

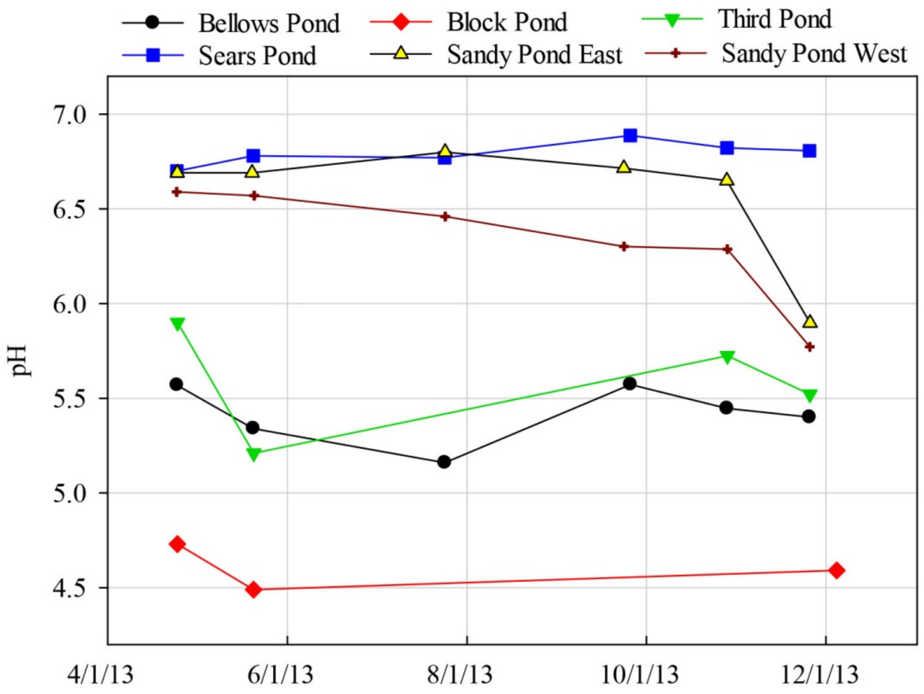


Figure 12. Measurements of acid-neutralizing capacity for each water sample collected in the six ponds during the study period

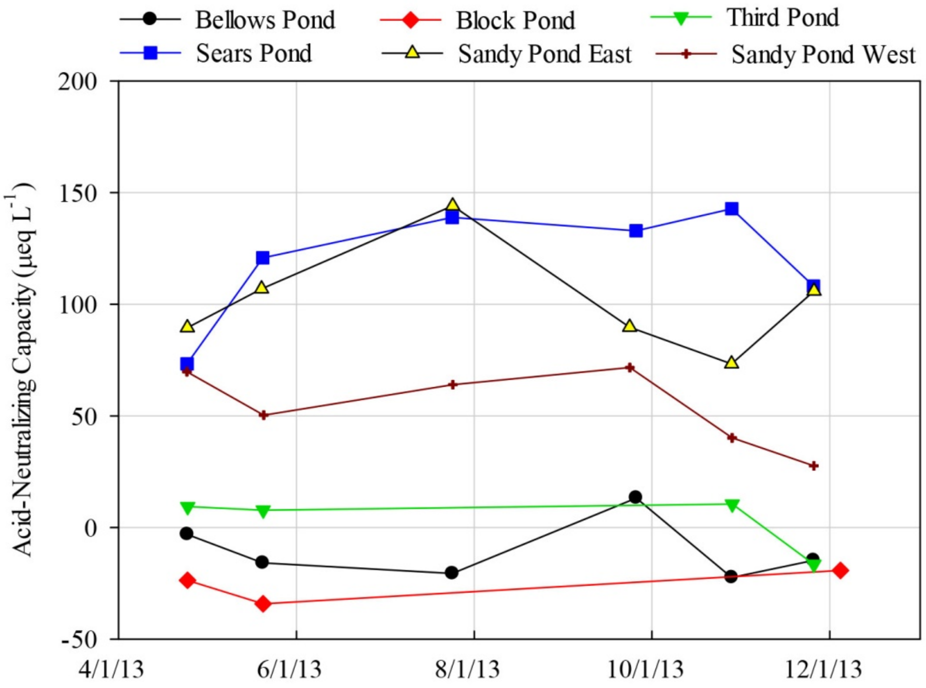
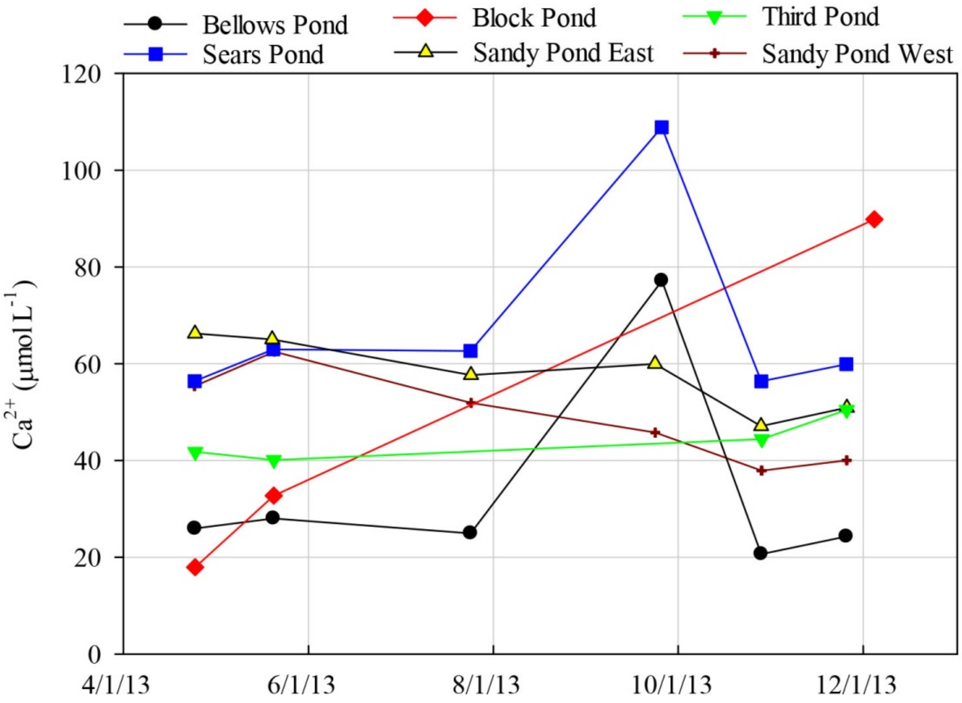


Figure 13. Measurements of Ca^{2+} concentration for each water sample collected in the six ponds during the study period



Concentrations of NH_4^+ were below 5.0 mmol/L in all ponds on most sampling dates (Figure 14) and concentrations were generally similar among ponds. A single high value approaching 20 mmol/L was measured in Sandy Pond East in the November sampling. Similar to NH_4^+, concentrations of total P were generally low; approximately 10 mg/L or less in most ponds on most sampling dates (Figure 15). However, P concentrations in Third Pond and Block Pond were somewhat higher, ranging between 20 and 40 mg/L. Furthermore, atypically high values were measured in Bellows Pond in October and in Sandy Pond West in November. Concentrations of SO_4^{2-} ranged between 20 and 60 mmol/L in all ponds over the sampling period (Figure 16). In all ponds except Block Pond, for which there were no data, concentrations tended to be lowest from the late July sampling through October sampling. Of the ponds sampled at least 4 times, Sandy Pond East exhibited the largest variation in SO_4^{2-} concentrations over the sampling period and Bellows Pond exhibited the least.

Figure 14. Measurements of NH_4^+ concentration for each water sample collected in the six ponds during the study period

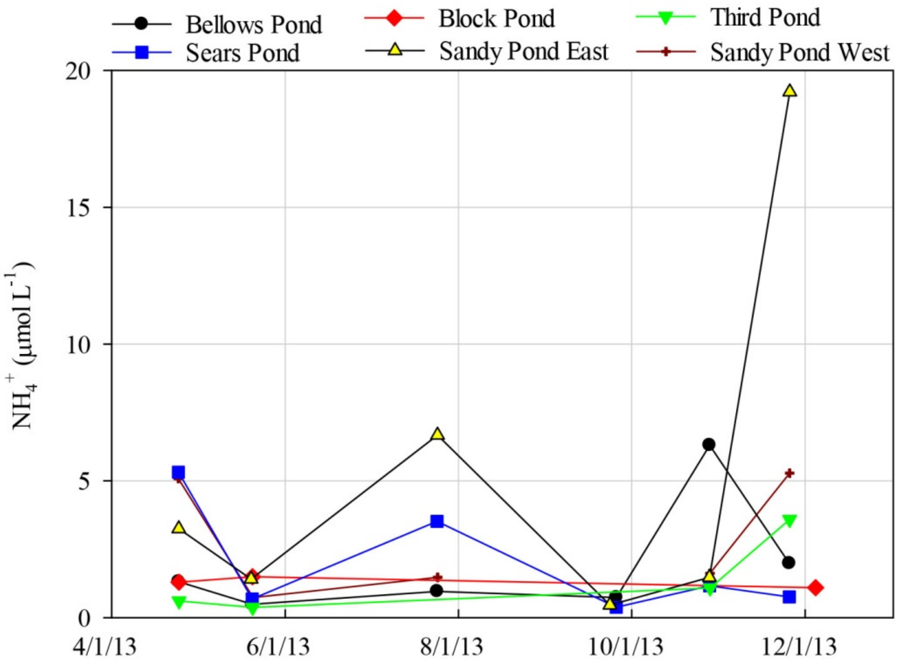


Figure 15. Measurements of total phosphorus concentration for each water sample collected in the six ponds during the study period

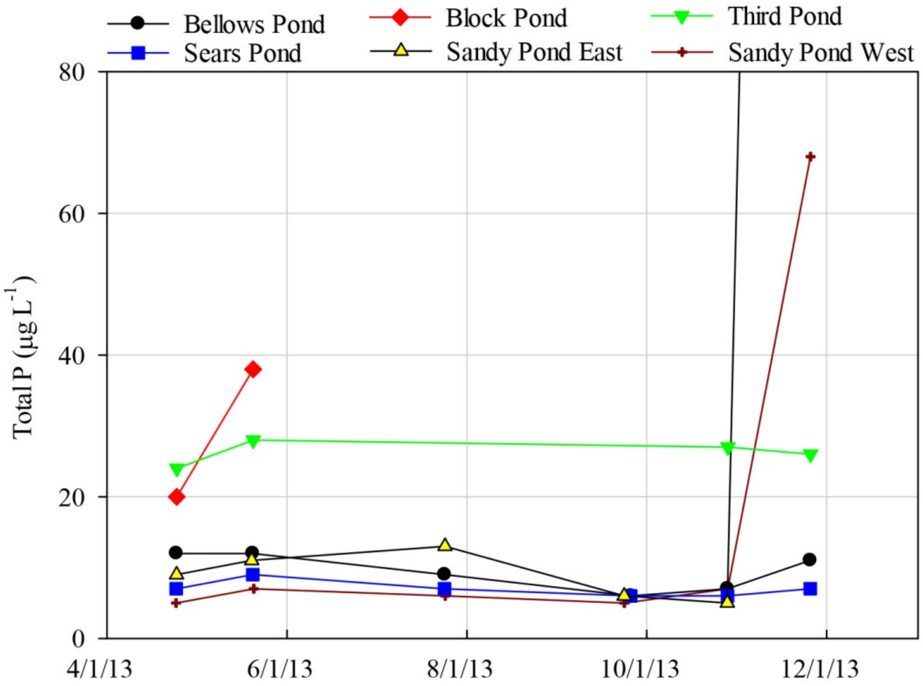
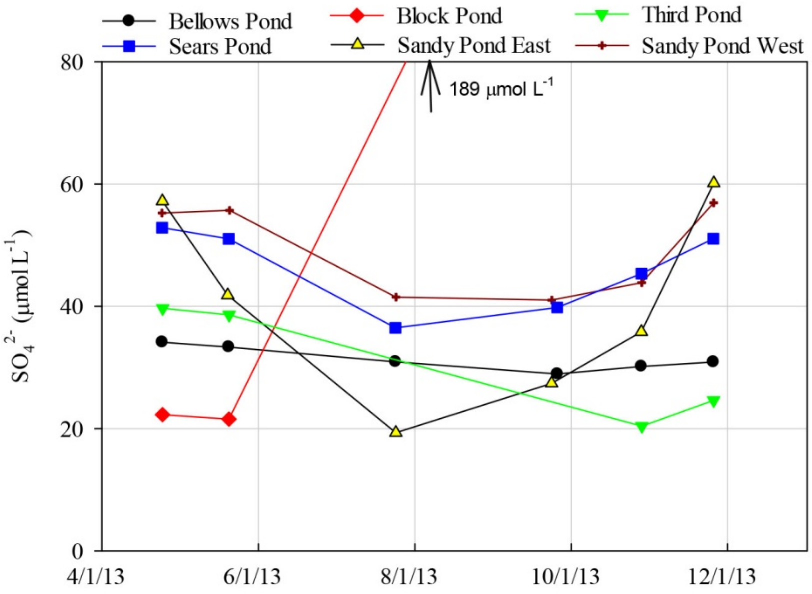
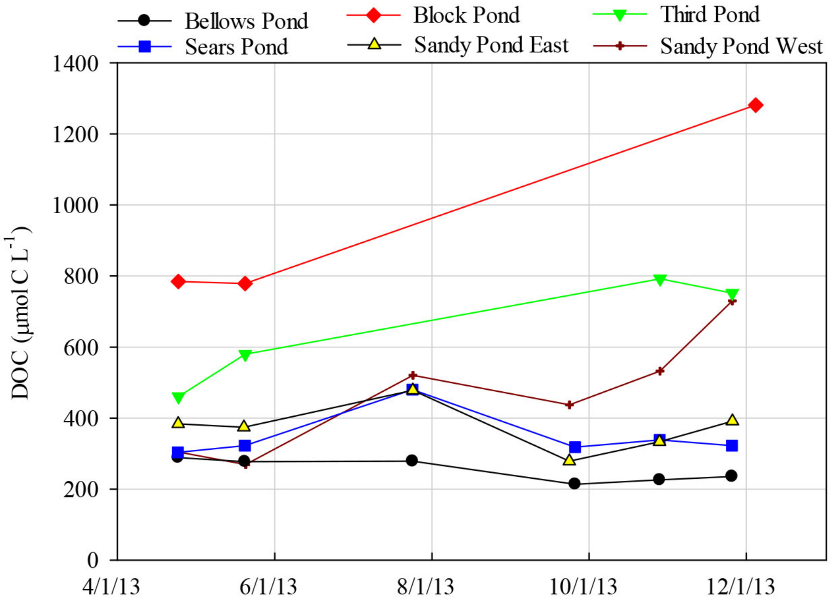


Figure 16. Measurements of SO_4^{2-} concentration for each water sample collected in the six ponds during the study period



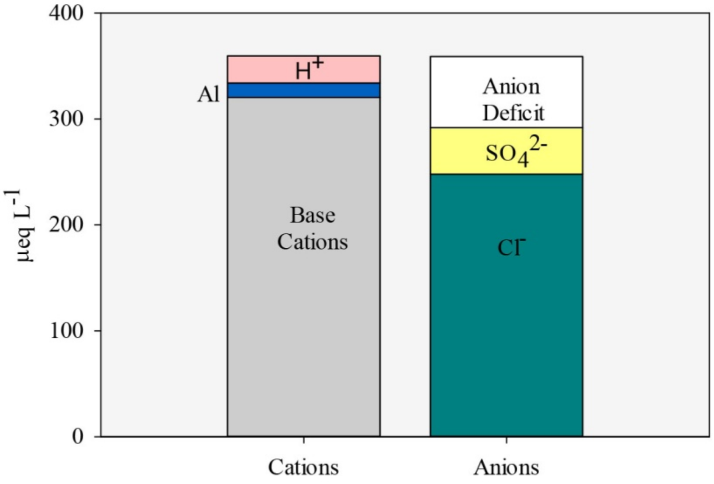
Concentrations of dissolved organic carbon (DOC) were similar among all ponds except Third Pond and Block Pond, in which DOC was consistently higher than in the other ponds (Figure 17). Concentrations in Sandy Pond West, Third Pond and Block Pond tended to increase over the sampling period, whereas concentrations in the remaining ponds remained relatively stable throughout the sampling period.

Figure 17. Measurements of dissolved organic carbon (DOC) concentration for each water sample collected in the six ponds during the study period



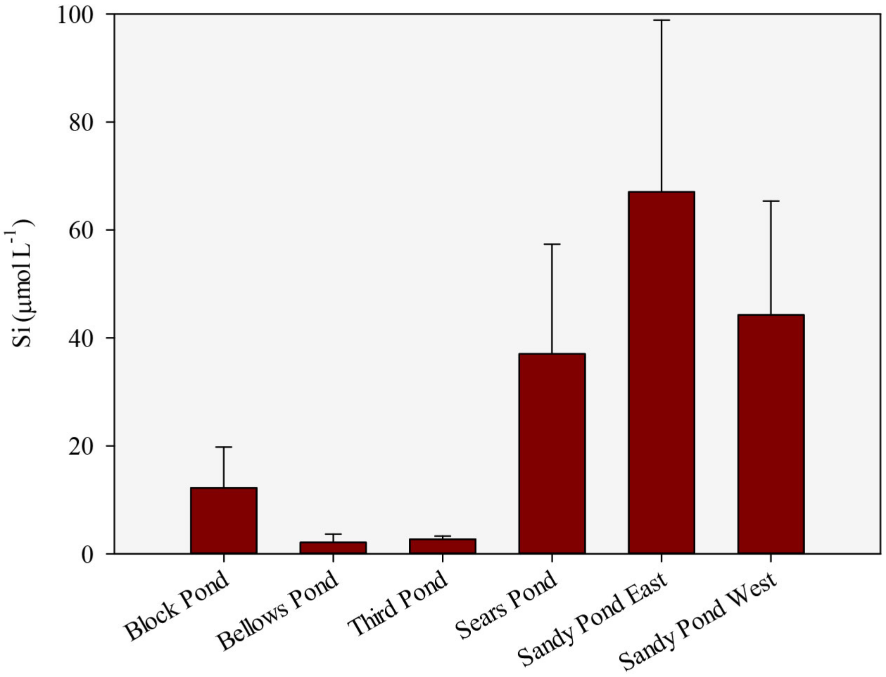
Before going dry, concentrations of DOC in Block Pond were substantially higher than concentrations of the other ponds. Organic acids associated with the DOC contributed to pH values at or below the lowest precipitation pH values (Figure 4 and Figure 11), and ANC values were well below zero (Figure 12). The contribution of acidic deposition relative to naturally-derived organic acids in Block Pond was compared in a charge balance. If the concentration of all cations and anions are measured, the sum of cation charges will equal the sum of anion charges. However, direct measurement of organic anion concentration is not possible. Therefore, plotting all measured cations and anions shows an anion deficit that can be assumed to approximate the charge associated with organic anions (Lawrence et al. 2007). The charge balance averaged for Block Pond in May and June (Figure 18) indicated that the organic anion estimate exceeded the sum of the concentrations of SO_4^{2-} plus NO_3^-. Concentrations of NO_3^- are not shown on Figure 18 because they were below the laboratory analytical reporting limit of 1 meq/L (Lincoln et al. 2009).

Figure 18. Charge balance of ionic concentrations for Block Pond samples averaged for April-May collections



Concentrations of silicon (Si) were also measured in the ponds to assess the relative influence of groundwater. Although the soils found at all these sites were high in Si, the rate at which Si is released from soil minerals through weathering is extremely slow. Therefore, the extended reaction time that occurs in groundwater, results in higher concentrations of Si than in water that has moved into ponds through shallow flow paths with relatively short residence times. The low Si concentrations (Figure 19) in Block Pond, Bellows Pond, and Third Pond indicate that these ponds are minimally influenced by groundwater, whereas Sears Pond, Sandy Pond East and Sandy Pond West do show an influence of groundwater. Values for all soil measurements are listed in Appendix C.

Figure 19. Mean concentrations and standard deviations (vertical lines) of Si concentrations for the six ponds over the study period



4.4 Mercury Concentrations in Birds

A total of 242 birds representing 28 species were captured, banded and/or sampled (Appendices D and E) during 14 days of field efforts by biologists from BRI with assistance from biologists from The Nature Conservancy of Long Island. In general blood Hg concentrations were below the known effect level of 0.7 ppm for songbirds (Jackson et al. 2011). The following species were found to be suitable indicators of mercury exposure and include Carolina Wren, Common Yellowthroat, Red-winged Blackbird, Red-eyed Vireo, and Pine Warbler. However, species (such as Carolina Wren) that consume mostly spiders and invertebrates higher on the food chain are better suited as indicators of Hg than, for example, the Gray Catbird. The diet of Gray Catbirds includes invertebrates, but is generally more than 50% fruits and berries (Ehrlich et al. 1988). Therefore, they are a relatively weak indicator of Hg accumulation, which is evident in the data (Figure 20). A wide range in blood Hg accumulation was measured in the species collected in this study (Figure 21).

Figure 20. Mean blood Hg concentrations of selected species across sites

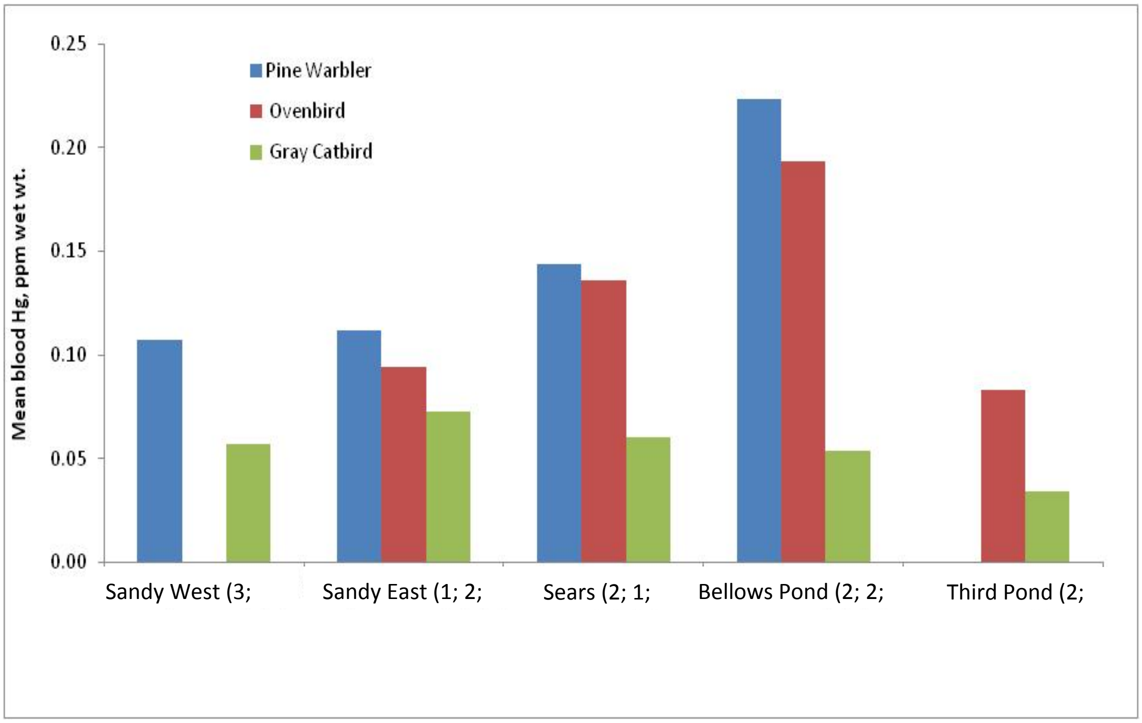
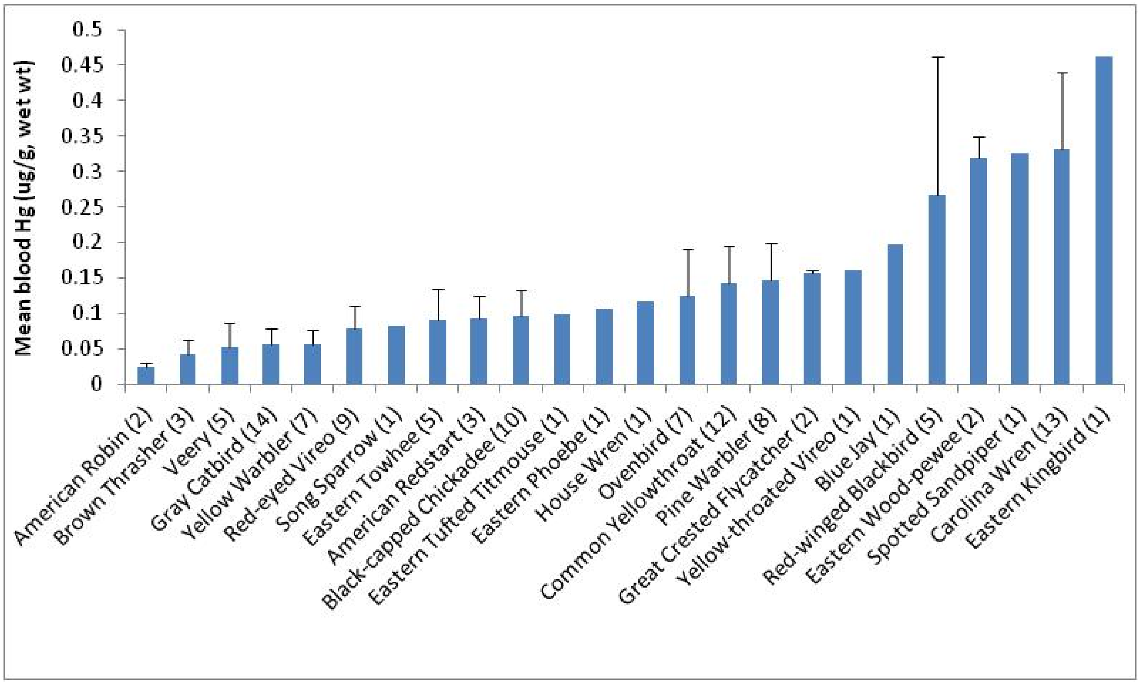


Figure 21. Mean blood Hg concentrations across all sites in all species sampled on Long Island, New York, 2012

Number of individuals per species indicated in parentheses.



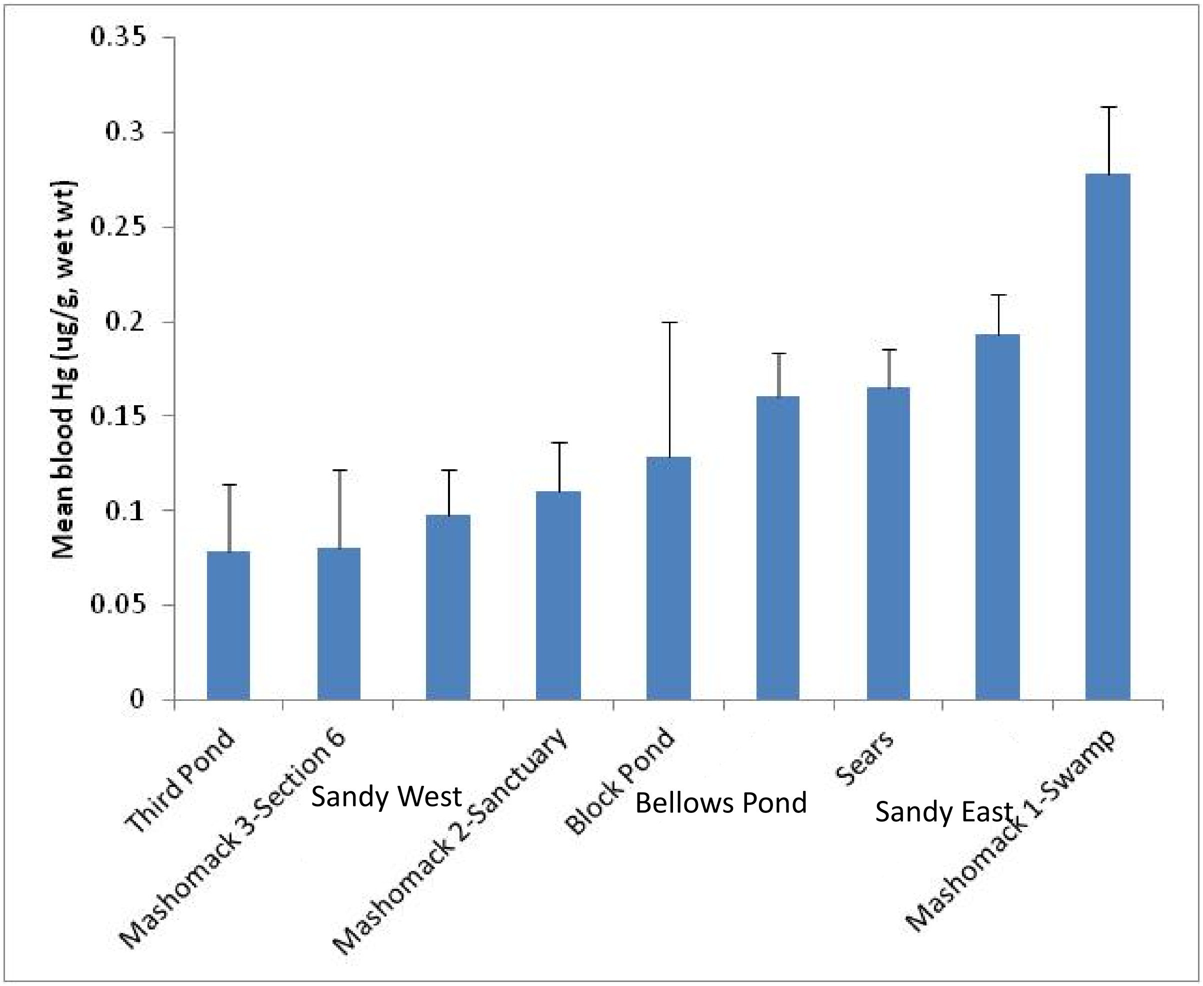
A Least Square Means (LSM) model was run on bird blood Hg data and found that 85% of variability in the model is explained by species and site effects (Table 3). Because bird age was not a significant variable, all ages were grouped for further statistical analyses.

Table 3. Summary of Least Square Means Model on log-transformed bird blood Hg data, New York, 2012.

Summary of Fit					
R2	0.8491				
Adjusted R2	0.7927				
Root Mean Square Error	0.3360				
Mean of Response	-2.251				
Observations	115				
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Ratio	
Model	31	52.73	1.70	15.06	
Error	83	9.37	0.1129		Prob > F
C. Total	114	62.11			<.0001
Effect Tests					
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Site	8	8	4.74	5.25	<.0001
Species	23	23	37.29	14.36	<.0001

Even though statistically significant differences in blood Hg were found among sites, the concentrations are still below the 0.7 effect level and are somewhat similar (Figure 22). In the seven songbirds sampled (four Carolina Wrens from Mashomack, two Red-winged Blackbirds and one Song Sparrow from Sandy Pond East), tail feather Hg exceeded the 3 ppm level at which the probability of one chick fledging declines by 10% (Jackson et al. 2011) (Appendix E).

Figure 22. Mean (arithmetic) blood Hg concentrations and standard errors of all invertivorous avian species, New York, 2012



4.5 Stable Isotopes of C and N in Birds

A subset of blood samples (n=60) was analyzed for the ratio of stable isotopes of nitrogen (^{15}N and ^{14}N, reported as δ^{15}N) and carbon (^{13}C and ^{12}C, reported as δ^{13}C) to better understand food web dynamics. In the Pine Barrens and at the Mashomack sites, a significant difference was not observed in bird blood δ^{15}N among sites (ANOVA: df=59, F=1.94, p=0.082). Values of δ^{15}N in bird blood ranged from 2.04 ‰ at Bellows Pond and Sandy Pond East, to a value of 8.88 ‰ also measured at Sandy Pond East (Table 4). The δ^{13}C in birds on Long Island ranged from -26.46 ‰ at Sandy Pond East to -23.89 ‰ also at Sandy Pond East (Table 4). There was a significant difference in bird δ^{13}C across sites (df=59, F=4.16, p=0.0011). Post hoc comparisons of δ^{13}C values in blood revealed that δ^{13}C values at Mashomack site 2-Sanctuary were significantly more negative (i.e., depleted in ^{13}C) than at Third Pond and Sandy Pond East. Based on the LSM model, mean blood Hg concentrations grouped by site were not significantly related to δ^{15}N (p>0.10), and only marginally related to δ^{13}C (p<0.087).

Table 4. Ranges of stable isotope ratios δ^{15}N and δ^{13}C (‰) in bird blood from Long Island, 2012

site	N (# of birds)	Min(δ 15N)	Max(δ 15N)	Min(δ 13C)	Max(δ 13C)
Mashomack 1-Swamp	6	4.31	5.96	-24.74	-24.07
Mashomack 2-Sanctuary	10	2.42	6.17	-25.32	-20.89
Mashomack 3-Section 6	9	2.29	4.81	-25.34	-24.43
Bellows Pond	6	2.04	6.59	-25.15	-24.43
Sandy Pond East	13	2.04	8.88	-26.46	-23.89
Sandy Pond West	3	2.09	2.77	-25.44	-25.24
Sears Pond	7	2.70	5.34	-25.18	-23.97
Third Pond	6	2.91	4.47	-26.30	-24.88

Blood Hg concentrations were positively correlated with δ^{15}N‰ although the relationship explained only 23% of the variability (Figure 23). Blood Hg concentrations were not related to δ^{13}C (p >0.10). Carbon isotopic ratios are largely controlled by differences in photosynthetic pathways among terrestrial plants. Most grasses and sedges are considered C4 plants and have δ^{13}C values of approximately -14‰ (Peterson and Fry 1987). Trees, as well as some wetland plants such as cattail and phragmites, are considered C3 plants and have lighter δ^{13}C values of approximately -28‰ (Peterson and Fry 1987). Although samples of vegetation were not analyzed as part of this project, it is likely that carbon acquired by birds in the Central Pine Barrens and Mashomack were influenced by C3 vegetation (Figure 24).

Figure 23. Relationship between bird blood Hg concentrations and δ N‰ values in birds

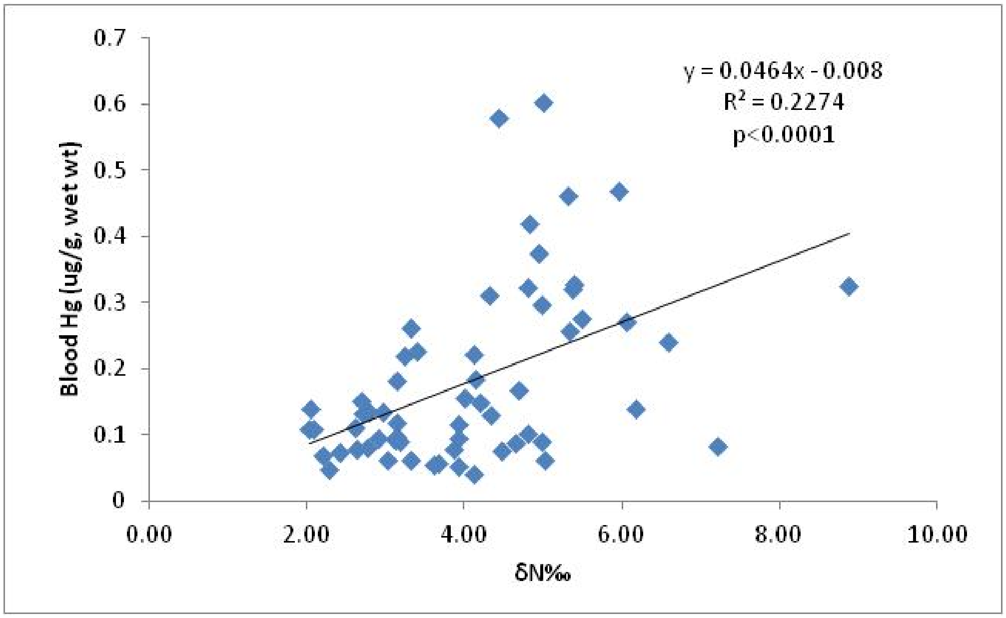
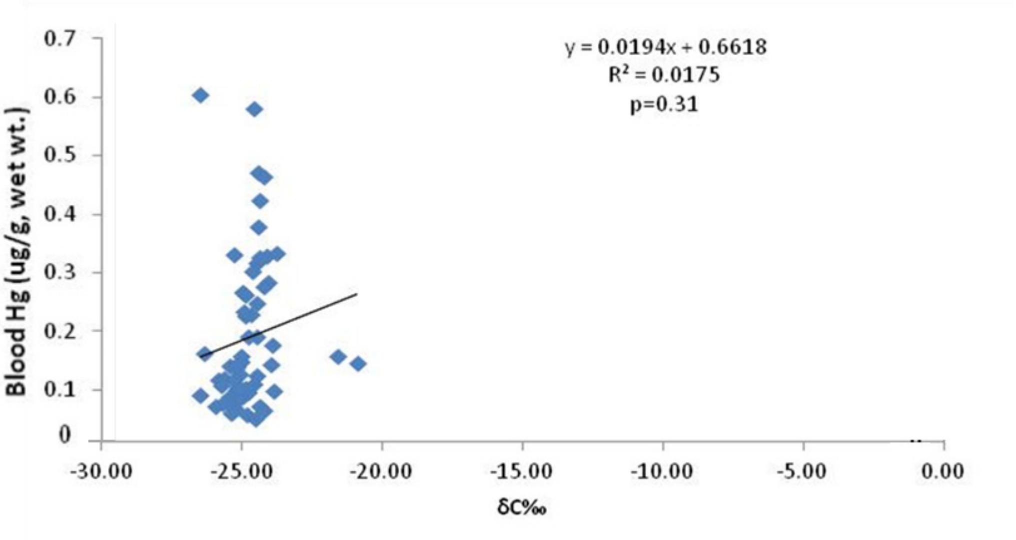


Figure 24. Relationship between bird blood Hg concentrations and δ C‰ values in birds



Evaluating the entire data set by species showed that δ ^{13}C and δ ^{15}N were significantly different among species (p=0.0044 and p<0.0001, respectively). However, the sample size of individuals within species was too small to make reliable conclusions regarding individual species. Nevertheless, it appears that in this study certain species such as American Redstart (AMRE), Carolina Wren (CARW), Eastern Kingbird (EAKI), Eastern Wood Pewee, House Wren (HOWR), Red-winged Blackbird (RWBL), Song Sparrow (SOSP) and Spotted Sandpiper (SPSA) feed at a higher trophic level than the remaining species such as Black-capped Chickadee (BCCH), Common Yellowthroat, and Pine Warbler (PIWA) (Figure 25).

The δ ^{13}C concentrations are more or less similar indicating a similar plant-based diet with the exception of RWBL, which is feeding on carbon-based food with heavier ^{13}C isotope (less negative δ ^{13}C therefore less depleted in ^{13}C), indicating a more aquatic carbon base (Figure 26. All values of C and N isotopes are listed in Appendix F.

Figure 25. Values of δ^{15}N in selected bird species sampled on Long Island, 2012

Species are arranged alphabetically; AMRE=American Redstart, BCCH=Black-Capped Chickadee, CARW=Carolina Wren, COYE=Common Yellowthroat, EAKI=Eastern Kingbird, EWPI=Eastern Wood Pewee, HOWR=House Wren, OVEN=Ovenbird, PIWA=Pine Warbler, REVI-Red-Eyed Vireo, RWBL=Red-Winged Blackbird, SOSP=Song Sparrow, SPSA=Spotted Sandpiper, YEWA=Yellow Warbler. The horizontal line indicates the mean of all values.

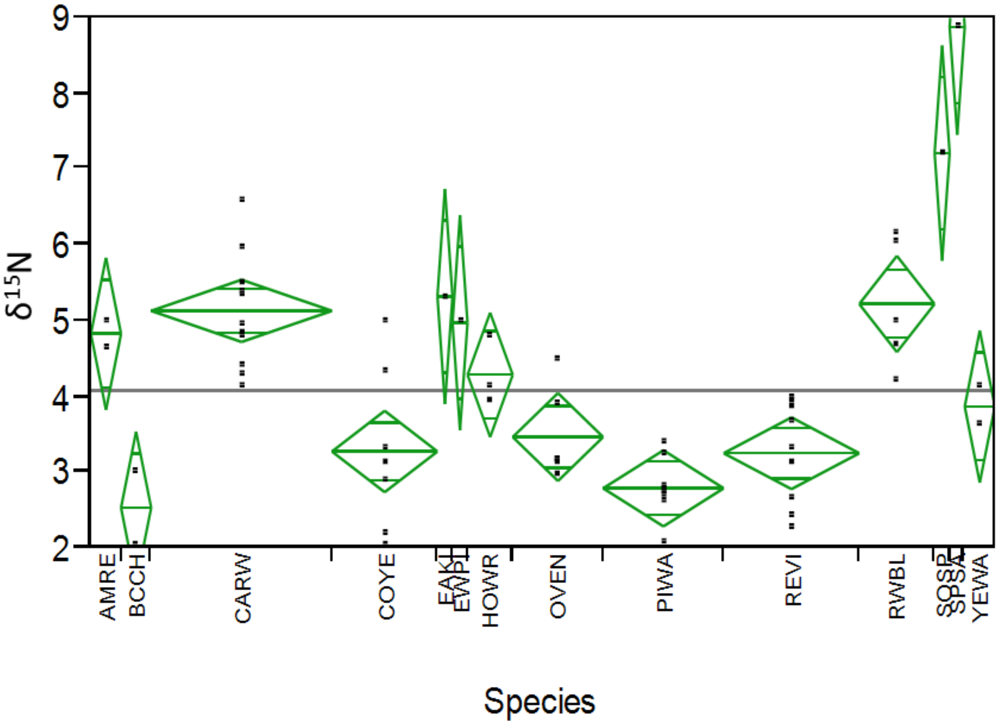
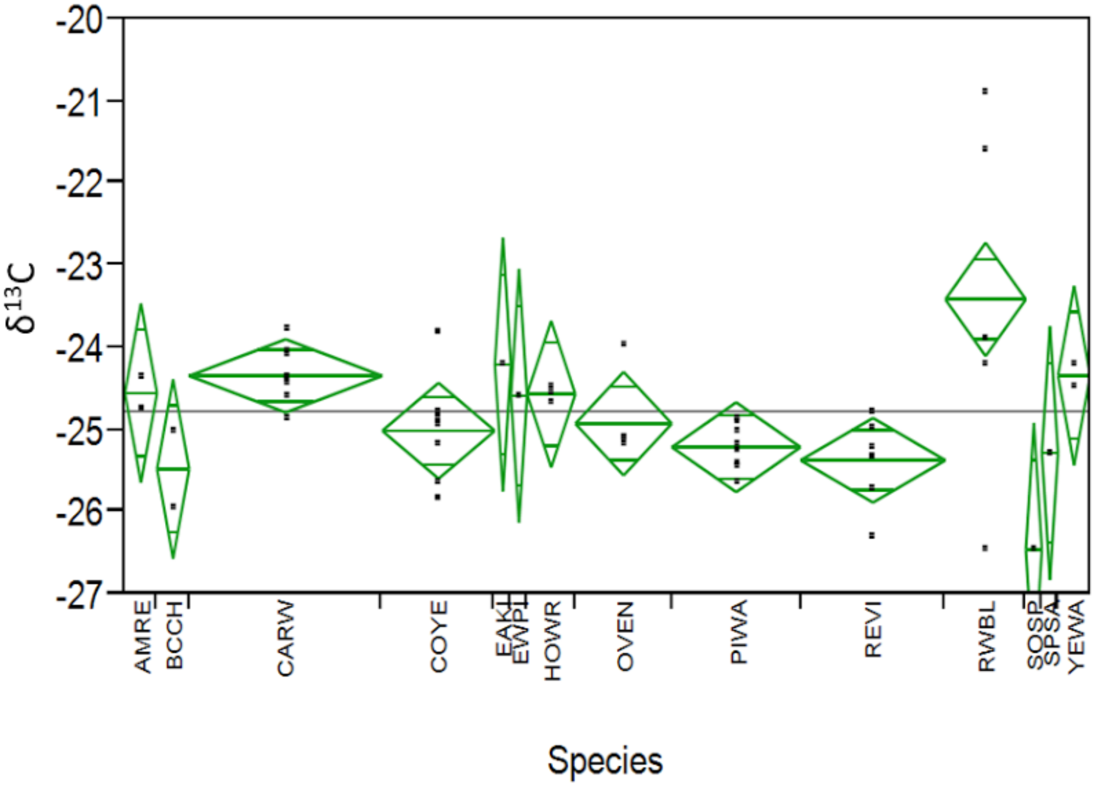


Figure 26. Values of δ ^{13}C in selected bird species sampled on Long Island, 2012

(Species are arranged alphabetically; AMRE=American Redstart, BCCH=Black-Capped Chickadee, CARW=Carolina Wren, COYE=Common Yellowthroat, EAKI=Eastern Kingbird, EWPI=Eastern Wood Pewee, HOWR=House Wren, OVEN=Ovenbird, PIWA=Pine Warbler, REVI-Red-Eyed Vireo, RWBL=Red-Winged Blackbird, SOSP=Song Sparrow, SPSA=Spotted Sandpiper, YEWA=Yellow Warbler. The horizontal line indicates the mean of all values.



4.6 Relating Bird Blood Hg to the Chemistry of Water and Soil

Statistically significant relationships were not observed between bird blood Hg and pond water chemistry ($p > 0.05$). This is possibly due to (1) the small number of ponds (n=6), (2) the timing of water sampling, (3) and or the birds selecting prey other than emergent aquatic insects. Variations in hydrology and water chemistry among ponds were also likely to contribute to a lack of significant relationships among pond chemistry measurements and Hg concentrations in bird blood. However, with soil chemistry measurements, marginally significant negative relationships ($p < 0.10$) were observed between bird blood Hg and Ca, Mg, K (Figure 27), and total N (Figure 28). Furthermore, organic carbon was negatively correlated ($p < 0.05$) with bird blood Hg (Figure 29).

Figure 27. Bird blood Hg (ppm wet wt) concentrations versus exchangeable cations in upper mineral soil (A or E horizon), 2012

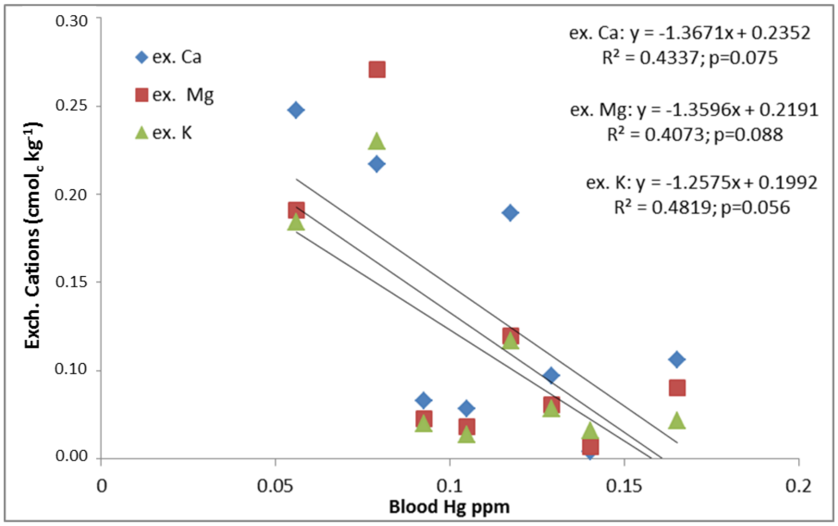


Figure 28. Bird blood Hg (ppm wet wt) concentrations versus total nitrogen (%) in upper mineral soil (A or E horizon), 2012

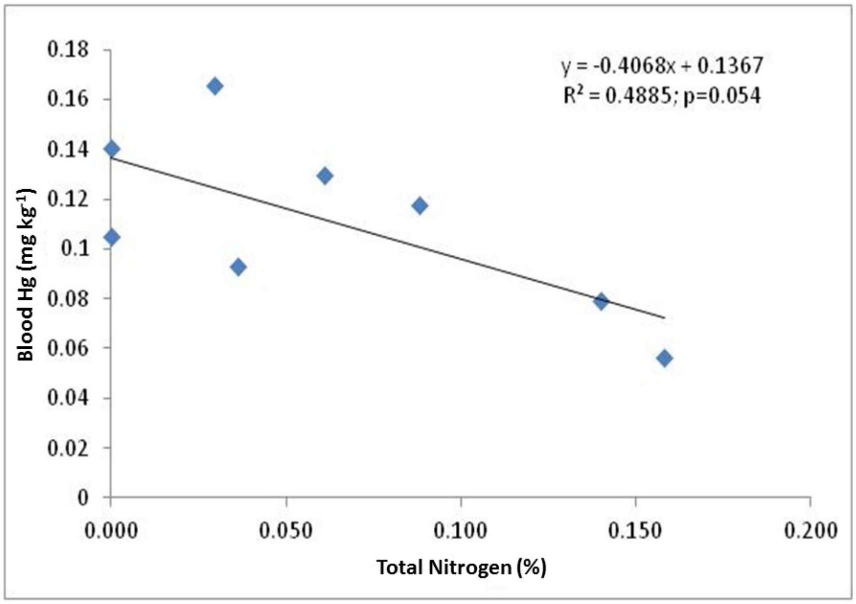
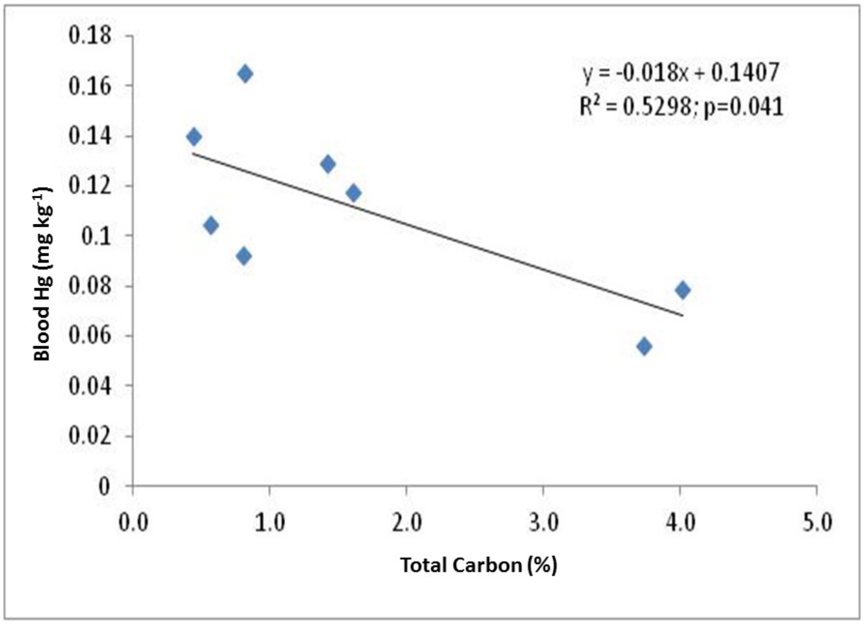


Figure 29. Bird blood Hg (ppm wet wt) concentrations versus total carbon (%) in upper mineral soil (A or E horizon), 2012



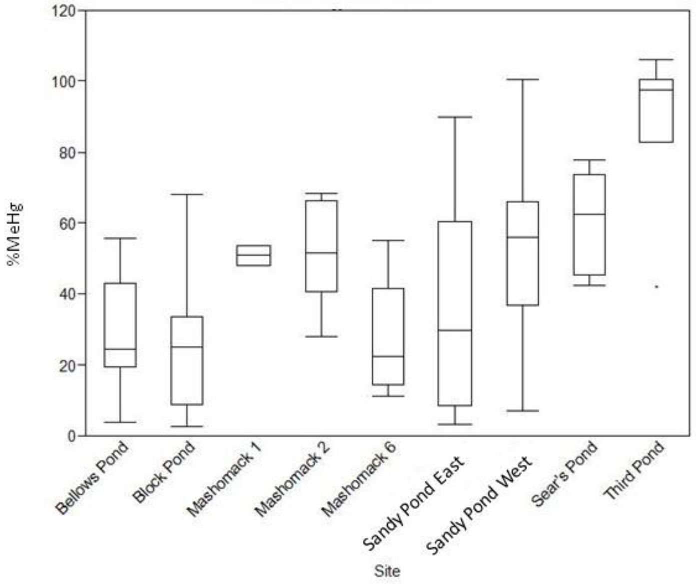
4.7 Hg Concentrations in Invertebrates

Invertebrates were analyzed for total Hg (THg), methylmercury (MeHg) and percent MeHg because, unlike birds and fish, invertebrate levels of MeHg and %MeHg vary among taxa, within taxa and among individuals (Table 5, Appendix G). Methylmercury is the primary form of Hg that gets incorporated and bioconcentrates in the food web and is toxic to biota. Concentrations of MeHg ranged from 3.1 ng/g (or ppb) dry weight in praying mantis from Block Pond to 322 ng/g in Tetragnathidae (spider) from Sandy Pond West. The %MeHg of total Hg ranged from 2.4% in praying mantis to 100% in Anisoptera (dragonfly) from Third Pond. When invertebrate data were grouped by pond (Figure 30), considerable variation in %MeHg of total Hg was observed, ranging from approximately 25% near Bellows Pond to nearly 100% near Third Pond.

Table 5. Mean (ng/g, dry wt.) and range of percent MeHg in invertebrates collected from Long Island, New York, 2012, all sites combined

Order	Family/Suborder	Common Name	Minimum	Maximum	Mean	Stdev	N
Araneae	Araneidae	Orb weavers	14.32	69.26	39.87	17.48	6
Araneae	Lycosidae	Wolf spiders	24.16	99.65	61.39	28.51	6
Araneae	Miturgidae	Spider	42.22	58.94	51.34	8.40	4
Araneae	Oxyopidae	Lynx spiders	67.80	67.80	67.80		1
Araneae	Philodromidae	Running crab spiders	27.86	72.67	54.96	18.42	6
Araneae	Salticidae	Jumping spiders	35.59	67.31	49.46	12.34	5
Araneae	Tetragnathidae	Long-jawed orb weavers	3.83	97.51	47.61	26.61	13
Araneae	Thomisidae	Crab spiders	43.96	67.05	59.49	10.71	4
Araneae	Unknown	Spider	16.02	32.98	24.71	8.49	3
Diptera	Tabanidae	Deerfly	7.02	82.95	50.42	26.27	6
Isopoda	Armadillidiidae	Pill bug	10.89	53.76	32.73	21.45	3
Mantodea	Mantidae	Praying mantid	2.42	8.80	5.61	4.51	2
Odonata	Anisoptera	Dragonfly	3.40	106.13	37.63	28.67	13
Odonata	Zygoptera	Damselfly	3.29	100.39	58.07	35.83	8
Opiliones	Arachnid/	Harvestmen (daddy-longlegs)	20.22	64.38	35.64	24.91	4

Figure 30. Percent MeHg in invertebrates collected in 2012, all orders combined, (Mashomack 6 = site 3)



4.8 Relating Invertebrate Total and Methylmercury to Soil Chemistry

To analyze the relationship between invertebrate Hg and soil chemistry, all invertebrate data were grouped because of the small sample size of families and orders. Site, Least Square Means of site, and soil chemistry parameters were used in a linear regression model to determine if any relationships existed between chemistry and invertebrate Hg concentrations. Similar to relationships with bird blood Hg, invertebrate THg was correlated ($p < 0.05$) with Ca, Mg, K and Na (Table 6). The strongest correlations were between base saturation and MeHg ($p < 0.05$), and base saturation and THg ($p < 0.01$).

Table 6. P-values from linear regressions of soil chemistry parameters and invertebrate mercury Least Square Means

Chemistry parameter	p-value MeHg	p-value THg
Exchangeable Aluminum	0.081	0.25
Exchangeable Calcium	0.11	0.074
Exchangeable Magnesium	0.12	0.047
Exchangeable Potassium	0.15	0.043
Exchangeable Sodium	0.076	0.044
Base saturation	0.037	0.0097
Loss of ignition	0.14	0.076

5 Discussion

5.1 Assessment of Acidic Deposition Effects on Soil Chemistry

One of the primary effects of acidic deposition on ecosystems has been the depletion of exchangeable Ca in soils (Driscoll et al. 2001). As the predominant base cation in forest soils, Ca plays a key role in the neutralization of acidity, both natural and anthropogenic, as well as being an essential nutrient for biota. The importance of soil Ca availability to both forest and aquatic ecosystems has become well recognized over the past two decades (McLaughlin and Wimmer 1999, Jeziorski et al. 2009). As such, Ca is an effective biogeochemical indicator of acidification effects on ecosystems.

Soils with slowly-weathering parent materials, low in Ca and other base cations, tend to have naturally low concentrations of exchangeable Ca that can be depleted by inputs of acidity. Decreases of exchangeable Ca concentrations in soils have been measured through resampling throughout the northeastern United States in areas where soil parent materials are low in Ca (Lawrence et al. 2013). Although soil resampling studies have not been done in pine barren soils on Long Island or elsewhere, these soils could be considered susceptible to Ca depletion by acidic deposition due to their extremely low mineral weathering rates and low cation exchange capacity (Johnson 1979). Soils in pine barrens ecosystems have been established as having extremely low concentrations of exchangeable Ca and other bases relative to other forest soils (Morgan 1984), and acidic deposition levels on eastern Long Island are similar to levels in other areas where Ca depletion has been documented.

Soil measurements in this study confirmed that, relative to other northeastern forest soils, concentrations of exchangeable Ca were very low, although similarly low concentrations have been measured in areas such as the Adirondack, Catskill, and White Mountains. For example, in a recent study, Adirondack soils in which sugar maple regeneration was impaired had an average A horizon base saturation of approximately 30% (Sullivan et al. 2013), only slightly greater that the average A horizon base saturation of 25% measured in this study. In the Long Island soils, the mean exchangeable Ca concentration for the nine sites was approximately 0.04 $\text{cmol}_c\ \text{kg}^{-1}$ for all mineral soil horizons measured below the A horizon (E, Bw1, Bw2, and C). A similarly low value of 0.09 $\text{cmol}_c\ \text{kg}^{-1}$ was reported for Montauk fine sandy loam soil in the interior of Shelter Island, within the Mashomack Preserve (Abrams and Hayes 2008). Similar concentrations of exchangeable Ca were measured below the A horizon of forest soils in the Allegheny Plateau of western Pennsylvania (Bailey et al. 2005).

The concentrations of exchangeable Ca measured in this study, although extremely low, are not on their own indicative of Ca depletion by acidic deposition. Without soil data that predate acidic deposition, it is not clear if there has been a decrease in exchangeable Ca in these soils during the acid rain era. In the absence of this information, assessment of the biogochemical processes that control Ca availability in Central Pine Barrens soils, suggests that acidic deposition is not having a large effect on the acidity status of this ecosystem. Low exchangeable Ca concentrations are due in part to low cation exchange capacity resulting from the coarse texture of the soils. The mineral surfaces of these sands and sandy loams have low surface area and minimal surface charge for cation adsorption. Therefore, most of the cation exchange capacity results from organic carbon that coats mineral surfaces. However, the organic carbon content is low in these soils due to several factors related to the excessive drainage, as well as low forest productivity, and at some locations, fires within the past several decades. An intense fire burned within a few hundred yards of one of the soil sampling sites during the study period.

Coupled with the low cation exchange capacity are the low weathering rates of the quartz and granite that compose much of the mineral composition of the soils. As a result of these factors, the soil processes that provide mineral nutrition in most types of forest ecosystems are relatively ineffective in pine barrens ecosystems. Therefore, a large share of the base cation supply is provided by precipitation and dry deposition (Yuretich et al. 1981, Morgan and Good 1988). Atmospheric deposition of base cations is aided by close proximity to the ocean, which results in higher atmospheric deposition of Ca than in non-coastal environments because Ca is abundant in seasalt (Stumm and Morgan 1981). For example, wet deposition of Ca on eastern Long Island is approximately twice that of the central Adirondack region (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=NY96&net=NTN). Because the Ca originates from the ocean, resupply is continual, without risk of depletion by acidic deposition. This mechanism supplies very low levels of Ca, but unlike most soils, the soils in this study are not heavily dependent on the balance between weathering rates and leaching rates (that have been elevated by acidic deposition).

In soils that have been depleted of Ca by acidic deposition, concentrations of exchangeable Al tend to be high, which results in low values of base saturation. High concentrations of exchangeable Al result from dissolution of Al-bearing minerals under conditions of low pH. The soils in this study have low values of base saturation, which reflects high availability of Al relative to Ca, but due to the extremely low CEC, the absolute concentrations of Al are low, and not likely to cause negative effects on vegetation, particularly since the base saturation of the A horizon (the primary zone of root uptake) is greater than 20%, which is above the threshold for mobilization of toxic inorganic monomeric Al (Reuss 1983).

The interpretation that acidic deposition is not contributing substantially to acidification of the sandy soils of eastern Long Island is consistent with previous studies of surface waters. Acidification of soils by acidic deposition would be expressed by acidification of surface water and in an early study, Johnson (1979) attributed the low pH of New Jersey pine barrens streams in large part to mineral acidity resulting from atmospheric sulfur pollution. However, the analysis of Morgan (1984) questioned the assertion that the acidity of these streams had been substantially worsened by acidic deposition, pointing to the overall 30-year record of stream pH that was stable, and disturbances such as burning and seasonal weather extremes that caused both increases and decreases in stream pH over the course of the record (Morgan 1984). Furthermore, an analysis of pH reconstructed from diatom assemblages in the sediment of a kettle pond within the outwash plain of Cape Cod indicated that (1) the pond chemistry was acidic throughout its history, (2) fluctuations in pH occurred throughout the Holocene period, and (3) although mean pH over the past 150 years is 5.1 compared to the overall average of 5.3, the pH has been as low as the present at other times in the past 12,000 years (Winkler 1988). A literature search did not find any studies of pine barrens ecosystems that identified increasing trends in surface water acidity that could suggest possible soil acidification of pine barrens soils by acidic deposition.

5.2 Assessment of Acidic Deposition Effects on Pond Chemistry

The low CEC and base saturation of surrounding soils was a feature common to all the ponds and therefore could not explain the distinct differences in acid-base chemistry that occurred among ponds. Differences in the degree of neutralization were in large part related to hydrologic differences. Pond water that is most strongly influenced by direct interaction with the groundwater system will likely express the most acid neutralization because groundwater has extended residence times that provide greater opportunity for mineral weathering. Concentrations of Si in surface waters provide a useful index of weathering because silicate minerals, which predominate in the soils and subsoils of the Long Island Central Pine Barrens, weather slowly. Therefore, elevated concentrations of Si in surface waters are indicative of extended groundwater residence times (Johnson et al. 1981), which increase acid neutralization capacity. Ponds more dependent on precipitation and shallow runoff will likely be more acidic than ponds that are dependent on groundwater because the soils of all the study sites are relatively ineffective at neutralizing acidity.

One further characteristic of these ponds that can provide neutralization of acidic deposition is the high surface area to water volume ratio. This ratio aids productivity in the water column thereby increasing biological oxygen demand. As oxygen is consumed through decomposition processes, acidity is neutralized. However, dissolved oxygen measurements in the lower water column (Figure 10) indicated that the oxygen consumption that occurred would have been largely restricted to the sediment-water interface, where organic matter can accumulate.

The following discussion is organized based on the differing hydrology of these ponds in the order of least to most effectively neutralized.

5.2.1 Block Pond – Minimal Groundwater Interaction

Block Pond, which was the most acidic of the study ponds, appeared to be separated from the groundwater system during the study period so that it did not benefit from neutralization that typically occurs in groundwaters with extended residence times. This interpretation is supported by the low concentrations of Si (Figure 19), low pH (Figure 11) and relatively high DOC concentrations (Figure 17). This pond also did not have any inlets contributing surface flow, and because it was located in an area with little relief and was not likely to receive subsurface event water other than from close proximity to the pond itself. The pond dried up sometime between the May and July sampling, and did not hold water again until December. Depth from the surface to the water table measured by the closest well at approximately the same surface elevation (Monti et al. 2013) was 1.4 m (error of $\underline{+}$1.5 m) in April-May 2010, which suggests that the groundwater table does not often rise enough to intersect the bottom of this pond that has a depth of less than 0.5 m. Its former use for cranberry cultivation supports this interpretation. Upon rewetting in December, concentrations of mineral constituents were elevated as evaporated and dry deposited solutes dissolved (Figure 13). Elevated concentrations of SO_4^{2-} (Figure 16) and DOC (Figure 17) were likely the result of organic matter decomposition and mineralization during the dry period (Lawrence 2002).

The average charge balance for Block Pond in May and June (Figure 18) indicated that the organic anion estimate exceeded the sum of the concentrations of SO_4^{2-} plus NO_3^-, which originated from atmospheric deposition comprising both acidic deposition plus seasalt. When a correction for the marine source of SO_4^{2-} is made based on (1) the ratio of SO_4^{2-} to Na^+ in seawater (Keene et al. 1986) and (2) the assumption that all the measured Na^+ is derived from sea water, the mean SO_4^{2-} concentration decreases from 43.8 to 25.6 meq/L, which is less than half the concentration of organic anions. On the basis of this analysis, acidic deposition is playing a smaller role in the acidification of Block Pond than natural organic acidity.

However, concentrations of inorganic monomeric Al of 2-3 mmol/L were indicative of a clear effect of acidic deposition on Block Pond because measureable concentrations of inorganic monomeric Al do not occur in the absence of acidic deposition or some other source of sulfuric acid (Lawrence et al. 2007). For point of reference, 2 mmol/L of inorganic monomeric Al causes mortality of fingerling brook trout, the most acid-tolerant fish in the Northeast (Baldigo et al. 2007).

5.2.2 Bellows Pond and Third Pond – Collection of Event Water

Bellows Pond was the next most acidic of the ponds, but the pH and ANC of Third Pond were nearly as low, and Si concentrations in both ponds were extremely low relative to the other ponds (Figure 19), as well as other surface waters acidified by acidic deposition in the northeastern U.S. (Johnson et al. 1981, NYSERDA 2008). Bellows Pond was also the deepest of all the ponds, with a maximum depth of at least 4.3 m, which suggests a connection to the groundwater system. However, the chemistry of Bellows Pond suggests little influence of groundwater with extended residence times. Bellows Pond is also the only study pond with some topographic convergence immediately surrounding the pond, whereas the other five ponds lie in areas with little or no relief. This means that during rain events the pond is likely to collect water through shallow flow paths within its watershed that had not interacted with the regional groundwater table.

This hydrologic pathway dilutes and acidifies, to some degree, any contribution of groundwater resulting from interception with the water table in the deepest portions of the pond. This interpretation is supported by the low $Ca^{2+}$and Si concentrations (Figure 10, Figure 19), as well as the low pH and ANC (Figure 8, Figure 9). Although Third Pond lies in a flat area, it receives water from upstream ponds that are connected by surface flow. This drainage pattern provides a variable source area that can collect some additional surface water during events as the area with exposed surface water increases (Dunne 1983). Nevertheless, Third Pond is similar to Block Pond in that it dried up between the May and October samplings (with the exception of one small hole), which suggests minimal connection with the groundwater system.

5.2.3 Groundwater Influences – Sears Pond, Sandy Pond East, and Sandy Pond West

Highest pH, ANC values, and Si concentrations (Figure 19) occurred in Sears Pond, Sandy Pond East, and Sandy Pond West. Although these ponds are shallow, with approximate maximum depths of 0.9 to 1.8 m, they all maintained surface water through the dry summer-fall study period. The chemistry and persistence of pond water through the dry period provide strong evidence that the groundwater system was well connected to the surface water of each of the ponds throughout the year. At Sears Pond, drainage off the moraine ridge to the south (Figure 2) may contribute groundwater that has been well neutralized with extended subsurface contact time, but is not fully connected with the regional water table. The surface outflow into Flanders Bay, and lack of surface inflow of Sears Pond suggests this possibility.

At the two Sandy Ponds, the depth to water table is likely to be less than 1.3 m because they are further downstream in the drainage than the well at approximately the same surface elevation that showed a depth to water table of 1.3 m (Monti et al. 2013). These two ponds are also further down the drainage than Third Pond, which also helps to explain why they did not dry up whereas Third Pond did become dry.

5.3 Assessment of Possible Nutrient Loading from Atmospheric Deposition or Development

This study did not find evidence supporting eutrophication effects from atmospheric deposition of nitrogen. In all ponds, concentrations of NO_3^- were below the laboratory reporting limit (2.0 mmol/L), and NH_4^+ concentrations were less than 5 mmol/L (reporting limit 2.0 mmol/L) on most sampling dates. Furthermore, deionized water extractions in situ and after a 2-week incubation measured little NH_4^+ or NO_3^-, which is the result that would be expected in a forest soil that was nitrogen limited. These data provided no indication that the ecosystem was approaching a condition of nitrogen availability in excess of forest ecosystem needs.

There was also no general evidence of nutrient loading from encroaching development or nutrient-enriched groundwater. However, a few individual measurements of NH_4^+ and total P did indicate concentrations that suggest some type of contamination from human activity. These measurements all occurred in Sandy Pond East and Sandy Pond West. Both of these ponds receive groundwater, but if the source was regional groundwater, the elevated concentrations would be likely to occur more often. The infrequent spikes are more likely the result of unusual runoff conditions in the vicinity of the ponds. Both East and West Sandy Ponds receive surface flow from upstream drainages that could have played a role.

Sears Pond did not record any elevated nutrient measurements, but its location could make it susceptible to human activities on the ridge to the south. However, most of this area falls within the protected county park limits. Bellows Pond also did not exhibit any elevated nutrient concentrations or tendency toward eutrophication despite the camping and picnicking area on its shore. The upstream drainage that connects to Third Pond is undeveloped and under its present condition not putting the pond chemistry at risk.

5.4 Mercury in Birds and Invertebrates

In general, birds sampled for this study do not appear to be at risk of the effects of Hg at this time. Although sample sizes were too small to allow for statistical comparisons across trophic levels, the data suggest a relationship between increasing THg concentrations in blood and increasing $\delta^{15}N$. This finding is consistent with previous mercury studies that showed animals foraging at higher trophic levels tend to have higher blood Hg concentrations. Mercury bioconcentrates up the food chain and is bioavailable in the methyl form at higher concentrations to animals that feed higher in the food chain.

When stable isotopes are used in conjunction with contaminant analysis, it is possible to examine the bioaccumulation and biomagnification of contaminants. Contaminants that enter food webs are accumulated by organisms at lower trophic levels and then are magnified by consumers at higher levels in the food web. Stable nitrogen isotope ratios help to confirm the trophic position of organisms. The relationship between $\delta^{15}N$ and Hg also represents a technique for examining trophic transfer of Hg within and across taxa (Rasmussen and Vander Zanden 2004).

Stable carbon isotopes ($\delta^{13}C$) help determine basal carbon sources within particular food webs and potentially identify where contaminants are entering the food web. The combination of nitrogen and carbon isotopic analysis ($\delta^{15}N$ and $\delta^{13}C$, respectively) provides a two-dimensional interpretation of food web dynamics (Rasmussen and Vander Zanden 2004). Moving up through a food web, $\delta^{15}N$ values show a consistent enrichment of the heavier nitrogen isotope (^{15}N) because organisms preferentially excrete the lighter nitrogen isotope (^{14}N). This produces a trophic level shift of approximately 3.5 parts per million (‰), allowing for trophic position of particular components of the food web to be determined quantifiably. By contrast, there is very little enrichment of $\delta^{13}C$ values through a food web (<1.0‰ is generally understood). Values of $\delta^{13}C$ instead reflect the dietary preference of animal versus plant material at each trophic level (Peterson and Fry 1987). The $\delta^{15}N$ and $\delta^{13}C$ measured in producers and consumers can provide an integrated assessment of trophic interactions and help describe food web pathways leading from the base of the food web up to the top-level consumers (Peterson and Fry 1987).

The data collected for this study indicate that the avian species with the highest Hg concentrations are: Carolina Wren, Eastern Kingbird, Spotted Sandpiper, Eastern Wood Pewee, and Red-winged Blackbird. However, because of low site-specific abundances of the above listed species only Carolina Wren was captured at a number of sites (5). Therefore, it was identified it as the best indicator species for future studies in the area. In addition, because not all species are present at every study location, surrogates must be identified that occupy a similar trophic position and tend to have similar blood Hg concentrations. Based on $\delta^{15}N$ and Hg data such species were Red-winged Blackbird, Song Sparrow, Eastern Kingbird and Eastern Wood Pewee. The relatively ubiquitous Red-eyed Vireo was identified as a second best alternative indicator species. Surrogates of the Red-eyed Vireo would be the Pine Warbler, Ovenbird, Yellow Warbler and Common Yellowthroat.

5.5 Relations Between Biota and Chemistry

The Central Pine Barrens and Mashomack Preserve can potentially be sites of elevated Hg production and methylation because of their tendencies to be naturally acidic. Levels of Hg in fish in the New Jersey Pine Barrens region were significantly higher than in the industrialized parts of New York State (Horowitz et al. 2002).

In this study, the inverse correlation between blood Hg and concentrations of Ca, Mg and K, as well as base saturation suggests greater uptake of Hg by biota at sites where mineral nutrients were least available in the upper soil (Figure 17). This result is consistent with greater blood Hg levels where organic carbon was also lower (Figure 29) because in these low-nutrient soils, availability of mineral nutrients is largely determined by organic carbon, which provides CEC. Availability of nitrogen is also positively correlated with organic carbon, and therefore would be expected to show the same relationship with blood Hg as that of organic carbon. The inverse correlation between base saturation and Hg in blood is consistent with other studies that have indicated increased Hg in biota in acidic ecosystems. However, in this preliminary study, data needed to determine where and how the methylation occurs and what the birds are using as a food source was not collected. It is unclear if the ponds are providing conditions needed for strong methylation or if the uptake is occurring through some terrestrial process. The Hg concentrations measured in the spiders, which do not have an aquatic stage in their life cycle, suggest this possibility (Table 5).

To determine if the ponds are playing a role in Hg mobilization in this ecosystem, additional measurements would be needed that would include measurements of MeHg and THg in waters and sediments. Conditions that promote the methylation of Hg^{2+} by sulfate reducing bacteria include low oxygen, high inputs of labile organic carbon, and a supply of sulfate and Hg^{2+} (Todorova et al. 2009). These shallow ponds tended to be oxygenated near the sediment water interface. They also are low in nutrient concentrations and receive small inputs of allochthonous carbon. It is also uncertain whether the supply of SO_4^{2-} through acidic deposition and marine sources is sufficient for the methylation process, and the deposition levels of Hg are not known. In sum, these characteristics do not suggest a high capacity for methylation in the ponds.

6 Conclusion

The soils sampled in the Central Pine Barrens and in Mashomack Preserve were all similar with respect to their extremely low acid-neutralizing capacity. However, this was in large part due to their natural characteristics of extremely coarse texture, excessively high drainage and low cation-exchange capacity. Therefore, acidic deposition was not likely to have substantially reduced the acid-neutralization capacity of these soils.

Because of the extremely low cation-exchange capacity, the storage of available soil Ca was also very low, even in the absence of acidic deposition. Therefore, acidic deposition was not likely to have lowered Ca availability a great deal. Furthermore, Ca availability was supplemented by seasalt deposition, that provides a consistent, albeit small input of Ca.

The ponds in this study encompassed hydrologic variations that included close interaction with the regional water table (the Sandy Ponds), precipitation collection with little interaction with groundwater (Block Pond and Third Pond), interaction with local groundwater (Sears Pond), and collection of event water moving through soils (Bellows Ponds). Most of the coastal plain ponds in eastern Long Island are likely to occur in one of these hydrologic settings, although there may be other hydrologic settings not covered in this study.

In combination, the factors of soils, hydrologic pathways and atmospheric deposition result in conditions that prevent severe acidification, although moderate decreases in pH in some ponds were likely to have been attributable to acidic deposition. Bird blood Hg concentrations were below effect levels and it is unclear if the ponds are providing conditions needed for strong methylation or if the uptake is occurring through some terrestrial process. The low concentrations of Hg in bird blood in the species living near the ponds suggest that neither chemical processes within the ponds nor in the adjacent forests and woodlands were playing a large role in making Hg available to the food chain. On the basis of the information obtained from these six ponds, the primary questions outlined in the introduction of this report are addressed in the following subsections section.

6.1 Acidification

Is “acid rain” reducing coastal plain pond water pH and buffering capacity today, or are such impacts likely in the future?

“Acid rain” is likely to be reducing pond water pH and buffering capacity in ponds that are not in contact with the regional groundwater system through most of the year or are collecting substantial amounts of event water through shallow flowpaths. However, the effect is moderated somewhat by the neutralizing effects of maritime aerosols on precipitation chemistry and dry deposition. Ponds in contact with the regional groundwater table are likely to be sufficiently buffered to avoid acidification. The impact of acidic deposition is likely to decrease in the future as deposition levels are expected to continue decreasing.

If atmospheric deposition is reducing water pH, might there be indirect impacts on other chemical constituents of pond water or sediment? (e.g., increased solubility of Al or release of P, Hg etc. from sediments)

Mobilization of inorganic Al, the form toxic to aquatic life, was documented in the one pond most dominated by precipitation (Block Pond), but pH was too high for mobilization to occur in any of the other ponds. The concentrations of total P do not suggest substantial mobilization of P from the sediments. Concentrations of Hg were not measured in pond water or pond sediments, so it is unclear if the conditions in these ponds are conducive to methylation.

To what extent does soil type on Long Island influence acidification from precipitation independent of land-based anthropogenic inputs?

The coarse sandy soils on Long Island can be considered somewhat resistant to acidification from acidic deposition, not because they are well buffered, but because they are naturally depleted of minerals (Ca and Mg) and inputs from atmospheric deposition of sea salts compensate for the extremely low mineral supply from weathering. Without the inputs of sea salt, these ecosystems would be somewhat more nutrient poor with regard to essential minerals. Concentrations of exchangeable Al are low because of the extremely low cation-exchange capacity, and therefore are not likely to impair plant growth.

Could climate change alter the severity of acid rain impacts in the future? (Predictions are for increased temperature, and some increased precipitation primarily in winter).

Increased temperature would not have a large influence on future acid rain impacts, but increases in precipitation could result in some degree of dilution and possibly a lowering of pH in ponds not buffered by the regional groundwater system.

6.2 Nutrient Enrichment

Has N availability to biota increased due to atmospheric deposition?

The forest ecosystems remain nitrogen limited despite additional atmospheric deposition of nitrogen.

What is the relative importance of atmospheric deposition of N to ponds versus anthropogenic inputs through groundwater?

Groundwater inputs of nitrogen did not result in elevated concentrations of NO_3^- or NH_4^+ in pond water. The condition of forest nitrogen limitation suggests that little atmospheric N reaches the groundwater in the vicinity of the ponds.

Are Ca and Mg from liming of cultivated landscapes and agricultural fields counteracting acidification of ponds from precipitation?

It is possible, but concentrations in pond water indicate that the effect is not large, as the pond chemistry remains dilute.

Could climate change affect the amount of atmospheric nitrogen deposition in the future, and/or alter biological impacts especially from invasive N fixers? (Predictions are for increased temperature, and some increased precipitation primarily in winter).

Invasive N-fixing species may be able to compete in these soils if precipitation increases sufficiently. Black locust (Robinia pseudoacacia) are outcompeting pitch pine in a pine-oak forest growing on infertile sands in Albany, NY (Rice et al. 2004). Increased precipitation in this area over the past two decades may have contributed to the black locust invasion, but this possibility has not been investigated.

6.3 Mercury Contamination

Are birds breeding in the Central Pine Barrens accumulating harmful levels of Hg?

In general, blood Hg concentrations were below the known effect level of 0.7 ppm for songbirds, and so they do not appear to be at risk to Hg effects at this time.

What are the Hg levels of invertebrates that serve as food for these birds?

Concentrations of MeHg ranged from 3.1 ng/g (or ppb) dry wt. in praying mantis from Block Pond to 322 ng/g in Tetragnathidae (spider) from Sandy-Peconic Pond. The %MeHg of total Hg ranged from 2.4% in praying mantis to 106% in Anisoptera (dragonfly) from Third Pond.

Were Hg concentrations in biota related to the chemical measurements of soils or pond water?

There were no significant relationships between Hg concentrations in bird blood or invertebrates and pond chemistry, but these Hg measurements had significant ($p < 0.05$) negative correlations with soil carbon concentrations and base saturation.

6.4 Potential Future Efforts

Based on the generally low Hg concentrations in biota, it did not appear that Hg methylation was introducing large amounts of Hg to the food web in the vicinity of the ponds. This observation suggests that either the ponds were not a source of methyl Hg or that the birds were not obtaining food linked to the aquatic food web. With this preliminary sampling design, it was not possible to verify which or both of these factors were responsible for the low levels of Hg in birds. However, the levels of Hg in terrestrial invertebrates suggest that a terrestrial process may be introducing Hg into the food chain. To address these unknowns, the following steps would be needed:

- If possible, conduct pond water chemistry collections earlier than or closer to the biota sampling events to account for seasonal variability.
- Sample pond biota such as aquatic invertebrates and fish to determine if Hg was entering the aquatic food web.
- Increase the number of ponds/sites sampled to better account for hydrochemical differences among ponds.
- Increase sample size of target bird species: Carolina Wren, Red-winged Blackbird, Red-eyed Vireo, Song Sparrow, Yellow Warbler and Common Yellowthroat to improve the sensitivity of detection.
- Increase effort to collect higher sample size of spiders, Odonates, and Dipterans to better characterize Hg content of these insect orders.

7 References

Aber, J. D., C. L. Goodale, S. V. Ollinger, M.-L. Smith, A. H. Magill, M. E. Martin, R. A. Hallett, J. L. Stoddard, and N. Participants. 2003. Is Nitrogen Deposition Altering the Nitrogen Status of Northeastern Forests? BioScience 53:375-390

Abrams, M. D. and V. W. Hayes. 2008. Impacts of contrasting land-use history on composition, soils, and development of mixed-oak, coastal plain forests on Shelter Island, New York. Journal of the Torrey Botanical Society 135:37-52.

Bailey, S. W., S. B. Horsley, and R. P. Long. 2005. Thirty years of change in forest soils of the Allegheny Plateau, Pennsylvania. Soil Science Society of America Journal 69:681-690.

Baldigo, B. P., G. B. Lawrence, and H. A. Simonin. 2007. Persistent mortality of brook trout in episodically acidified streams of the southwestern Adirondack Mountains, New York. Transactions of the American Fisheries Society 136:121-134.

Bennington, J. B. 2003. New observations on the glacial geomorphology of Long Island from a digital elevation model (DEM). Long Island Geologists Conference, Stony Brook, New York, April 2003. http://people.hofstra.edu/J_B_Bennington/research/long_island/geology_Li_Bennington.pdf

Bloom, N. S. and W. F. Fitzgerald. 2007. Determination of volatile mercury species at the picogram level by low-temperature gas chromatography with cold-vapor atomic fluoresence detection. Analytica Chimica Acta 208:151-161.

Boerner, R. E. S. and R. T. Forman. 1982. Hydrologic and mineral budgets of New Jersey Pine Barrens upland forests following two fire intensities. Canadian Journal Forest Research 12:503-510.

Buck, D.G. and M. Duron. 2010. Biodiversity Research Institute: Protocol for collecting invertebrates for contaminant analysis. Report BRI 2010-20, Biodiversity Research Institute, Gorham, Maine.

Cristol, D. A., R. L. Brasso, A. M. Condon, R. E. Fovargue, S. L. Friedman, K. K. Hallinger, A. P. Monroe, and A. E. White. 2008. The movement of aquatic mercury through terrestrial food webs. Science 320:335.

Driscoll, C. T., Y. J. Han, C. Chen, D. Evers, K. F. Lambert, T. Holsen, N. Kamman, and R. Munson. 2007. Mercury contamination in remote forest and aquatic ecosystems in the northeastern U.S.: sources, transformations and management options. BioScience 57:29-43.

Driscoll, C. T., G. B. Lawrence, A. J. Bulger, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard, and K. C. Weathers. 2001. Acidic Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. BioScience 51:180-198.

Dunne, T. 1983. Relation of field studies and modeling in the prediction of storm runoff. Journal of Hydrology 65:25-48.

Ehrlich, P. R., D. S. Dobkin, and D. Wheye. 1988. The birders handbook. Simon & Schuster Inc. NY.

Greller, A. M., D. C. Locke, V. Kilanowski, and G. E. Lotowycz. 1990. Changes in vegetation composition and soil acidity between 1922 and 1985 at a site on the North Shore of Long Island, New York. Bulletin of the Torrey Botanical Club 117:450-458.

Hammerschmidt, C. R. and W. F. Fitzgerald. 2006. Bioaccumulation and trophic transfer of methylmercury in Long Island Sound. Archives of Environmental Contamination and Toxicology. 51:416-424.

Horowitz, R. J., D. J. Valinsky, P. Overbeck, P. Kiry, and B. Ruppel. 2002. Assessment of total mercury concentrations in fish from rivers, lakes and reservoirs in New Jersey. Research project summary, NJ DEP. www.state.nj.us/dep/dsr.

Husar, R. B., T. J. Sullivan, and D. F. Charles. 1991. Historical trends in atmospheirc sulfur deposition and methods for assessing long-term trends in surface water chemistry. Pages 65-82 *in* D. F. Charles, editor. Acidic Deposition and Aquatic Ecosystems. Springer-Verlag, New York.

Jackson, A. K. 2011. Biodiversity Research Institute: Current lowest observed adverse effects level (LOAEL) for mercury in tree swallows (Tachycineta bicolor). BRI report #2010-27.

Jackson, A. K., S. B. Folsom, J. Detweiler, A. M. Condon, J. Schmerfeld, M. Etterson, D. C. Evers, and D. A. Cristol. 2011. Modeling the effect of mercury exposure on the reproductive success of a free-living terrestrial songbird. Auk 128:759-769.

Jeziorski, A., N. D. Yan, A. M. Paterson, A. M. DeSellas, M. A. Turner, D. S. Jeffries, B. Keller, R. C. Weeber, D. K. McNicol, M. E. Palmer, K. McIver, K. Arseneau, B. K. Ginn, B. F. Cumming, and J. P. Smol. 2009. The widespread threat of calcium decline in fresh waters. Science 322:1374-1377.

Johnson, A. H. 1979. Acidification of headwater streams in the New Jersey Pine Barrens. Journal of Environmental Quality 8:383-386.

Johnson, N. M., W. H. McDowell, C. T. Driscoll, J. S. Eaton, and G. E. Likens. 1981. 'Acid rain', dissolved aluminum and chemical weathering at the Hubbard Brook Experimental Forest, New Hampshire. Geochimica et Cosmochimica Acta 45:1421-1437.

Jordan, M., J., W. A. Patterson, and A. G. Windisch. 2003. Conceptual ecological models for the Long Island pitch pine barrens: implications for managing rare plant communities. Forest Ecology and Management 185:151-168.

Keene, W. C., A. P. Pszenny, J. N. Galloway, and M. E. Hawley. 1986. Sea-salt corrections and interpretation of constituent ratios in marine precipitation. Journal of Geophysical Research 91:6647-6658.

Kurczewski, F. E. and H. F. Boyle. 2000. Historical changes in the pine barrens of central suffolk county, New York. Northeastern Naturalist 7:95-112.

Lane, O., D. Buck, and K. Regan. 2011a. Mercury assessment of saltmarsh sparrows on Long Island, New York, 2010. Report BRI 2011-02 submitted to NYSERDA. Biodiversity Research Institute, Gorham, Maine.

Lane, O., K. O'Brien, D. C. Evers, T. P. Hodgman, A. Major, N. Pau, M. Ducey, R. Taylor, and D. Perry. 2011b. Mercury in breeding saltmarsh sparrows (Ammodramus caudacutus caudacutus). Ecotoxicology 20:1984-1991.

Lawrence, G. B. 2002. Persistent episodic acidification of streams linked to acid rain effects on soil. Atmospheric Environment 36:1589-1598.

Lawrence, G. B. and M. B. David. 1996. Chemical evaluation of soil solution in acid forest soils. Soil Science 161:298-313.

Lawrence, G. B., I. Fernandez, D. D. Richter, D. S. Ross, P. W. Hazlett, S. W. Bailey, R. Ouimet, R. A. F. Warby, A. H. Johnson, H. S. Lin, J. M. Kaste, A. G. Lapenis, and T. J. Sullivan. 2013. Measuring environmental change in forest ecosystems by repeated soil sampling: a North American perspective. Journal of Environmental Quality 42:623-639.

Lawrence, G. B., J. W. Sutherland, C. W. Boylen, S. A. Nierzwicki-Bauer, B. Momen, B. P. Baldigo, and H. A. Simonin. 2007. Acid rain effects on aluminum mobilization clarified by inclusion of strong organic acids. Environmental Science and Technology 41:93-98.

Lincoln, T. A., D. A. Horan-Ross, M. R. McHale, and G. B. Lawrence. 2009. Quality-assurance data for routine water analyses by the U.S. Geological Survey laboratory in Troy, New York—July 2001 through June 2003: U.S. Geological Survey Open-File Report 2009–1232, 32 p. available at http://pubs.usgs.gov/of/2009/1232/. U.S. Geological Survey Open-File Report 2008-xxxx, Albany, NY.

McLaughlin, S. B. and R. Wimmer. 1999. Tansley Review No. 104, Calcium physiology and terrestrial ecosystem processes. New Phytologist 142:373-417.

Michener, R. and K. Lajtha, editors. 2007. Stable Isotopes in Ecology and Environmental Science, 2nd Edition. Blackwell Publishing, Ltd., Oxford, UK.

Monti, J. J., M. Como, and R. Busciolano. 2013. Water-table and potentiometric-surface altitudes in the upper glacial, Magothy, and Lloyd aquifers beneath Long Island, New York, April-May 2010: U.S. Geological Survey, Scientific Investigations Map 3270, 4 sheets, scale 1:125,000, http://dx.doi.org/10.3133/sim3270.

Morgan, M. D. 1984. Acidification of headwater streams in the New Jersey Pinelands: a re-evaluation. Limnology and Oceanography 29:1259-1266.

Morgan, M. D. and R. E. Good. 1988. Stream chemistry in the New Jersey Pinelands: the Influence of precipitation and watershed disturbance. Water Resources Research 24:1091-1100.

Negra, C. and K. F. Lambert. 2008. MercNet – Establishing a comprehensive national mercury monitoring network. 2008 Workshop results. Submitted to U.S. EPA, contract no. EP-W-08-018, November 2008.

NYSERDA. 2008. Results of the 2003-2005 Western Adirondack Stream Survey (WASS)," NYSERDA Report 08-22. Prepared by Lawrence, G. B., K. M. Roy, B. P. Baldigo, H. A. Simonin, S. I. Passy, B. R.W., and S. B. Capone.

NYSERDA. 2011. "Mercury Assessment of Saltmarsh Sparrows on Long Island, New York," NYSERDA Report 11-09. Prepared by Lane, O., S. Edmonds, D. Buck, and K. Regan (Biodiversity Research Institute, Gorham, ME). nyserda.ny.gov/publications

Peterson, B. J. and B. Fry. 1987. Stable isotopes in ecosystem studies. Annual Review of Ecology and Systematics 18: 293-320. Annual Review of Ecology and Systematics 18:293-320.

Rasmussen, J. B. and M. J. Vander Zanden. 2004. The variation of lake food webs across the landscape and its effect on contaminant dynamics. In G. A. Polis, M. E. Power, and G. R. Huxel (Eds.), Food Webs at the Landscape Scale. The University of Chicago Press, Chicago, Illinois, pp. 169-182.

Reuss, J. O. 1983. Implications of the calcium-aluminum exchange system for the effect of acid precipitation on soils. Journal of Environmental Quality 12:591-595.

Rice, S. K., B. Westerman, and R. Federici. 2004. Impacts of the exotic, nitrogen-fixing black locust (Robinia pseudoacacia) on nitrogen-cycling in a pine–oak ecosystem. Plant Ecology 174:97-107.

Rimmer, C. C., K. P. McFarland, D. C. Evers, E. K. Miller, Y. Aubrey, D. Busby, and R. J. Taylor. 2005. Mercury concentrations in Bicknell's thrush and other insectivorous passerines in montane forests of northeastern North America. Ecotoxicology 14:223-240.

Rimmer, C. C., E. K. Miller, K. P. McFarland, T. R.J., and S. D. Faccio. 2010. Mercury bioaccumulation and trophic transfer in the terrestrial food web of a montane forest. Ecotoxicology 19:697-709.

Ross, D. S., G. B. Lawrence, and G. Fredriksen. 2004. Mineralization and nitrification patterns at eight northeastern US forested research sites. Forest Ecology and Management 188:317-335.

Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, and W. D. Broderson. 2002. Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Stumm, W. and J. J. Morgan. 1981. Aquatic Chemistry. Wiley and Sons, New York.

Sullivan, T. J., G. B. Lawrence, S. W. Bailey, T. C. Mcdonnell, C. M. Beier, K. C. Weathers, G. T. McPherson, and K. Bishop. 2013. Effects of Acidic Deposition and Soil Acidification on Sugar Maple Trees in the Adirondack Mountains, New York. Environmental Science & Technology 47:12687-12694.

Todorova, S. G., C. T. Driscoll, D. A. Matthews, S. W. Effler, M. E. Hine, and E. A. Henry. 2009. Evidence for regulation of monomethyl mercury by nitrate in a seasonally stratified, eutrophic lake. Environmental Science & Technology 43:6572-6578.

Tseng, C.-M., C. R. Hammerschmidt, and W. F. Fitzgerald. 2004. Determination of methylmercury in environmental matrixes by on-line flow injection and atomic fluoresence spectrometry. Analytical Chemistry 76:7131-7136.

Turner, R. S., A. H. Johnson, and D. Wang. 1985. Biogeochemistry of aluminum in McDonalds Branch Watershed, New Jersey Pine Barrens. Journal of Environmental Quality 14:314-323.

Winkler, M. G. 1988. Paleolimnology of a Cape Cod kettle pond: diatoms and reconstructed pH. Ecological Monographs 58:197-214.

Wolfe, M. F., S. Schwarzbach, and R. A. Sulaiman. 1988. Effects of mercury on wildlife: a comprehensive review. Environmental Toxicology and Chemistry 17:146-160.

Yuretich, R. F., D. A. Crerar, D. J. J. Kinsman, J. L. Means, and M. P. Borcsik. 1981. Hydrochemistry of the New Jersey Coastal Plain, 1, Major element cycles in precipitation and river water. Chemical Geology 33:1-21.

Appendix A

Soil Chemistry. Heading abbreviations: CEC (Cation Exchange Capacity); LOI (Loss On Ignition, an estimate of organic carbon concentration); BS (Base Saturation). Concentrations of 0.0 indicate that the constituent was not detected in the analysis.

Site Name	Site Code	Horizon	Depth (cm)	Al	Ca	H	Mg	K	Na	CEC	LOI	Total C	Total N	BS	pH	pH
				$(\text{cmol}_c\ \text{kg}^{-1})$							(%)				(CaCl$_2$)	(H$_2$0)
Mashomack	LIPMS01	A	4-25	1.174	0.139	0	0.07	0.067	0.029	1.479	3.891	1.6019	0.088	20.59	4.09	4.74
Mashomack	LIPMS01	Bw1	25-70	0.743	0.034	0	0.026	0.027	0.024	0.854	1.523	0.3955	0.029	12.97	4.23	4.88
Mashomack	LIPMS01	Bw2	70-120	1.333	0.033	0	0.03	0.021	0.048	1.464	2.183	0.3592	0	8.981	4.07	4.77
Mashomack	LIPMS01	Bw3	120-141	0.088	0.015	0	0.015	0.013	0.015	0.146	0.787	0.0417	0	39.69	4.55	4.84
Mashomack	LIPMS02	A	3-15	1.804	0.167	0.339	0.221	0.18	0.052	2.762	7.77	4.0124	0.14	22.41	3.21	3.9
Mashomack	LIPMS02	Bw1	15-58	1.002	0.023	0	0.023	0.026	0.019	1.093	1.927	0.571	0.036	8.352	4.13	4.77
Mashomack	LIPMS02	Bw2	58-71	0.74	0.023	0	0.026	0.025	0.02	0.834	2.096	0.3105	0	11.29	4.19	4.92
Mashomack	LIPMS02	Cd1	71-88	0.51	0.036	0.069	0.023	0.022	0.029	0.69	1.606	0.2515	0	15.9	4.27	4.91
Mashomack	LIPMS02	Cd2	88-110	0.049	0.005	0.001	0.007	0.008	0.01	0.08	0.499	0.0588	0	37.7	4.77	4.82
Mashomack	LIPMS03	A	1-10	1.116	0.197	0.9	0.141	0.134	0.033	2.522	7.107	3.7301	0.158	20.05	3.77	4.55
Mashomack	LIPMS03	Bw1	10-44	0.479	0.017	0.707	0.03	0.036	0.021	1.29	2.626	0.8009	0.041	8.082	4.14	4.72
Mashomack	LIPMS03	Bw2	44-70	1.528	0.017	0.04	0.028	0.025	0.03	1.669	2.603	0.2883	0.029	6.039	4.09	4.82
Mashomack	LIPMS03	Cd1	70-86	0.112	0.006	0.01	0.016	0.018	0.014	0.176	0.696	0.049	0	30.91	4.73	4.81
Mashomack	LIPMS03	Cd2	86-110	0.101	0.006	0	0.014	0.014	0.01	0.144	0.402	0.0246	0	30.09	4.81	4.78
Bellows Pond	LIPBE01	E	3-18	0.367	0.056	0.361	0.04	0.021	0.016	0.861	1.891	0.8062	0.03	15.51	3.03	3.93
Bellows Pond	LIPBE01	Bw1	26-38	0.813	0.016	0	0.012	0.012	0.012	0.865	2.783	1.0252	0.044	6.056	4.21	4.3
Bellows Pond	LIPBE01	Bw2	38-62	0.585	0.014	0	0.01	0.012	0.015	0.637	3.642	1.2602	0.054	8.099	4.45	4.72
Bellows Pond	LIPBE01	BC	62-87	0.08	0.007	0.004	0.002	0.004	0.004	0.101	0.571	0.1182	0	17.08	4.56	4.68
Bellows Pond	LIPBE01	C	87-113	0.029	0.014	0	0.002	0.002	0.005	0.052	0.4	0.0459	0	44.46	4.8	4.81

Site Name	Site Code	Horizon	Depth	Al	Ca	H	Mg	K	Na	CEC	LOI	Total C	Total N	BS	pH	pH
				(cmolc kg^{-1})							(%)				(CaCl$_2$)	(H$_2$0)
Sears Pond	LIPSE01	E	4-19	0.358	0.004	0.077	0.007	0.016	0.007	0.469	0.987	0.4359	0	7.178	3.67	4.34
Sears Pond	LIPSE01	Bw1	32-54	0.25	0.008	0	0.007	0.015	0.004	0.283	1.982	0.5218	0.035	11.64	4.64	4.86
Sears Pond	LIPSE01	Bw2	54-80	0.111	0.004	0	0.005	0.013	0.006	0.138	0.687	0.2019	0	19.91	4.58	4.84
Sears Pond	LIPSE01	Bc1	80-104	0.032	0.012	0	0.004	0.006	0.007	0.062	0.395	0.0395	0	47.45	4.68	4.82
Sears Pond	LIPSE01	Bc2	104-125	0.04	0.002	0	6E-04	0.005	0.003	0.05	0.201	0.0359	0	20.2	4.76	4.76
Third Pond	LIPRH01	A	4-7	1.217	0.982	2.403	0.893	0.366	0.095	5.956	19.21	8.1776	0.288	39.22	3	3.91
Third Pond	LIPRH01	AB	7-11	1.468	0.024	0.21	0.041	0.037	0.011	1.791	2.419	1.2057	0.048	6.329	3.28	3.9
Third Pond	LIPRH01	Bw1	11-57	0.857	0.013	0	0.021	0.037	0.011	0.941	1.953	0.4348	0.029	8.829	4.21	4.69
Third Pond	LIPRH01	Bw2	57-97	0.987	0.014	0.013	0.025	0.033	0.014	1.086	1.631	0.1764	0	7.898	4.13	4.81
Third Pond	LIPRH01	BC	97-120	0.125	0.008	0.008	0.002	0.004	0.003	0.149	0.202	0.049	0	11.06	4.36	4.65
Third Pond	LIPRL01	E	3-15	0.358	0.033	0.549	0.023	0.02	0.01	0.993	1.518	0.7974	0.036	8.666	3.15	3.83
Third Pond	LIPRL01	Bhs	15-26	0.572	0.023	0.477	0.021	0.024	0.013	1.13	1.213	0.4658	0.03	7.165	3.6	4.19
Third Pond	LIPRL01	Bl	26-39	0.44	0.011	0.105	0.007	0.012	0.006	0.582	1.518	0.3603	0	6.233	4.3	4.67
Third Pond	LIPRL01	B2	39-94	0.265	0.017	0.106	0.01	0.015	0.006	0.42	1.026	0.1357	0	11.43	4.33	4.74
Third Pond	LIPRL01	BC	94-130	0.151	0.011	0	0.006	0.008	0.006	0.182	0.295	0.043	0	17.36	4.42	4.71
Third Pond	LIPRL01	C	>130	0.038	0.009	0	0.003	0.005	0.006	0.06	0.903	0.0244	0	37.18	4.66	4.75
Sandy Pond East	LIPSC01	E	2-9	1.095	0.047	0.872	0.031	0.029	0.013	2.085	2.291	1.4187	0.061	5.708	3.25	3.86
Sandy Pond East	LIPSC01	Bs	9-18	1.518	0.029	0.291	0.022	0.029	0.014	1.904	1.908	0.724	0.035	4.972	3.69	4.21
Sandy Pond East	LIPSC01	Bw1	18-32	0.728	0.02	0.062	0.018	0.026	0.012	0.866	1.982	0.6338	0.041	8.739	4.29	4.64
Sandy Pond East	LIPSC01	Bw2	32-96	0.847	0.017	0.142	0.024	0.026	0.012	1.067	1.389	0.1786	0	7.339	4.11	4.65
Sandy Pond East	LIPSC01	Bw3	96-120	0.835	0.015	0.262	0.023	0.019	0.015	1.168	0.903	0.0653	0	6.131	4.1	4.63
Sandy Pond East	LIPSC01	C	120-135	0.275	0.01	0.06	0.012	0.01	0.007	0.375	0.365	0.0311	0	10.77	4.27	4.67
Sandy Pond West	LIPSP01	E	3-21	0.236	0.028	0.171	0.018	0.014	0.006	0.473	0.879	0.5639	0	13.96	3.24	3.91
Sandy Pond West	LIPSP01	Bw1	21-60	0.225	0.007	0.023	0.003	0.005	0.004	0.268	1.01	0.3603	0.025	7.051	4.45	4.68
Sandy Pond West	LIPSP01	Bw2	60-92	0.226	0.01	0.031	0.009	0.009	0.006	0.291	0.916	0.1382	0	11.51	4.23	4.61
Sandy Pond West	LIPSP01	Bw3	92-128	0.092	0.008	0	0.002	0.004	0.003	0.109	0.384	0.0655	0	15.44	4.42	4.6
Sandy Pond West	LIPSP01	C	>128	0.035	0.009	0	0.002	0.003	0.002	0.051	0.301	0.0338	0	30.97	4.62	4.68

Appendix B

B.1 Soil profile descriptions.

Bellows Pond soil description.

[Carver and Plymouth sands; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-3	10YR2/2	--	--	--	--	--
E	3-18	10YR4/1	LS	1FGR	L	<5%	C
EB	18-26	2.5Y5/2	S	1FGR	L	<5%	C
Bw1	26-38	7.5Y4/6	S	1FGR	L	5-10%	C
Bw2	38-62	10YR4/6	LS	1MSBK	FR	5-10%	C
BC	62-87	2.5Y7/6	S	1FGR	L	5%	F
C	87-113	2.5Y6/4	S	1FGR	L	<5%	F

Sears Pond soil description.

[Carver and Plymouth sands; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-4	--	--	--	--	--	--
E	4-19	10YR5/1	LS	1FSBK	VFR	0%	F
EB	19-32	10YR6/3	LS	1FSBK	VFR	0	0
Bw1	32-54	10YR4/6	LS	1FSBK	VFR	<5%	F
Bw2	54-80	10YR6/6	LS	1FGR	L	5%	0
BC1	80-104	2.5Y6/4	S	1FGR	L	0%	0

Sandy Pond East soil description.

[Plymouth loamy sand; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-2	--	-	--	--	--	--
E	2-9	10YR4/2	SL	1FSBK	VFR	<5%	F
Bs	9-18	10YR4/4	SL	1FSBK	VFR	<5%	F
Bw1	18-32	10YR4/6	LS	1FSBK	VFR	<5%	F
Bw2	32-96	10YR5/6	SL	1FSBK	VFR	<5%	F
Bw3	96-120	2.5Y5/3	SL	1FSBK	VFR	<5%	F
C	120-135	10YR5/8	LS	1FGR	L	<5%	0

Sandy Pond West soil description.

[Carver and Plymouth sands; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-3	5YR2.5/1	--	--	--	--	M
E	3-21	10YR4/2	S	1FGR	L	0%	C
Bw1	21-60	10YR5/8	SL	1MSBK	FR	0%	C
Bw2	60-92	10YR5/8	S	1FGR	L	0%	F
Bw3	92-128	10YR7/6	S	1FGR	L	5-10%	0
C	>128	10YR6/6	S	1FGR	L	0%	F

Third Pond site 1 soil description.

[Riverhead sandy loam; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-4	--	--	--	--	--	--
A	4-7	10YR2/2	--	--	--	--	--
AB	7-11	10YR4/3	SL	1FSBK	VFR	0%	F
Bw1	11-57	10YR4/6	SL	1MSBK	FR	0%	C
Bw2	57-97	10YR4/6	SL	1MSBK	FR	0%	F
BC	97-120	10YR6/6	LS	1FGR	L	0%	0

Third Pond site 2 soil description.

[Carver and Plymouth sands; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-3	5YR2.5/1	--	--	--	--	C
E	3-15	7.5YR3/2	SL	1MSBK	FR	0%	F
Bhs	15-26	10YR3/6	SL	1MSBK	FR	0%	C
B1	26-39	10YR4/6	LS	1FGR	VFR	0%	F
B2	39-94	10YR5/8	S	1FGR	L	0%	F
BC	94-130	10YR6/8	S	1FGR	L	0%	F
C	>130	10YR6/6	S	1FGR	L	0%	0

Mashomack site 1 soil description.

[Plymouth loamy sand; Taxonomic class: coarse-loamy, mixed, subactive, mesic Oxyaquic Dystrudepts]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-4	--	--	--	--	--	--
A	4-25	10YR3/3	SL	1FSBK	VFR	0%	C
Bw1	25-70	10YR4/4	SL	2MSBK	VFR	0%	F
Bw2	70-120	10YR4/6	SL	2MSBK	VFR	0%	F
Bw3	120-141	10YR5/6	LS	1FGR	L	5%	0

Mashomack site 2 soil description.

[Montauk fine sandy loam; Taxonomic class: coarse-loamy, mixed, subactive, mesic Oxyaquic Dystrudepts; 5YR5/4 mottles in Cd2]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-3	10YR2/1	--	--	--	--	--
A	3-15	10YR3/2	SL	1FGR	FR	<5%	M
Bw1	15-58	10YR5/6	SL	1MSBK	FR	5%	C
Bw2	58-71	10YR5/6	SL	1MSBK	VFR	5%	F
Cd1	71-88	7.5YR5/6	LS	1FGR	L	10%	F
Cd2	88->110	7.5YR5/6	LS	1FGR	L	<5%	F

Mashomack site 3 soil description.

[Plymouth loamy sand; Taxonomic class: mesic, coated Typic Quartzipsamments]

Horizon	Depth	Color	Texture	Structure	Consistence	Coarse Fragments	Roots
Oe	0-1	10YR2/2	--	--	--	--	--
A	1-10	10YR3/2	L	2MSBK	FR	<5%	M
Bw1	Oct-44	10YR4/4	SL	2MSBK	FR	5%	C
Bw2	44-70	10YR4/4	SL	1FSBK	VFR	5%	C
Cd1	70-86	10YR5/6	LS	1FGR	L	5%	F
Cd2	86->110	10YR5/6	S	1FGR	L	<5%	F

Appendix C

Pond water chemistry. Heading abbreviations: inorganic monomeric Al (I.M. Al); organic monomeric Al (O.M. Al); dissolved organic carbon (DOC); specific conductance at 25 ° C (S.C.). Concentrations of 0.0 indicate that the constituent was not detected in the analysis. Values below the reporting limit for NO_3^-, (2.0 mmol/L), and I.M. Al and O.M. Al (1.5 mmol/L) do not meet data quality objectives and should be considered approximate.

Site ID	Date	ANC	pH	Cl^-	NO_3^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+	Si	I.M. Al	O.M. Al	NH_4^+	Total P	DOC	S.C.
	sampled	μeq L^{-1}		μmol L^{-1}											μg L-1	μmol C L^{-1}	μS cm^{-1}
Bellows Pond	4/24/2013	-3.1	5.6	250	0.3	34.1	25.9	31.4	7.5	233	0.6	0.7	0.0	1.3	12.0	289	43.9
Bellows Pond	5/20/2013	-15.9	5.3	261	0.0	33.3	28.0	32.3	6.7	235	1.0	0.2	0.0	0.5	12.0	277	44.8
Bellows Pond	7/24/2013	-20.6	5.2	236	0.0	30.9	25.0	29.4	2.7	222	1.1	0.8	0.0	1.0	9.0	279	45.3
Bellows Pond	9/25/2013	13.2	5.6	236	0.0	28.9	77.2	31.7	6.4	210	4.7	0.2	0.0	0.7	6.0	213	40.8
Bellows Pond	10/28/2013	-22.4	5.4	259	0.0	30.2	20.7	27.4	5.5	216	3.1	0.2	0.0	6.3	7.0	226	42.1
Bellows Pond	11/25/2013	-14.7	5.4	263	0.3	30.9	24.3	29.4	5.3	233	2.1	0.3	0.0	2.0	11.0	235	40.9
Sears Pond	11/22/2011		6.4	236	0.0	50.9	51.2	50.6	10.8	243	75.8	0.1	0.0	3.1	0.0	253	48.4
Sears Pond	4/24/2013	73.4	6.7	247	0.0	52.9	56.4	52.6	10.6	263	12.8	0.3	0.0	5.3	7.0	303	53.8
Sears Pond	5/20/2013	120.8	6.8	303	0.0	51.1	63.0	56.5	11.3	277	12.5	0.0	0.0	0.7	9.0	322	56.2
Sears Pond	7/24/2013	138.9	6.8	251	0.0	36.5	62.6	54.2	8.6	267	48.4	0.5	0.0	3.5	7.0	480	57.3
Sears Pond	9/25/2013	132.9	6.9	250	0.0	39.8	108.9	53.5	10.5	247	42.9	0.3	0.0	0.4	6.0	318	56.4
Sears Pond	10/28/2013	142.9	6.8	269	0.0	45.3	56.4	49.9	10.9	252	36.1	0.2	0.0	1.2	6.0	338	57.3
Sears Pond	11/25/2013	108.2	6.8	271	0.2	51.1	59.9	53.7	11.2	273	30.4	0.0	0.0	0.8	7.0	322	58.2
Block Pond	4/24/2013	-23.7	4.7	262	0.6	22.3	18.0	24.4	10.6	233	20.5	2.0	3.3	1.3	20.0	785	47.1
Block Pond	5/20/2013	-34.2	4.5	234	0.5	21.5	32.7	25.8	5.5	190	10.5	2.8	2.9	1.5	38.0	779	47.6
Block Pond	12/4/2013	-19.3	4.6	322	0.4	189.6	89.8	83.8	15.6	371	5.6			1.1	0.0	1282	97.3
Sandy Pond East	11/22/2011		6.0	216	0.2	45.6	47.4	42.7	16.2	209	87.5	0.4	0.0	3.1	0.0	299	44.5
Sandy Pond East	4/24/2013	89.6	6.7	260	1.1	57.2	66.3	50.6	27.9	254	42.7	0.6	0.1	3.3	9.0	384	56.5
Sandy Pond East	5/20/2013	106.9	6.7	270	0.4	41.8	65.0	51.2	28.1	259	27.0	0.1	0.0	1.4	11.0	374	54.6
Sandy Pond East	7/24/2013	144.1	6.8	208	0.2	19.3	57.7	46.0	12.0	210	120.7	0.7	0.6	6.7	13.0	478	47.6
Sandy Pond East	9/23/2013	89.8	6.7	198	0.0	27.4	60.0	45.1	11.3	195	81.2	0.4	0.0	0.5	6.0	279	45.1
Sandy Pond East	10/28/2013	73.3	6.6	272	0.0	35.9	47.1	44.3	13.9	227	62.2	0.3	0.0	1.5	5.0	333	52.1
Sandy Pond East	11/25/2013	106.0	5.9	379	2.5	60.2	50.9	51.4	20.9	256	47.9			19.2	516.0	391	57.8
Third Pond	11/22/2011		5.4	173	0.2	15.9	37.9	21.5	6.6	154	2.3	0.7	2.4	7.4	0.0	654	32.9
Third Pond	4/24/2013	9.3	5.9	195	0.2	39.7	41.8	27.5	15.2	186	3.1	0.9	0.9	0.6	24.0	461	40.7
Third Pond	5/20/2013	7.7	5.2	203	0.0	38.6	40.1	23.7	7.9	190	3.3	1.4	0.4	0.4	28.0	580	40.6
Third Pond	10/28/2013	10.5	5.7	237	0.0	20.4	44.4	29.2	13.5	159	2.8	1.3	0.7	1.1	27.0	792	40.4
Third Pond	11/25/2013	-16.5	5.5		1.0	24.6	50.5	33.0	16.4	174	1.9			3.6	26.0	752	42.7

Site ID	Date	ANC	pH	Cl$^-$	NO$_3^-$	SO$_4^{2-}$	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$	Si	I.M. Al	O.M. Al	NH$_4^+$	Total P	DOC	S.C.
	sampled	µeq L^{-1}		µmol L^{-1}											µg L-1	µmol C L^{-1}	µS cm^{-1}
Sandy Pond West	11/22/2011		6.0	216	0.1	37.4	38.4	38.8	9.8	219	60.7	0.3	0.0	4.8		217	43.6
Sandy Pond West	4/24/2013	69.8	6.6	324	0.5	55.3	55.4	49.3	11.5	293	68.8	0.4	0.0	5.1	5.0	305	57.8
Sandy Pond West	5/20/2013	50.3	6.6	291	0.3	55.7	62.5	49.9	11.2	283	44.5	0.0	0.0	0.7	7.0	269	55.4
Sandy Pond West	7/24/2013	64.0	6.5	249	0.1	41.5	51.9	41.6	7.6	241	49.7	0.3	0.0	1.5	6.0	520	51.9
Sandy Pond West	9/23/2013	71.7	6.3	230	0.0	41.0	45.8	39.0	7.5	225	41.3	0.3	0.0		5.0	437	47.7
Sandy Pond West	10/28/2013	40.1	6.3	307	0.0	43.9	37.9	42.4	11.5	267	42.6	0.6	0.0	1.6	7.0	532	54.7
Sandy Pond West	11/25/2013	27.6	5.8	382	2.6	56.9	40.0	47.1	27.1	325	2.4	1.0	0.3	5.3	68.0	730	62.9

Appendix D

Blood mercury results (ppm, wet wt.) from birds sampled from the Central Pine Barrens ponds and at Mashomack Preserve, Long Island, New York, 2012. Abbreviations in the column labeled age are as follows: AHY=after hatch year; HY=hatch year, ASY=after second year; SY=second year; U=unknown age.

Location	Site	Species	Band #	Sex	Age	Blood Hg (ppm, ww)
Pine Barrens	Bellows Pond	Black-capped Chickadee	2690-82750	F	AHY	0.107
	Bellows Pond	Black-capped Chickadee	2690-82753	F	AHY	0.140
	Bellows Pond	Black-capped Chickadee	2690-82749	U	HY	0.101
	Bellows Pond	Black-capped Chickadee	2690-82751	U	HY	0.127
	Bellows Pond	Black-capped Chickadee	2690-82755	U	HY	0.128
	Bellows Pond	Black-capped Chickadee	2690-82752	U	HY	0.137
	Bellows Pond	Carolina Wren	2341-75287	U	AHY	0.241
	Bellows Pond	Common Yellowthroat	2690-82748	M	AHY	0.130
	Bellows Pond	Common Yellowthroat	2690-82754	M	AHY	0.155
	Bellows Pond	Common Yellowthroat	2690-82747	M	AHY	0.178
	Bellows Pond	Eastern Towhee	1232-31012	M	ASY	0.136
	Bellows Pond	Gray Catbird	2331-52361	M	AHY	0.038
	Bellows Pond	Gray Catbird	2331-52360	F	AHY	0.069
	Bellows Pond	Ovenbird	2311-56097	U	AHY	0.119
	Bellows Pond	Ovenbird	2311-56098	U	AHY	0.268
	Bellows Pond	Pine Warbler	2690-82756	M	AHY	0.22
	Bellows Pond	Pine Warbler	2690-82757	M	AHY	0.227
	Block Pond	Common Yellowthroat	2540-71759	M	AHY	0.129
	Sandy Pond East	Brown Thrasher	1292-68532	M	AHY	0.046
	Sandy Pond East	Common Yellowthroat	2690-	M	AHY	0.069

			82734			
Pine Barrens	Sandy Pond East	Common Yellowthroat	2690-82732	M	AHY	0.108
	Sandy Pond East	Common Yellowthroat	2690-82738	F	AHY	0.261
	Sandy Pond East	Eastern Kingbird	2341-75276	M	AHY	0.461
	Sandy Pond East	Eastern Tufted Titmouse	2341-75273	U	HY	0.098
	Sandy Pond East	Eastern Wood-pewee	2690-82733	U	AHY	0.298
	Sandy Pond East	Gray Catbird	2331-52349	U	AHY	0.041
	Sandy Pond East	Gray Catbird	2331-52352	F	AHY	0.071
	Sandy Pond East	Gray Catbird	2331-52348	F	AHY	0.107
	Sandy Pond East	Great Crested Flycatcher	2341-75277	F	AHY	0.154
	Sandy Pond East	Ovenbird	2311-56094	M	AHY	0.092
	Sandy Pond East	Ovenbird	2311-56093	U	AHY	0.096
	Sandy Pond East	Pine Warbler	2690-82735	M	AHY	0.112
	Sandy Pond East	Red-winged Blackbird	1292-68534	M	AHY	0.604
	Sandy Pond East	Red-winged Blackbird	1292-68533	M	HY	0.169
	Sandy Pond East	Red-winged Blackbird	2331-52351	F	HY	0.271
	Sandy Pond East	Song Sparrow	2341-75272	U	HY	0.083
	Sandy Pond East	Spotted Sandpiper	2341-75274	U	U	0.326
	Sandy Pond East	Yellow Warbler	2690-82736	U	HY	0.072
	Sandy Pond East	Yellow Warbler	2690-82737	M	SY	0.088
	Sandy Pond East	Yellow-throated Vireo	2311-56095	U	AHY	0.161
	Sandy Pond West	Black-capped Chickadee	2690-82760	F	AHY	0.055
	Sandy Pond West	Black-capped Chickadee	2690-82761	U	AHY	0.062
	Sandy Pond West	Black-capped Chickadee	2690-82759	U	HY	0.058
	Sandy Pond West	Brown Thrasher	1603-22828	U	HY	0.024
	Sandy Pond West	Eastern Phoebe	2690-82763	U	HY	0.107

	Sandy Pond West	Eastern Towhee	2331-52364	M	AHY	0.042
	Sandy Pond West	Eastern Towhee	2331-52366	M	AHY	0.049
	Sandy Pond West	Eastern Wood-pewee	2690-82762	U	AHY	0.34
	Sandy Pond West	Gray Catbird	2331-52363	U	AHY	0.028
	Sandy Pond West	Gray Catbird	2331-52370	M	AHY	0.063
	Sandy Pond West	Gray Catbird	2331-52369	M	AHY	0.066
	Sandy Pond West	Gray Catbird	2331-52362	F	AHY	0.072
	Sandy Pond West	Pine Warbler	2690-82765	M	AHY	0.108
	Sandy Pond West	Pine Warbler	2690-82758	M	AHY	0.133
	Sandy Pond West	Pine Warbler	2690-82764	U	HY	0.081
	Sandy Pond West	Veery	2341-75296	U	AHY	0.111
	Sears Pond	Blue Jay	1603-22827	U	AHY	0.198
	Sears Pond	Brown Thrasher	1603-22826	U	AHY	0.061
	Sears Pond	Carolina Wren	2341-75279	U	HY	0.257
	Sears Pond	Carolina Wren	2341-75280	U	HY	0.419
	Sears Pond	Carolina Wren	2341-75281	U	HY	0.58
	Sears Pond	Common Yellowthroat	2690-82740	M	AHY	0.152
	Sears Pond	Common Yellowthroat	2690-82739	M	AHY	0.163
	Sears Pond	Common Yellowthroat	2690-82741	M	AHY	0.183
	Sears Pond	Eastern Towhee	1292-68536	M	ASY	0.12
	Sears Pond	Eastern Towhee	1292-68535	M	SY	0.11
	Sears Pond	Gray Catbird	2331-52355	M	AHY	0.047
	Sears Pond	Gray Catbird	2331-52357	M	AHY	0.062
	Sears Pond	Gray Catbird	2331-52354	F	AHY	0.072
	Sears Pond	Great Crested Flycatcher	2331-52359	F	AHY	0.159
	Sears Pond	Ovenbird	2311-	U	AHY	0.136

			56096			
	Sears Pond	Pine Warbler	2690-82743	F	AHY	0.136
	Sears Pond	Pine Warbler	2690-82744	F	AHY	0.151
	Sears Pond	Veery	2341-75283	M	ASY	0.035
	Sears Pond	Veery	2341-75282	M	ASY	0.047
	Sears Pond	Veery	2341-75284	U	HY	0.032
	Sears Pond	Veery	2341-75278	M	SY?	0.042
	Third Pond	American Robin	1232-31018	U	HY	0.021
	Third Pond	American Robin	1232-31019	U	HY	0.029
	Third Pond	Black-capped Chickadee	2690-82768	U	AHY	0.063
	Third Pond	Common Yellowthroat	2690-82767	M	AHY	0.094
	Third Pond	Gray Catbird	2331-52382	F	AHY	0.03
	Third Pond	Gray Catbird	2331-52383	M	AHY	0.037
	Third Pond	Ovenbird	1601-37287	U	AHY	0.091
	Third Pond	Ovenbird	1601-37288	U	AHY	0.075
	Third Pond	Red-eyed Vireo	1601-37285	M	AHY	0.098
	Third Pond	Red-eyed Vireo	1601-37286	M	AHY	0.155
Shelter Island	Mashomack 3-Section 6	Carolina Wren	2341-75268	U	HY	0.184
	Mashomack 3-Section 6	House Wren	2690-82721	M	AHY	0.116
	Mashomack 3-Section 6	House Wren	2690-82722	U	AHY	0.112
	Mashomack 3-Section 6	House Wren	2690-82723	F	AHY	0.123
	Mashomack 3-Section 6	House Wren	2690-82725	M	AHY	0.223
	Mashomack 3-Section 6	House Wren	2690-82728	M	AHY	0.101
	Mashomack 3-Section 6	House Wren	2690-82729	M	AHY	0.121
	Mashomack 3-Section 6	Red-eyed Vireo	2311-56088	M	AHY	0.049
	Mashomack 3-Section 6	Red-eyed Vireo	2311-56091	M	AHY	0.052

	Mashomack 3-Section 6	Red-eyed Vireo	2311-56090	U	AHY	0.057
	Mashomack 3-Section 6	Red-eyed Vireo	2311-56092	M	AHY	0.063
	Mashomack 3-Section 6	Red-eyed Vireo	2311-56089	M	AHY	0.079
	Mashomack 1-Swamp	American Redstart	2690-82702	F	AHY	0.088
	Mashomack 1-Swamp	American Redstart	2690-82701	F	AHY	0.126
	Mashomack 1-Swamp	Carolina Wren	2341-75259	U	HY	0.216
	Mashomack 1-Swamp	Carolina Wren	2341-75255	U	HY	0.311
	Mashomack 1-Swamp	Carolina Wren	2341-75252	U	HY	0.32
	Mashomack 1-Swamp	Carolina Wren	2341-75251	U	HY	0.323
	Mashomack 1-Swamp	Carolina Wren	2341-75249	U	HY	0.374
	Mashomack 1-Swamp	Carolina Wren	2341-75250	U	HY	0.469
	Mashomack 2-Sanctuary	American Redstart	2690-82710	M	SY	0.062
	Mashomack 2-Sanctuary	Carolina Wren	2341-75262	F	AHY	0.328
	Mashomack 2-Sanctuary	Carolina Wren	2341-75261	U	HY	0.277
	Mashomack 2-Sanctuary	Common Yellowthroat	2690-82708	M	AHY	0.09
	Mashomack 2-Sanctuary	Red-eyed Vireo	2311-56087	M	AHY	0.073
	Mashomack 2-Sanctuary	Red-eyed Vireo	2311-56086	F	AHY	0.078
	Mashomack 2-Sanctuary	Red-winged Blackbird	2331-52342	F	AHY	0.149
	Mashomack 2-Sanctuary	Red-winged Blackbird	1292-68527	M	ASY	0.139
	Mashomack 2-Sanctuary	Yellow Warbler	2690-82709	F	AHY	0.042
	Mashomack 2-Sanctuary	Yellow Warbler	2690-82713	F	AHY	0.043
	Mashomack 2-Sanctuary	Yellow Warbler	2690-82714	F	AHY	0.056
	Mashomack 2-Sanctuary	Yellow Warbler	2690-82717	U	HY	0.034
	Mashomack 2-Sanctuary	Yellow Warbler	2690-82715	F	U	0.067

Appendix E

Tail (outer tail feather=R6) feather mercury concentrations (ppm, fw) from birds sampled in the Central Pine Barrens ponds and at Mashomack Preserve, Long Island, New York, 2012 (highlighted in blue exceed 3 ppm effect concentration for feathers).

Location	Site	Species	Band #	R6 Hg
Pine Barrens	Bellows Pond	Black-capped Chickadee	2690-82750	0.666
	Bellows Pond	Black-capped Chickadee	2690-82753	1.171
	Bellows Pond	Black-capped Chickadee	2690-82755	2.254
	Bellows Pond	Black-capped Chickadee	2690-82749	2.287
	Bellows Pond	Black-capped Chickadee	2690-82751	2.326
	Bellows Pond	Black-capped Chickadee	2690-82752	2.399
	Bellows Pond	Carolina Wren	2341-75287	0.498
	Bellows Pond	Common Yellowthroat	2690-82748	0.527
	Bellows Pond	Common Yellowthroat	2690-82747	0.620
	Bellows Pond	Common Yellowthroat	2690-82754	0.782
	Bellows Pond	Eastern Towhee	1232-31012	1.001
	Bellows Pond	Gray Catbird	2331-52360	0.380
	Bellows Pond	Gray Catbird	2331-52361	0.700
	Bellows Pond	Ovenbird	2311-56097	1.581
	Bellows Pond	Ovenbird	2311-56098	2.106
	Bellows Pond	Pine Warbler	2690-82756	0.579
	Bellows Pond	Pine Warbler	2690-82757	1.468
	Block Pond	Common Yellowthroat	2540-71759	0.509
	Sandy Pond East	Brown Thrasher	1292-68532	0.274
	Sandy Pond East	Common Yellowthroat	2690-82738	0.670
	Sandy Pond East	Common Yellowthroat	2690-82734	0.722
	Sandy Pond East	Common Yellowthroat	2690-82732	0.742
	Sandy Pond East	Eastern Kingbird	2341-75276	0.278
	Sandy Pond East	Eastern Tufted Titmouse	2341-75273	0.628
	Sandy Pond East	Eastern Wood-pewee	2690-82733	1.714
	Sandy Pond East	Gray Catbird	2331-52352	0.359
	Sandy Pond East	Gray Catbird	2331-52348	1.457
	Sandy Pond East	Gray Catbird	2331-52349	2.955
	Sandy Pond East	Great Crested Flycatcher	2341-75277	1.004
	Sandy Pond East	Ovenbird	2311-56093	1.049
	Sandy Pond East	Ovenbird	2311-56094	1.180
	Sandy Pond East	Pine Warbler	2690-82735	0.870
	Sandy Pond East	Red-winged Blackbird	2331-52351	0.187

Pine Barrens	Sandy Pond East	Red-winged Blackbird	1292-68534	0.267
	Sandy Pond East	Red-winged Blackbird	1292-68533	3.547
	Sandy Pond East	Song Sparrow	2341-75272	8.633
	Sandy Pond East	Spotted Sandpiper	2341-75274	1.213
	Sandy Pond East	Yellow Warbler	2690-82737	0.096
	Sandy Pond East	Yellow Warbler	2690-82736	1.572
	Sandy Pond East	Yellow-throated Vireo	2311-56095	0.306
	Sandy Pond West	Brown Thrasher	1603-22828	1.262
	Sandy Pond West	Eastern Towhee	2331-52366	0.314
	Sandy Pond West	Eastern Towhee	2331-52364	0.970
	Sandy Pond West	Gray Catbird	2331-52370	0.344
	Sandy Pond West	Gray Catbird	2331-52369	0.794
	Sandy Pond West	Gray Catbird	2331-52363	0.880
	Sandy Pond West	Gray Catbird	2331-52362	1.269
	Sandy Pond West	Veery	2341-75296	0.450
	Sears Pond	Blue Jay	1603-22827	0.584
	Sears Pond	Brown Thrasher	1603-22826	0.469
	Sears Pond	Carolina Wren	2341-75279	0.558
	Sears Pond	Carolina Wren	2341-75280	0.663
	Sears Pond	Carolina Wren	2341-75281	1.367
	Sears Pond	Common Yellowthroat	2690-82739	2.415
	Sears Pond	Eastern Towhee	1292-68536	0.612
	Sears Pond	Eastern Towhee	1292-68535	0.658
	Sears Pond	Gray Catbird	2331-52355	0.642
	Sears Pond	Gray Catbird	2331-52357	0.950
	Sears Pond	Gray Catbird	2331-52354	1.566
	Sears Pond	Great Crested Flycatcher	2331-52359	1.061
	Sears Pond	Ovenbird	2311-56096	2.346
	Sears Pond	Veery	2341-75278	0.543
	Sears Pond	Veery	2341-75283	0.570
	Sears Pond	Veery	2341-75282	1.138
	Sears Pond	Veery	2341-75284	1.422
	Third Pond	Gray Catbird	2331-52382	0.362
	Third Pond	Gray Catbird	2331-52383	0.368
	Third Pond	Ovenbird	1601-37287	1.067
	Third Pond	Ovenbird	1601-37288	1.078
	Third Pond	Red-eyed Vireo	1601-37286	0.494
Shelter Is.	Pine Swamp (Mashomack 1)	American Redstart	2690-82701	1.852
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75259	0.860
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75255	1.221
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75250	1.877

Shelter Is.	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75251	4.386
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75252	4.596
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75249	4.704
	Sanctuary (Mashomack 2)	American Redstart	2690-82710	1.339
	Sanctuary (Mashomack 2)	Carolina Wren	2341-75261	1.057
	Sanctuary (Mashomack 2)	Carolina Wren	2341-75262	1.926
	Sanctuary (Mashomack 2)	Common Yellowthroat	2690-82708	0.549
	Sanctuary (Mashomack 2)	Red-eyed Vireo	2311-56086	0.185
	Sanctuary (Mashomack 2)	Red-eyed Vireo	2311-56087	0.378
	Sanctuary (Mashomack 2)	Red-winged Blackbird	2331-52342	0.146
	Sanctuary (Mashomack 2)	Red-winged Blackbird	1292-68527	0.296
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82717	0.367
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82713	0.426
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82709	0.464
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82714	0.481
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82715	0.567
	Section Six, (Mashomack 3)	Carolina Wren	2341-75268	3.209
	Section Six, (Mashomack 3)	House Wren	2690-82721	0.841
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56090	0.306
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56088	0.428
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56091	0.523
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56089	0.585
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56092	0.623

Appendix F

Blood $\delta^{13}C$ and $\delta^{15}N$ ratios (per mil) from birds in the Central Pine Barrens ponds and at Mashomack Preserve, Long Island, New York, 2012.

Location	Site	Species	Band #	δ13C	δ15N
Pine Barrens	Bellows Pond	Black-capped Chickadee	2690-82753	-25.01	2.04
	Bellows Pond	Carolina Wren	2341-75287	-24.43	6.59
	Bellows Pond	Common Yellowthroat	2690-82748	-25.15	4.33
	Bellows Pond	Gray Catbird	2331-52361	-25.22	5.62
	Bellows Pond	Gray Catbird	2331-52360	-24.97	6.73
	Bellows Pond	Ovenbird	2311-56097	-25.08	3.15
	Bellows Pond	Pine Warbler	2690-82757	-24.89	3.40
	Bellows Pond	Pine Warbler	2690-82756	-24.87	3.23
	Sandy Pond East	Common Yellowthroat	2690-82732	-25.84	2.04
	Sandy Pond East	Common Yellowthroat	2690-82734	-25.65	2.21
	Sandy Pond East	Common Yellowthroat	2690-82738	-24.94	3.32
	Sandy Pond East	Eastern Kingbird	2341-75276	-24.20	5.32
	Sandy Pond East	Eastern Wood-pewee	2690-82733	-24.58	4.98
	Sandy Pond East	Ovenbird	2311-56094	-25.16	3.12
	Sandy Pond East	Ovenbird	2311-56093	-25.11	3.92
	Sandy Pond East	Pine Warbler	2690-82735	-25.62	2.61
	Sandy Pond East	Red-winged Blackbird	1292-68534	-26.46	5.01
	Sandy Pond East	Red-winged Blackbird	2331-52351	-24.22	6.06
	Sandy Pond East	Red-winged Blackbird	1292-68533	-23.89	4.69
	Sandy Pond East	Song Sparrow	2341-75272	-26.45	7.22
	Sandy Pond East	Spotted Sandpiper	2341-75274	-25.28	8.88
	Sandy Pond West	Gray Catbird	2331-52362	-26.69	5.31
	Sandy Pond West	Gray Catbird	2331-52369	-25.01	4.91
	Sandy Pond West	Pine Warbler	2690-82758	-25.44	2.72
	Sandy Pond West	Pine Warbler	2690-82764	-25.39	2.77
	Sandy Pond West	Pine Warbler	2690-82765	-25.24	2.09
	Sears Pond	Carolina Wren	2341-75279	-24.84	5.34
	Sears Pond	Carolina Wren	2341-75281	-24.57	4.43
	Sears Pond	Carolina Wren	2341-75280	-24.37	4.83
	Sears Pond	Common Yellowthroat	2690-82741	-24.77	3.14
	Sears Pond	Gray Catbird	2331-52357	-25.43	5.44
	Sears Pond	Gray Catbird	2331-52354	-24.35	7.38
	Sears Pond	Ovenbird	2311-56096	-23.97	2.97
Pine Barrens	Sears Pond	Pine Warbler	2690-82743	-25.18	2.80

	Sears Pond	Pine Warbler	2690-82744	-25.02	2.70
	Third Pond	Black-capped Chickadee	2690-82768	-25.94	3.02
	Third Pond	Common Yellowthroat	2690-82767	-24.88	2.91
	Third Pond	Gray Catbird	2331-52382	-26.21	4.71
	Third Pond	Gray Catbird	2331-52383	-25.81	5.57
	Third Pond	Ovenbird	1601-37287	-25.11	3.18
	Third Pond	Ovenbird	1601-37288	-25.09	4.47
	Third Pond	Red-eyed Vireo	1601-37286	-26.30	4.00
	Third Pond	Red-eyed Vireo	1601-37285	-25.73	3.14
Shelter Is.	Pine Swamp (Mashomack 1)	American Redstart	2690-82702	-24.74	4.65
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75255	-24.44	4.31
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75250	-24.40	5.96
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75249	-24.38	4.94
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75252	-24.34	5.38
	Pine Swamp (Mashomack 1)	Carolina Wren	2341-75251	-24.07	4.81
	Sanctuary (Mashomack 2)	American Redstart	2690-82710	-24.36	5.01
	Sanctuary (Mashomack 2)	Carolina Wren	2341-75261	-24.03	5.48
	Sanctuary (Mashomack 2)	Carolina Wren	2341-75262	-23.77	5.38
	Sanctuary (Mashomack 2)	Common Yellowthroat	2690-82708	-23.82	4.99
	Sanctuary (Mashomack 2)	Red-eyed Vireo	2311-56086	-25.32	3.87
	Sanctuary (Mashomack 2)	Red-eyed Vireo	2311-56087	-25.31	2.42
	Sanctuary (Mashomack 2)	Red-winged Blackbird	2331-52342	-21.59	4.20
	Sanctuary (Mashomack 2)	Red-winged Blackbird	1292-68527	-20.89	6.17
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82709	-24.49	4.12
	Sanctuary (Mashomack 2)	Yellow Warbler	2690-82714	-24.19	3.62
	Section Six, (Mashomack 3)	Carolina Wren	2341-75268	-24.43	4.13
	Section Six, (Mashomack 3)	House Wren	2690-82725	-24.67	4.13
	Section Six, (Mashomack 3)	House Wren	2690-82728	-24.56	4.81
	Section Six, (Mashomack 3)	House Wren	2690-82721	-24.46	3.93
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56091	-25.34	3.93
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56092	-25.32	3.33
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56090	-25.22	3.67
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56089	-24.98	2.64
	Section Six, (Mashomack 3)	Red-eyed Vireo	2311-56088	-24.79	2.29

Appendix G

Total, methyl (ppb, dw) and % methylmercury in the invertebrates collected in 2012 on Long Island, New York.

Site	Order	Family/Suborder	Common Name	MeHg	THg	%MeHg
Bellows Pond	Araneae	Araneidae	spider	52	139	37
Bellows Pond	Araneae	Lycosidae	spider	65	269	24
Bellows Pond	Araneae	Philodromidae	spider	118	264	45
Bellows Pond	Araneae	Salticidae	spider	85	153	56
Bellows Pond	Araneae	Salticidae	spider	124	294	42
Bellows Pond	Araneae	Tetragnathidae	spider	11	287	4
Bellows Pond	Araneae	Tetragnathidae	spider	43	181	24
Bellows Pond	Araneae	Thomisidae	spider	40	91	44
Bellows Pond	Diptera	Tabanidae	horsefly AD	16	228	7
Bellows Pond	Odonata	Anisoptera	dragonfly	50	268	19
Bellows Pond	Odonata	Anisoptera	dragonfly	129	612	21
Bellows Pond	Odonata	Anisoptera	dragonfly	51	197	26
Bellows Pond	Opiliones	harvestmen	harvestmen	18	89	20
Block Pond	Araneae	spider	spider	91	362	25
Block Pond	Araneae	spider	spider	63	191	33
Block Pond	Diptera	Tabanidae	deerfly AD	30	44	68
Block Pond	Isopoda	Armadillidiidae	pill bug	57	170	34
Block Pond	Mantidae	mantis	mantis	3.1	128	2
Block Pond	Mantidae	mantis	mantis	11	125	9
Block Pond	Odonata	Zygoptera	damselfly	53	222	24
Sandy Pond East	Araneae	Tetragnathidae	spider	322	359	90
Sandy Pond East	Araneae	Tetragnathidae	spider	90	321	28
Sandy Pond East	Araneae	Tetragnathidae	spider	126	410	31
Sandy Pond East	Araneae	Tetragnathidae	spider	236	392	60
Sandy Pond East	Araneae	Thomisidae	spider	177	291	61
Sandy Pond East	Odonata	Anisoptera	dragonfly	14	412	3
Sandy Pond East	Odonata	Anisoptera	dragonfly	25	180	14
Sandy Pond East	Odonata	Anisoptera	dragonfly	106	355	30
Sandy Pond East	Odonata	Zygoptera	damselfly	7.3	222	3
Sandy Pond West	Araneae	Araneidae	spider	84	211	40
Sandy Pond West	Araneae	Araneidae	spider	214	309	69
Sandy Pond West	Araneae	Philodromidae	spider	< 42	127	
Sandy Pond West	Araneae	Philodromidae	spider	83	133	62
Sandy Pond West	Araneae	Salticidae	spider	42	118	36
Sandy Pond West	Araneae	Tetragnathidae	spider	203	358	57
Sandy Pond West	Araneae	Tetragnathidae	spider	62	223	28

Sandy Pond West	Araneae	Thomisidae	spider	175	261	67
Sandy Pond West	Diptera	Tabanidae	deerfly AD	19	33	58
Sandy Pond West	Odonata	Anisoptera	dragonfly	9.4	131	7
Sandy Pond West	Odonata	Anisoptera	dragonfly	54	124	44
Sandy Pond West	Odonata	Anisoptera	dragonfly	38	69	55
Sandy Pond West	Odonata	Zygoptera	damselfly	257	256	100
Sears Pond	Araneae	Miturgidae	spider	89	151	59
Sears Pond	Araneae	Miturgidae	spider	67	145	46
Sears Pond	Araneae	Miturgidae	spider	98	169	58
Sears Pond	Araneae	Miturgidae	spider	76	180	42
Sears Pond	Araneae	Philodromidae	spider	234	322	73
Sears Pond	Araneae	Salticidae	spider	140	208	67
Sears Pond	Araneae	Tetragnathidae	spider	227	342	66
Sears Pond	Odonata	Zygoptera	damselfly	147	194	76
Sears Pond	Odonata	Zygoptera	damselfly	67	158	42
Sears Pond	Odonata	Zygoptera	damselfly	166	214	78
Third Pond	Araneae	Lycosidae	spider	286	287	100
Third Pond	Araneae	Lycosidae	spider	174	195	89
Third Pond	Araneae	Tetragnathidae	spider	196	201	98
Third Pond	Araneae	Tetragnathidae	spider	42	100	42
Third Pond	Diptera	Tabanidae	deerfly AD	73	88	83
Third Pond	Odonata	Anisoptera	dragonfly	173	163	106
Third Pond	Odonata	Zygoptera	damselfly	272	271	100
Mashomack 1	Diptera	Tabanidae	deerfly	4.8	10	48
Mashomack 1	Isopoda	Armadillidiidae	pill bug	50	93	54
Mashomack 1	Opiliones	harvestmen	harvestmen	< 6	62	
Mashomack 2	Araneae	Araneidae	spider	50	123	41
Mashomack 2	Araneae	lycosidae	spider	110	188	59
Mashomack 2	Araneae	Oxyopidae	spider	80	118	68
Mashomack 2	Araneae	Philodromidae	spider	39	140	28
Mashomack 2	Araneae	Philodromidae	spider	137	204	67
Mashomack 2	Araneae	Salticidae	spider	105	225	47
Mashomack 2	Araneae	Tetragnathidae	spider	57	140	41
Mashomack 2	Araneae	Tetragnathidae	spider	111	215	52
Mashomack 2	Araneae	Thomisidae	spider	119	180	66
Mashomack 2	Diptera	Tabanidae	deerfly AD	26	67	39
Mashomack 2	Odonata	Anisoptera	dragonfly	43	75	57
Mashomack 2	Odonata	Anisoptera	dragonfly	67	98	68
Mashomack 2	Odonata	Anisoptera	dragonfly	43	111	39
Mashomack 2	Odonata	Zygoptera	damselfly	27	66	41
Mashomack 2	Opiliones	harvestmen	harvestmen	47	73	64
Mashomack 3-Sec. 6	Araneae	Araneidae	spider	6.3	44	14
Mashomack 3-Sec.	Araneae	Araneidae	spider	71	188	38

6						
Mashomack 3-Sec. 6	Araneae	Lycosidae	spider	42	101	42
Mashomack 3-Sec. 6	Araneae	Lycosidae	spider	90	163	55
Mashomack 3-Sec. 6	Araneae	Unknown	spider	29	181	16
Mashomack 3-Sec. 6	Isopoda	Armadillidiidae	pill bug	11	101	11
Mashomack 3-Sec. 6	Opiliones	harvestmen	harvestmen	27	121	22
Mashomack Plot 9	Opiliones	harvestmen	harvestmen	39	113	35
Mashomack-Five S	Araneae	Thomisidae	spider	450	649	69
Mashomack-Five S	Diptera	Tabanidae	deerfly	20	25	80
Mashomack-Five S	Opiliones	harvestmen	harvestmen	69	120	58
Mashomack-SE	Araneae	spider	spider	246	850	29
Mashomack-SE	Diptera	Tabanidae	deerfly	12	22	55

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

NEW YORK
STATE OF
OPPORTUNITY.™

NYSERDA

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | John B. Rhodes, President and CEO