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The Missing Link: The Ecology of the Serpentine and the Implications for East and North Ponds

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Problems in Environmental Science course (Biology 493), Colby College

The Missing Link:
The Ecology of the Serpentine and the Implications for East and North Ponds

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Executive Summary

During the fall of 2011, the Colby Environmental Assessment Team (CEAT) studied the Serpentine connecting East Pond and North Pond. East and North Ponds are members of the larger seven-lake system known as the Belgrade Lakes, located in central Maine. There are over 5,500 lakes in Maine that contribute $6.7 billion to the economy annually through activities including boating, fishing, swimming etc. Additionally, Maine's lakes are sources of municipal and agricultural water, act as flood buffers, and host a wide range of plant, animal, and fish life. Lakes in Maine are a crucial part society and should be studied and preserved.

Previous research efforts of CEAT have focused on the environmental and ecological parameters associated with a single lake in the Belgrade system. The significance of the linkages between the lakes is understudied. As a result, CEAT 2012 aims to investigate the interconnection between the lake systems of East and North Ponds. In order to evaluate the ecological interactions between East Pond, North Pond, and the Serpentine (the linkage between North and East Ponds), and to assess how these water bodies affect each other, CEAT 2012 conducted a comprehensive survey of the Serpentine environment. Studies including an in depth analysis of land use, surface water chemistry, substrate chemistry, fish communities, algal populations, and plant populations were conducted. In particular, the CEAT 2012 was interested in what role the Serpentine might play in the dynamics of algal blooms within East and North Ponds. The following is a brief summary of findings from the CEAT 2012 study of the Serpentine and its interactions with East Pond and North Pond:

- Spatial analysis revealed 34.5% of the North Pond watershed was rated as high erosion potential, while the East Pond watershed has only 27.4% of the watershed with high erosion potential. Erosion impact was estimated to be greater in the East Pond watershed with 39.4% of the land cover indicating high erosion impact, and only 27.8% of the land cover in North Pond showing high erosion impact. The Serpentine is directly adjacent to some of the largest areas of erosion impact and erosion potential. Erosion can have heavy impacts on lakes, and must be considered throughout the entire watershed- not just the immediate lake buffer zone.
- Water chemistry investigations show that many nutrients, including Ca, Mg, Al, and Fe, exhibit declining trends in concentration moving from the confluence towards North Pond. This finding supports the theory of a mixture occurring at the confluence with

variable input levels from input streams and from East Pond. The concentrations of Ca and Mg between the input streams and North Pond indicates that the majority of the water flowing over the dam originates from the input streams. Further, the concentrations of Fe and P support the hypothesis that the majority of water in the Serpentine is provided by input streams and not East Pond. The DO concentrations at the confluence also indicate a large component of post-confluence flow is input stream water.

- Biogeochemistry may explain the difference in occurrence and severity of algal blooms between East Pond and North Pond. North Pond is shallower, and experiences more wind fetch than East Pond allowing it to remain mixed throughout the summer. North Pond remains aerobic as a result of mixing; thus the Al:Fe ratio that regulates phosphorus and other nutrient cycling in sediment is a non-issue. East Pond however, is susceptible to anoxic conditions and therefore prone to release nutrients. Upstream sites S1 and S2 do not release many nutrients from the sediments, as is indicated by high TOC concentrations, high DO, and the presence of sphagnum moss. The nutrients entering the Serpentine and eventually flowing into North Pond remain in the water and do not settle out in the sediments. In sites I1, I2, SC, (and to a lesser extent in S3 and AD) there are low concentrations of DO, TOC, and phosphorus associated with organic matter. This is likely the result of higher amounts of inorganic sediment and higher rates of decomposition at these sites. This area of the Serpentine has lower concentrations of DO, indicating that it may go anoxic at times. However, releasable P at sites I1, I2, Sc, S3 and Ad is low; thus, even in anoxic conditions, there will not be a large-scale release of nutrients. Most of the phosphorus in the Serpentine is tied up in organic matter and will be released slowly as the organic matter decomposes.
- An extensive literature review in addition to CEAT 2012 water chemistry results, were used to compare the habitat requirements of the fish found in East Pond with the habitat characteristics of the Serpentine. This analysis revealed that 9 of the 12 species found in East Pond could use the Serpentine as effective habitat (species included: Chain Pickerel, bullhead, Largemouth Bass, Smallmouth Bass, Black Crappie, Pumpkinseed Sunfish, White Sucker, White Perch, and Yellow Perch). Brown trout and rainbow smelt are not thought to use the Serpentine based on their highly specific habitat requirements. The lack of information about golden shiner’s habitat requirements makes it difficult to

determine whether it would utilize the Serpentine. Investigation of the biomanipulation project on East Pond in 2008 revealed some potential issues with the plan. The presence of White Perch in the Serpentine indicates that this water body could have acted as a shelter for White Perch during the mass removal, which might have lowered the effectiveness of the biomanipulation project. Additionally, it was noticed cyanophyta tend to be resilient to zooplankton grazing. Therefore, a biomanipulation project aimed at increasing zooplankton numbers might prove less effective than originally hoped.

- More algal genera were observed in East Pond than in North Pond or the Serpentine. The genera in East Pond represented the greatest number of phyla. North Pond, which does not bloom as frequently, had the second highest abundance of phyla and genera.
- In the Fen ecosystem adjacent to the Serpentine, 49 plant species were found present. The two most dominant species, based on abundance and frequency, were sphagnum moss and leatherleaf. Cotton grass, sweetgale, large and small leaf cranberries, and gramminoids were common, but with low dominance. The remaining 42 observed species were found in very low abundance and frequency. This indicates a species distribution with few very common species and a large number of very uncommon species. This observation is confirmed by Rank Abundance curves and Shannon-Weiner indexes showing the same pattern across the serpentine. Overall, species diversity trends slightly downward from the confluence to East Pond, and species richness clearly declines moving upstream from the confluence through the input streams. This finding could indicate nutrient loading from the agricultural land adjacent to the input streams. Sphagnum's high dominance indicates the substantial impact the fen has on decomposition in the Serpentine, as Sphagnum decreases decomposition in a number of ways. The substrate in the fen portion of the Serpentine supports the evidence of low decomposition with high concentrations of TOC. Low decomposition in the fen and high TOC in the substrate indicate that the fen acts as a nutrient and carbon sink in this freshwater ecosystem. This ecosystem service is particularly important in the context of global climate change. The fen provides very valuable carbon sequestration, creating yet another important reason to protect and preserve this ecosystem.

Further study is necessary to thoroughly assess the complex ecological relationships

between the Serpentine, East Pond, and North Pond. CEAT 2012 suggests further study on surface-water flow through water bodies, because it is an important factor in determining nutrient concentrations in freshwater ecosystems. Additionally, an in-depth analysis of fish communities using an electro-shock boat is recommended to accurately determine fish species are present in the Serpentine, and to understand how these species may be impacting their ecosystem structure. A geomorphic study of the fen is also recommended to better understand how groundwater might impact nutrient levels across the entire ecosystem.

1. BACKGROUND: GENERAL NATURE OF THE STUDY

As the "Vacationland" of the United States, Maine is known for its scenic coastline, abundant forests, and picturesque lakes and streams. However, as the impact of tourism increases, so too has the challenge of preserving these beautiful landscapes. Maine has over 6,000 lakes, which are used by locals as well as tourists for boating, swimming, and other recreational purposes with a total recreational use greater than 12 million user days (DEP 2005b). Maine residents profit from the tourism through the creation of jobs in the recreation sector and tourism industry. Taking into account the direct and indirect effects of lake tourism on Maine's economy, the total net economic value of Maine's Great Ponds is at least $6.7 billion annually (in July 1996 dollars; DEP 2005b).

The state of Maine not only benefits from the tourism pristine lakes and streams bring to its economy, but also from the ecological benefits of Maine's freshwater systems. These public service benefits from ecosystems are called ecosystem services and include providing a source of water for municipal and agricultural sectors, water filtration, nutrient cycling and buffering against flooding events (Conservation International 2010). Aquatic systems also foster a great diversity of life from algae and wetland plants to fish and bird species.

Unfortunately, Maine's lakes and streams are threatened by development, increased nutrient inputs, and environmental changes. Eutrophication as a result of anthropologic nutrient inputs is one of the main threats to water quality and leads to algal blooms in Maine's waterways. Nutrient loading is largely the result of urban development and increased agricultural land use patterns (Carpenter et al. 1998). Repeated occurrences of algal blooms have been recorded on more than 53 Maine lakes, with another 493 lakes being considered at significant risk of experiencing algal blooms (MDEP 2005b). Excessive algal blooms decrease water clarity and endanger freshwater biota when the blooms decompose and consume oxygen. Water quality is the single feature of lakes that has the most affect on people's enjoyment (MDEP 2005). Algal blooms also have a serious economic effect; they endanger the 8000 Maine jobs that are supported by the use of lakes, and cause a reduction in property values (as much as $200 per frontage foot, representing hundreds of millions of dollars in lost property value) (MDEP 2005b).

Over the past several decades, a number of organizations, including Colby College, have examined the anthropogenic impacts, direct and indirect, on lakes and rivers in central Maine. Studies conducted on the Belgrade Lakes system, a series of five interconnected lakes, provide an opportunity to study changes in the lakes over time and are of great interest due to their close proximity to the college. Historically these lakes have been studied as independent ecosystems and although the impacts of the surrounding terrestrial environment have been examined, little work has been done to better understand how the lakes affect the rivers and wetlands connecting and how the lakes affect each other.

As seen in Figure 1.3, the Belgrade Lakes are intricately linked with wetland, river, and peatland ecosystems. East Pond is the first lake in the Belgrade Lake system, and the Serpentine Stream connects it to North Pond. The first part of the Serpentine flows though large peatland areas, while the second part winds through residential and forested areas. There are two tributary streams that feed into the Serpentine, one of which passes through an area of agriculture. Just before the outlet of the Serpentine into North Pond there is a dam, which was built in 1947.

Lottig et al. (2007) noted the importance of understanding connections within freshwater systems in order to derive a holistic analysis of the ecosystem. Similarly, Kratz et al. (1997), studied the influence of landscape position, defined as "[a lake´s] hydrologic position within the local to regional flow system, as well as considerations of the relative spatial placement of neighboring lakes within a landscape," on lakes in northern Wisconsin. In light of new research suggesting that freshwater systems are intricately connected, our team (CEAT 2012) surveyed the Serpentine Stream, which connects East and North Ponds. This report serves as the first comprehensive study of the Serpentine and seeks to better understand its ecology and effects on East and North Ponds in the Belgrade Lakes network.

General Characteristics of Freshwater Ecosystems

Lakes

Although this report focuses on the Serpentine Stream ecosystem, aspects of East and North Ponds, the first two lakes in the Belgrade Lakes system, were also analyzed because they are linked by the stream. Lakes are most basically defined as depressions in the ground that are filled with water (Wessells and Hopson 1988). Although lakes may be connected to streams, for the most part they are self-contained and have clear natural boundaries. Lake biota are affected

by water quality, which in turn is affected by the physical and chemical properties of the surrounding environment. Characteristics such as depth, mean temperature, pH, and elemental composition, vary between lakes even within close proximity to one another (Kratz et al. 1997).

Water inputs such as those from groundwater and precipitation have the greatest effects on lake properties. The chemical properties of precipitation affect lakes more than streams, because of a longer residence time in lakes, rather than flowing and mixing with other water inputs (Lottig et al. 2011). As Moss (2010) notes, “the prime determinant of activity within the lake is the immediate surface catchment (the area from which water gathers, and runs into streams and rivers and thence lakes), its geology, terrestrial ecosystems and land use.” Often it is the water flowing through the catchment area that links terrestrial ecosystems and land use to lakes, by collecting debris and nutrients as it runs to the lakes. Lakes higher in the landscape have a greater input of groundwater, whereas lakes lower in the landscape are more affected by precipitation (Kratz et al. 1997). Groundwater input increases cation and silica input, which affect lake biota such as snails, crayfish and sponges. Kratz et al. (1997) also found that dissolved organic carbon (DOC), which often comes from runoff, colors the water and limits light penetration in lakes. Limited light availability in the water column negatively affects primary production, because freshwater biota like algae and wetland plants require light for photosynthesis.

Lakes may go through periods of stratification due to temperature gradients in the water at different depths. When the water becomes isothermal or there is a large wind event, the density barriers caused by water of different temperatures breaks, resulting in the mixing of the entire water column. This brings nutrients up from the bottom of the lake to the surface waters, where various forms of biota can use them. Nutrient levels are higher at the bottom of the lake because of falling detritus and low rates of decomposition due to low temperature and oxygen levels. In mixing events, this nutrient-rich water meets the highly-oxygenated, nutrient-poor surface water. Such an event is an important part of lake dynamics, because of the seasonal changes in temperature, dissolved oxygen and nutrient levels within the lake, which affect aquatic life such as fish and algae. Stratification and lake mixing are important drivers of internal loading and processing of nutrients.

Streams

Streams are lotic (flowing water) ecosystems that link both terrestrial and aquatic environments (Smith 1990). Streams act as transport systems for water, organic materials, and nutrients, ushering them to lakes and oceans (Moss 2010). While traveling downstream, these nutrients and minerals are also changed or taken up by biotic and abiotic processes (Smith 1990). Stream organisms in all trophic levels rely heavily on decomposition for the release of nutrients into the system (Moss 2010). Soil type, vegetation, substrate, morphology, and climate determine stream properties (Moss 2010).

In contrast to lakes, streams are more affected by groundwater inputs than by precipitation (Lottig et al. 2011). Stream chemistry in low groundwater flow conditions reflects a lower amount of mineral soil, however, in high-flow conditions, more nutrients and minerals from all soil horizons are found in stream water (Kratz et al. 1991). Moreover, the path of groundwater flow affects which nutrients and minerals end up in the stream; water flowing from high elevations usually flows through upper soil horizons, while water from lower in the landscape has contact with the very deep B-horizon. Groundwater chemistry also undergoes seasonal changes; water in the spring is more acidic than in other seasons, because the ions break down and dissolve into the first meltwaters, which then flow into streams and lakes (Kratz et al., 1991). Spring and fall lead to higher groundwater inputs, because precipitation is often increased and plants take up less water (Morley et al. 2011). Morely et al. (2011) found that seeps, groundwater slope wetlands characterized by permanent groundwater discharge along a sloping terrain, significantly influence physical and chemical properties in streams. Seeps can significantly increase the total cation concentration and are responsible for up to 50% of the total calcium and 35% of the total sodium inputs into the streams and therefore provide streams with a buffering capacity against downstream acidification from precipitation inputs (Morley et al. 2011). Interestingly, as the sizes of lakes and streams converge, their biogeochemical properties also converge - a small lake and a large stream are similar in chemical and physical properties (Lottig et al. 2011).

Peatlands

The Serpentine system is partially a wetland ecosystem, with peatland attributes. Freshwater wetland characteristics include a water table near or above the level of the land, soil that is periodically or perpetually saturated, non-soil substrates such as peat, and hydrophytic

vegetation that is adapted for life in saturated and anaerobic soils (Chiras 1991). Peatlands, which include bogs and fens, are found in the cool boreal zones of the world where precipitation rates exceed evaporation rates and lead to excess moisture accumulation (Mitsch et al. 2009).

Peatlands are characterized by oxidation of sulfur compounds and organic acids, limited nutrients, low primary productivity, slow decomposition, adaptive nutrient-cycling pathways, and peat accumulation. Because of cation exchange with mosses, limited inputs and large amounts of organic decomposition, bogs are generally nutrient poor and slightly acidic; Keddy (2010) defines bogs as having a pH less than 5. The high exchangeable hydrogen levels and lower pH in Sphagnum peat compared to sedge-dominated peat is most likely a result of the metabolic activity of the plants. Long-term studies have shown that peatlands act as effective nutrient sinks, especially for atmospheric carbon (Dean and Gorham 1998). The main difference between bogs and fens is that bogs have no inflow or outflow of water, and instead receive nutrients, water and other minerals exclusively by precipitation (CEAT 1991). Sphagnum moss is the dominant vegetation in bogs. Fens, on the other hand, are open peatland systems, often covered by grasses, sedges, or reeds that receive some input from surrounding mineral soils. Graminoid (grass) species and brown mosses dominate the vegetation cover in fens.

The development of a peatland ecosystem is directly related to the amount of surplus water and peat that accumulates, which may help explain exactly what type of ecosystem is found at the Serpentine peatland. (Mitsch et al. 2009). Adequate moisture is the first requirement for the successful development and survival of peatlands. Fens rely on precipitation and/or local river systems to maintain their moisture regime. A dam is located at the mouth of the Serpentine to North Pond, which may impact the water level and flow rates of the Serpentine. Excess water backed up by the dam may raise the natural level of the water, submerging plants that were once emergent or on land. This factor may be contributing to the transition of the Serpentine's wetland ecosystem.

The second requirement for peatland development is that accumulation of peat is greater than decomposition. Peat accumulates when the Sphagnum moss dies and is compacted under new plant growth. Compared to other ecosystems, primary production in peatlands is generally low, however not as low as decomposition rates. Sphagnum moss is a decay inhibitor, due to sphagnol, an anti-decay/antibiotic compound it contains (Aerts et al. 1999). Once formed, peatlands are very resistant to changes in water balance and peat accumulation (Mitsch et al.

2009). The slow decomposition rate combined with the balanced water table, the water-holding capacity of the peat, and the acidity, create a microclimate that can withstand significant environmental fluctuations.

As was briefly mentioned, fens can range from slightly acidic (poor fens) to strongly alkaline (rich fens) depending on the hydrology and biochemistry of the ecosystem (Mitsch et al. 2009). The pH of a peatland generally decreases and the organic content increases as it develops from a true fen to a bog. The wetland of the Serpentine is most likely in a transitional phase between a fen and a bog, also called a poor fen, because the vegetation is Sphagnum dominated, yet it receives groundwater and surface water inputs from the Serpentine and East Pond.

Stream properties such as depth, temperature, flow rate and dissolved nutrient levels affect the peatlands nearby, an important concept for the Serpentine ecosystem. Baattrup-Pedersen et al. (2011) found that stream channelization, when streams are widened or deepened to allow boat traffic, severely interferes with natural hydrology of riparian areas, adversely affecting conditions needed to sustain protected fen and meadow communities. Additionally, the authors found that water chemistry strongly influenced occurrence of fen and meadow vegetation in riparian areas, the interface between the terrestrial ecosystem and the stream (Baattrup-Pedersen et al. 2011). Increased phosphorus levels leads to changes in the types of vegetation in riparian habitats: the probability of finding fen and meadow vegetation was reduced when total phosphorus concentration exceeded 40-50 $\mu g\ P\ L^{-1}$(Baattrup-Pedersen et al. 2011). These findings suggest that fens are negatively affected by physical and chemical changes in the ecosystem. Various types of anthropogenic disturbances, which likely affect both the Serpentine itself and its fen-marsh area, surround the Serpentine ecosystem.

The Serpentine ecosystem also consists of marshlands, defined as wetlands dominated by herbaceous plants adapted to saturated soil conditions (Figure 1.1; Mitsch and Gosselink 2007). Marshes are characterized by variable water levels because they receive drainage primarily from groundwater movement. Marshes have shallower peat layers than bogs and fens, and tend to be nutrient rich. Common marsh vegetation includes emergent soft-stemmed vegetation such as sedges, pickerelweed, cattails, arrowheads and buttonbush. It is important to classify the Serpentine wetland as Sphagnum dominated peat or sedge-dominated peat with some marshland, as this provides a useful baseline from which to consider the interactions the vegetation has with

water chemistry and other biota. Recognizing the main functions of the wetland aids in understanding the impact it has on the surrounding ecosystem.

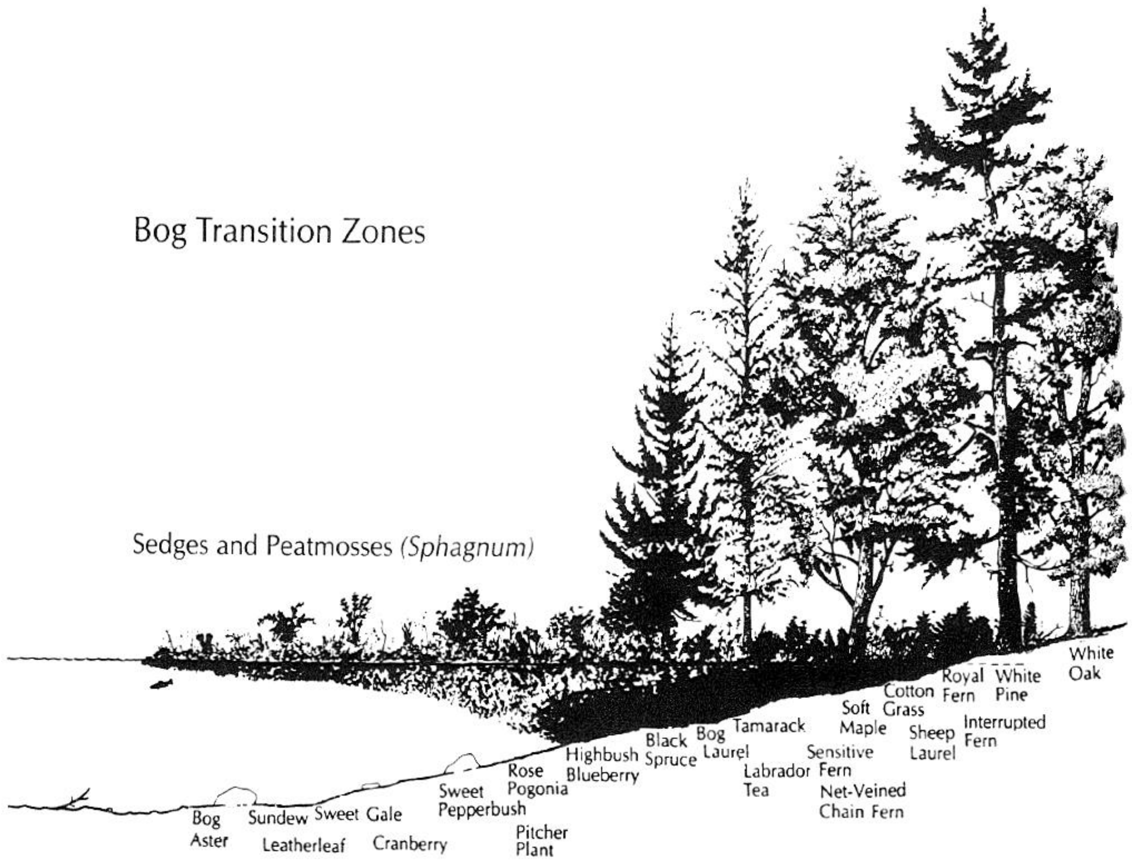

Figure 1.1. Bog vegetation bordering bodies of water in New England. Bog soils are nearly pure organic deposits beneath bog mats. (From Environmental Protection Agency, 1981, Region 1, New England Wetlands: Plant Identification and Protective Laws. Plants not drawn to scale.)

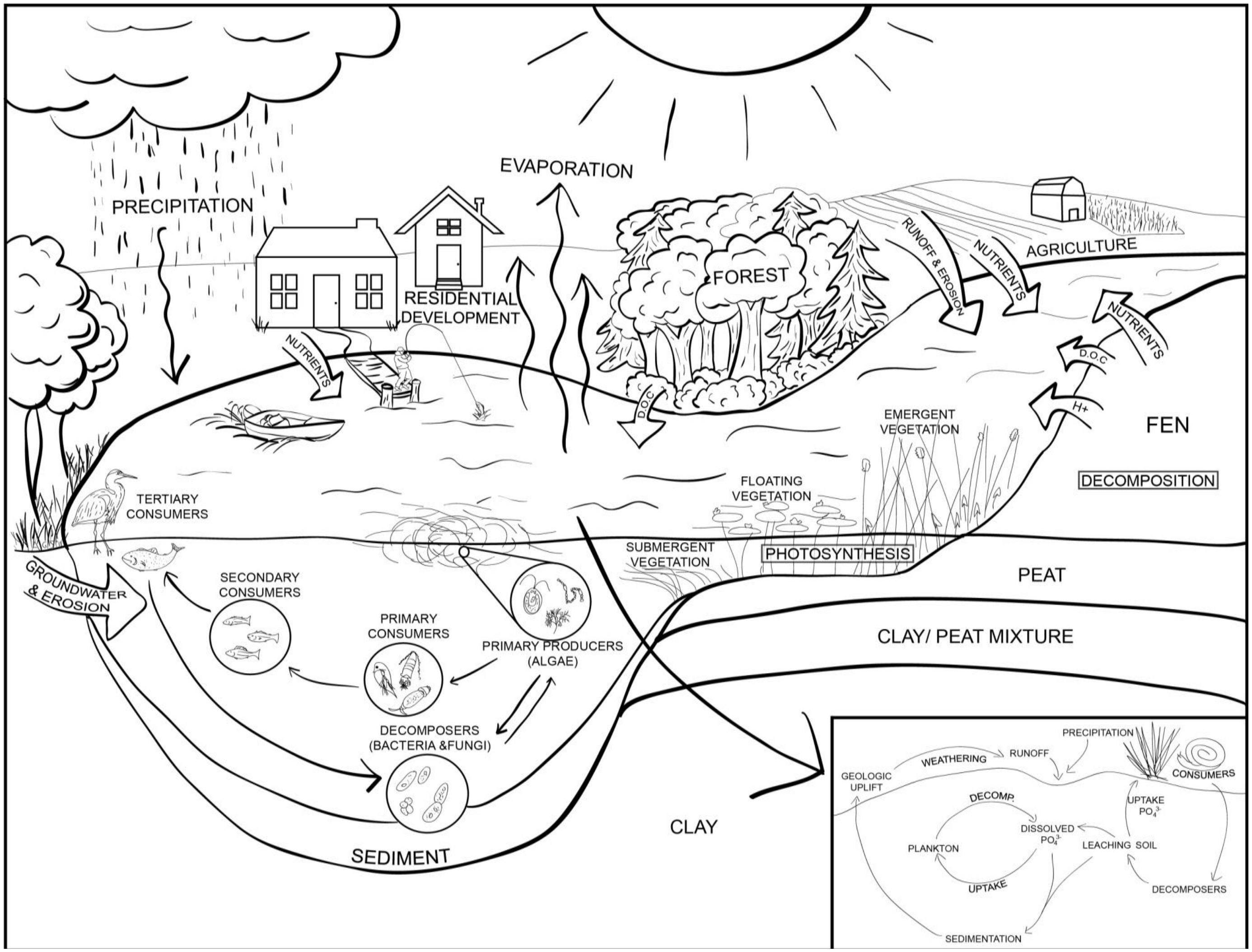

Figure 1.2. An illustration of the complexity of an aquatic system such as the Serpentine Stream. As can be seen from the diagram, these are multifaceted systems with many inputs and outputs, but also changes that happen within the system. Some factors that affect the system are nutrient cycles such as those of phosphorus, nitrogen and carbon; biotic interactions like predation and competition; weather events; decomposition; nutrient uptake; and runoff from agricultural and residential lands etc. The cycle in the lower left-hand corner is one example of a nutrient cycle: the phosphorus cycle. Overall, streams, like other aquatic systems, are greatly impacted by the surrounding environment. Illustrated by Autumn Smith.

Belgrade Lake System

Glacial Geology

From 25,000 years ago to 10,000 years ago, the Laurentide ice sheet covered almost all of Maine, depressing the continental crust with its weight (Marvinney and Thompson 1996). As a result, sea levels rose and covered areas that today well inland, so far that portions of the towns of Skowhegan and Millinokett would be submerged (USGS 2003). The glaciers gouged the earth, picking up debris of all sizes and carrying it, suspended in ice and melt water streams, to locations far from its origin (Marvinney and Thompson 1996).

Present-day Maine still bears the scars of glacial activity. As the glaciers melted, they dropped unsorted debris in place, leaving glacial till that comprises the majority of Maine's soil cover. Eskers developed in meltwater channels through the deposition of sand particles, and deltas formed where the glaciers met the ocean (Marvinney and Thompson 1996). Although the glaciers melted about 10,000 years ago, the flow channels and other geologic features they created remain, leaving behind freshwater systems like the Belgrade Lakes (Figure 1.3)

East Pond

East Pond is a lake in the towns of Smithfield and Oakland (Figure 1.4). It is the headwater of the Belgrade Lakes chain, which drains into the Messalonskee Stream system, covers 698 ha (1,725 acres or 7 km^2), and is shallow, with a mean depth of 5.5 m. The wide basin is oriented northwest to southeast and has a flushing rate of 0.25 flushes per year (Maine DEP 2010). The slow flow rate is due to the fact that East Pond has no aboveground input streams and receives input only from direct precipitation, groundwater, and runoff. East Pond is essentially a closed system, since it has only one output: the Serpentine stream. A slow flushing rate can indicate that a system processes nutrients slowly (MDEP 2010a). Due to the shallow depth and orientation that matches the prevailing winds, the lake is polymictic, meaning it experiences frequent mixing initiated by severe weather events, causing dissolved oxygen (DO) to remain constant at all depths (CEAT 2000). However, East Pond stratifies by temperature between mixing events (King, unpublished data). The towns of Smithfield and Oakland share East Pond's 1,123 ha (4.3 square mile) watershed (Table 1.1). East Pond is dammed at the outlet of the Serpentine into North Pond. The dam regulates water level by 12.0 in, but droughts can lower water levels below the dam, causing flow to stop (CEAT 2000).

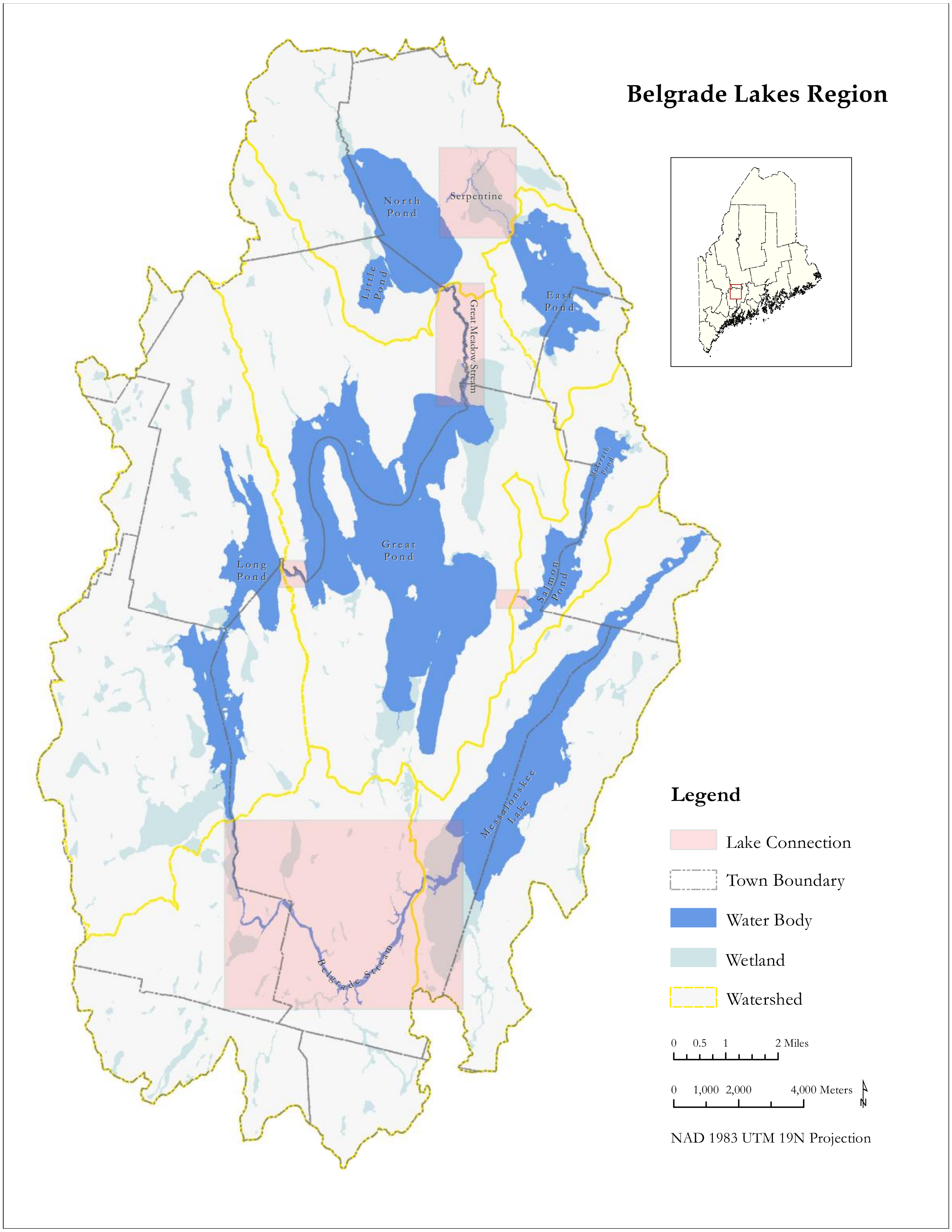

Figure 1.3. Belgrade Lakes region watershed with the linking ecosystems between lakes highlighted. The focus of our study included the Serpentine ecosystem connecting East Pond and North Pond.

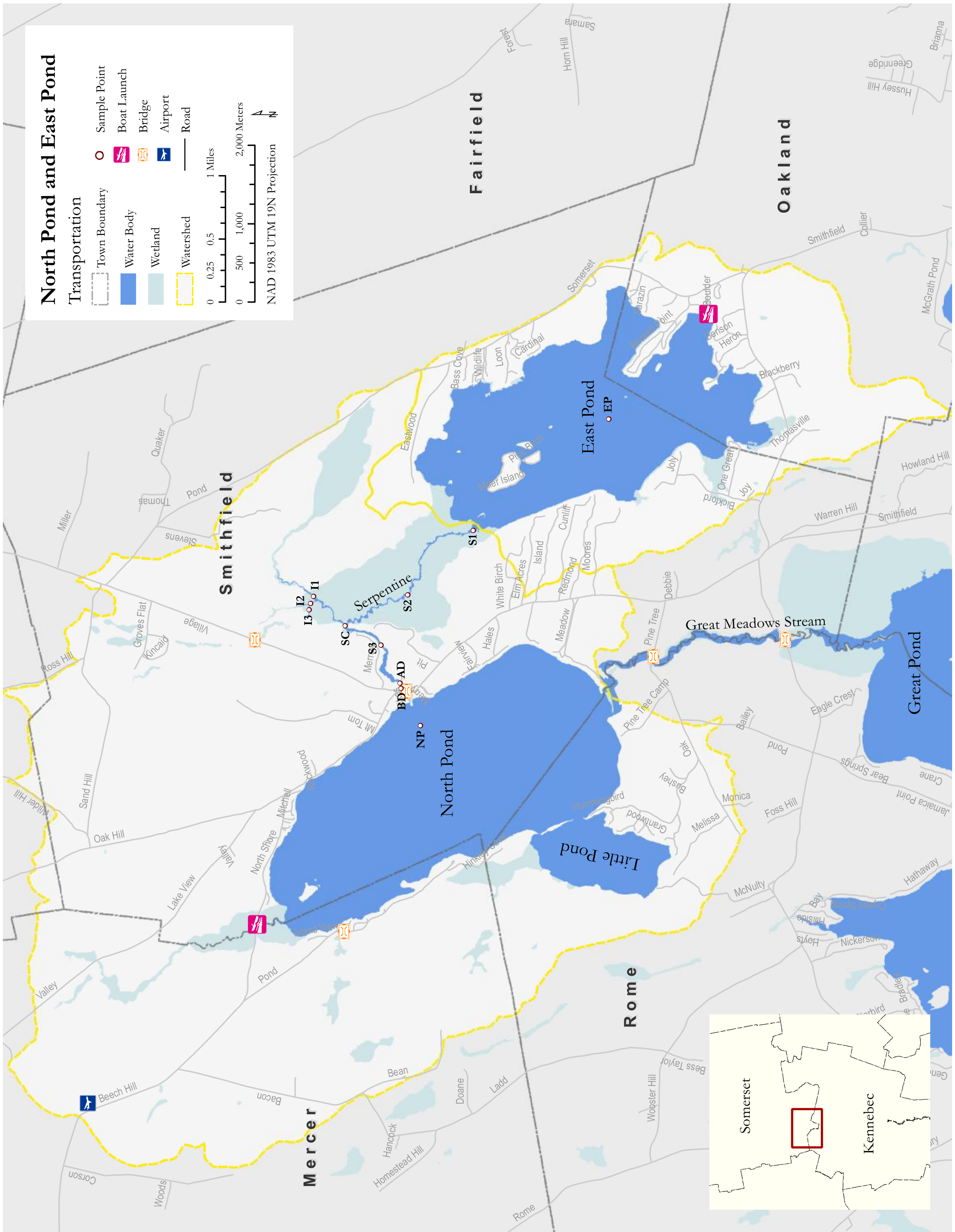

Figure 1.4. Transportation and political map of the East and North Pond watersheds. Sample sites are displayed with a two character designation (e.g., NP), which are more closely examined in Figure 1.10

Table 1.1. A comparison of the basic physical attributes of East and North Ponds.

Characteristics	**East Pond**	**North Pond**
Position in lake chain	1st	2nd
Area	698 ha	1,024 ha
Mean depth	5.5 m	4 m
Watershed size	1,123 ha	855 ha
Inputs	Groundwater, precipitation	Groundwater, stream, marsh, precipitation
Outputs	Serpentine Stream	Great Meadows Stream
Mixing	Polymictic	Polymictic
Flushing rate	0.25 per year	1per year

Historical Data

During the past 70 years, the East Pond watershed has experienced significant changes in land use. During and after World War II, many families abandoned small-scale farming. The forest regenerated, and in the 1960s, developers constructed roads and subdivided areas for residences (CEAT 2000).

Since the 1870s, Maine has been a popular vacation spot. Hotels and camps have been in the Belgrade Lakes region since 1900, with youth camps coming into vogue in the 1920s. Private vacation residences now dominate the valuable shoreline property and increasing property values continue to spur more subdivision and development. More people are converting structures into year-round residences, which can negatively affect water quality through increases in nutrient inputs due to prolonged habitat disturbance and land use changes when people are around more often. Additionally, heavier traffic increases runoff from roads (CEAT 2000).

The increase in development and other land-use changes in the East Pond watershed appear to correspond with higher phosphorus levels and more frequent algal blooms. High phosphorus concentrations in 1975 (~30 ppb) decreased for the next decade, perhaps coinciding with a decrease in watershed land use for agriculture (CEAT 2000). Since then, total phosphorus (TP) has hovered between 15 and 20 ppb (Figure 1.5). Chlorophyll A levels (a standard indicator of algal biomass) have also been changing in East Pond. Since 1975, levels of chlorophyll A show a generally increasing trend. Peaks probably indicate algal blooms, which have been more

frequent in the past decade. Algal blooms are most likely correlated with increased phosphorus inputs. Generally, algal biomass has increased in the past 30 years (Figure 1.6).

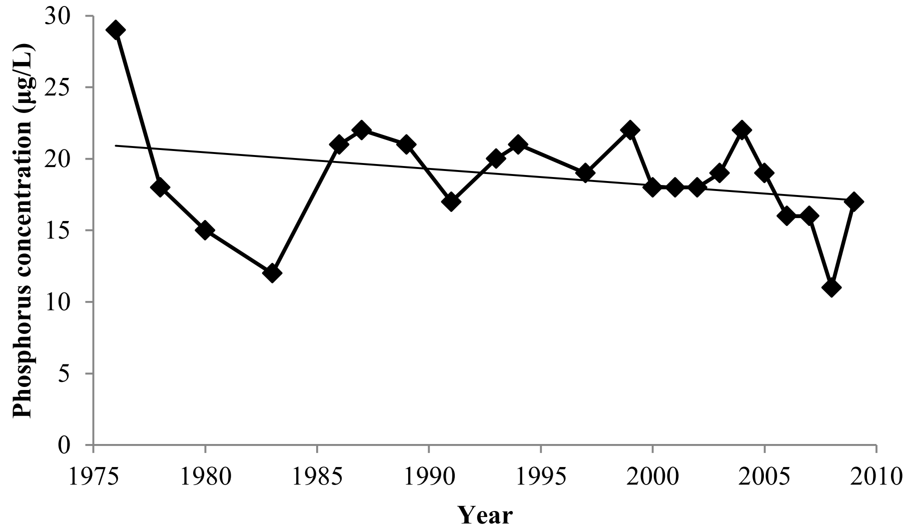

Figure 1.5. Phosphorus concentration (µg/L) in East Pond water from 1975 to 2010. Data from http://www.lakesofmaine.org/, collected through a collaboration of the Maine DEP, the Volunteer Lake Monitoring Program (VLMP), and the East Pond Association ($y = -0.1154x - 248.87$, $r^2 = 0.09969$).

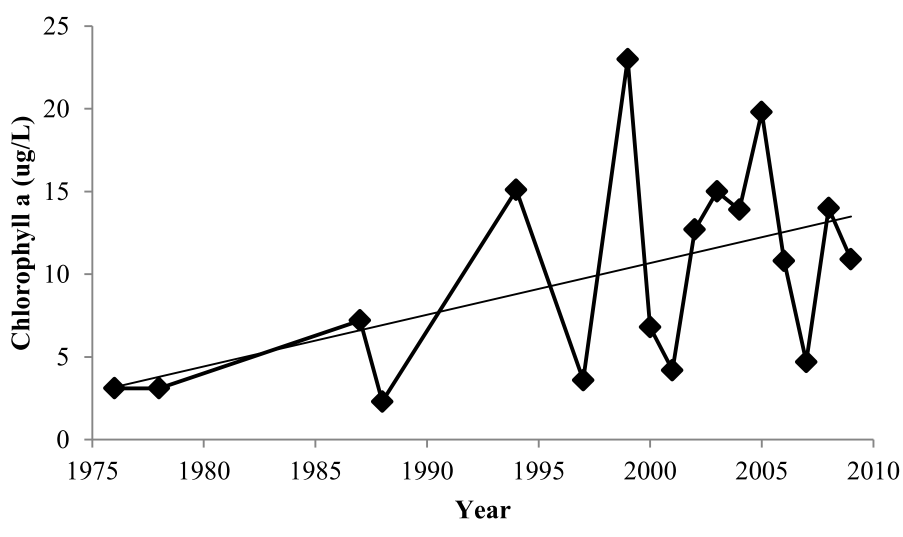

Figure 1.6. Chlorophyll a concentration (μ g/L) in East Pond water from 1975 to 2010. Data from http://www.lakesofmaine.org/, collected through a collaboration of the Maine DEP, the Volunteer Lake Monitoring Program (VLMP), and the East Pond Association ($y = 0.3128x - 651$, $r^2 = 0.25235$).

East Pond has a history of experiencing algal blooms that interfere with water quality and recreational activities. The first notable bloom since peak total phosphorus (TP) in the mid-1970s occurred in 1987. In the 1990s, volunteer water quality monitors noted significant blooms in 1991, 1993, 1995, 1998, and 1999 (CEAT 2000). East Pond also bloomed every year from 2002 to 2007 and in 2010 (MDEP 2011). Water quality fluctuates both seasonally and annually, but has declined over time and is now classified as impaired by the U.S. EPA, due to total phosphorus (MDEP 2001, EPA 2010).

Algal blooms may occur so frequently because of a net transport of phosphorus from the bottom sediments to the lake surface (Nesbada 2004). This process has two steps: (1) water-column stratification forms a thin, layer near the bottom of the pond with severely depleted oxygen levels (between 5 mg/L and 2.5 mg/L), which allows for phosphorus release from the sediments, and (2) winds shift from the southeast and move water towards the islands/boulders in the lake center. The water is deflected downward when it reaches the barriers and forms a vertical gyre that mixes the phosphorus-rich lens from the lake bottom, bringing the phosphorus to the water's surface and making it available for algae species. This phosphorus in the water column is taken up mainly by living organisms, including algae.

To combat the frequent algal blooms, the Maine Department of Environmental Protection (DEP) initiated an experimental biomanipulation project based on the trophic cascade hypothesis outlined by Carpenter et al. (1985). The trophic cascade hypothesis states that as piscivore biomass increases, planktivore biomass decreases, leading to increased zooplankton biomass, which will ultimately reduce algal biomass (Figure 1.7). However, instead of increasing piscivore biomass, the Maine DEP biomanipulation sought to decrease planktivore biomass. Since 2007, 40,570 White Perch have been removed (Halliwell and Evers 2008). White Perch eat zooplankton, which, in turn, should eat the algae causing blooms (MDEP 2005a). The experiment is not yet complete and results thus far have been mixed, as algal blooms continue to occur since the inception of the program (MDEP 2011). Additionally, in 1991 and 2000 the Colby College Environmental Assessment Team (CEAT) surveyed the lake and its watershed, finding that high total phosphorus (TP) from runoff contributed to algal blooms and water quality impairment.

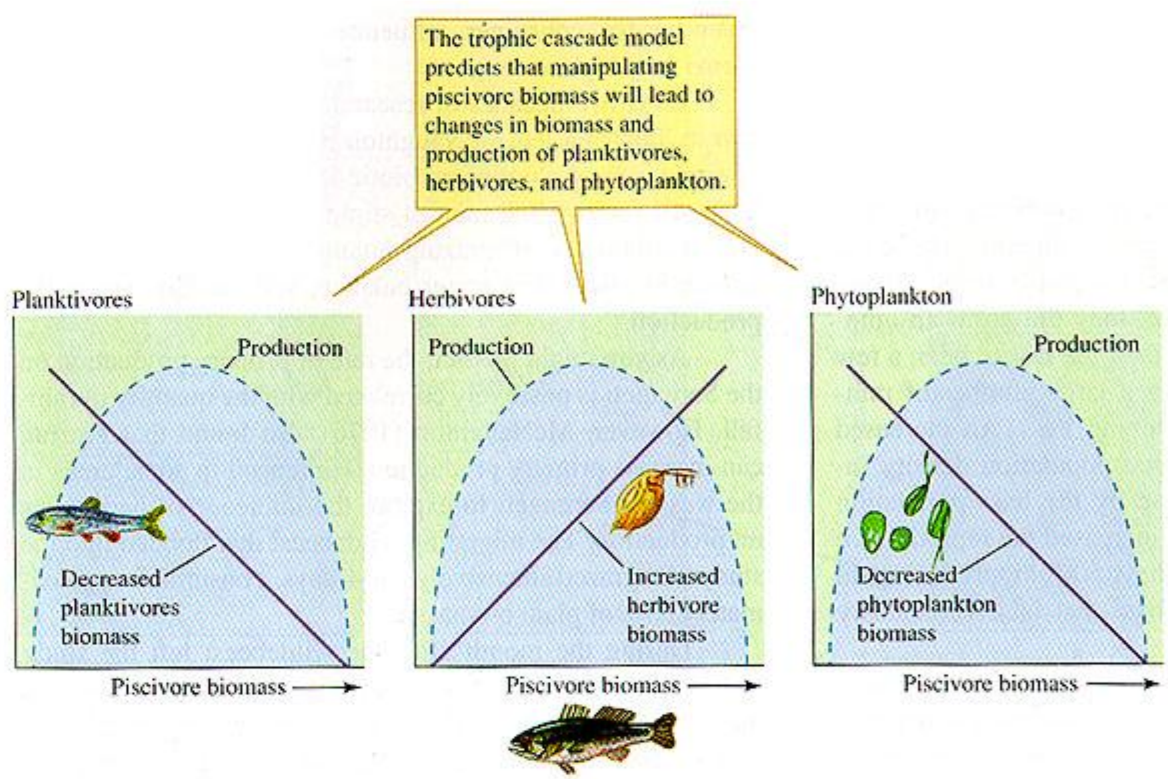

Figure 1.7. Trophic cascade hypothesis as proposed by Carpenter et al. (1985). In a simplified lake ecosystem, increasing piscivore biomass indirectly reduces algal (i.e., phytoplankton) biomass.

North Pond

Geological Characteristics

North Pond is a lake in Kennebec County, in the towns of Rome, Smithfield, and Mercer (Figure 1.2). Geographically, North Pond and East Pond share many characteristics. North Pond is the second highest lake in the Belgrade Lakes System, and water flows from East Pond into North. Both were formed during the last glacial period (CEAT 1997). In addition to the Serpentine, water inputs come from groundwater, streams, and marsh areas. Water progresses toward Great Pond though Great Meadows Stream at the southern end of North Pond.

North Pond is slightly larger than East Pond, with an area of 1,024 ha (2,531 acres) and a perimeter of 14.65 km (9.1 mi) (MDEP 2010a). It has a mean depth of 3.96 m and a maximum depth of 6.1 m (Table 1.1). The direct drainage area for North Pond is 855 ha (3.3 sq. mi.) and it flushes completely about once every year (MDEP 2010a). Both East Pond and North Pond are polymictic, and North Pond does not stratify seasonally (MDEP 2010a, King, unpublished data).

North Pond has a gradually sloping basin, reaching a maximum depth of over 6 m. Like East Pond, it is oriented from northwest to southeast. The prevailing winds blow from the northwest, building up as they follow the basin of the lake and the great amount of fetch causes frequent mixing events (CEAT 1997).

Historical Data

In the 1930s, only a few camps stood on the northern side of North Pond and only one existed on the southern side (CEAT 1997). Central Maine Power Company built the Coffin Dam at the outlet of the Serpentine in 1947 and the dam has regulated lake water levels ever since. Historically, activities on the shoreline and within the watershed have included agriculture, logging and sawmills, and residential development.

In 1997, CEAT studied North Pond and its watershed, and evaluated the potential contributors to lake eutrophication. North Pond is marginally eutrophic, but its water quality is not currently classified as impaired by the EPA (CEAT 1997, EPA 2010). It lacks a history of frequent algal blooms, but bloomed in 1998 and 2006 (MDEP 2011). Currently, the DEP classifies the water quality as “below average” (MDEP 2010b). TP has increased since 1980, from low to moderately high levels. Although data points are generally lacking, total phosphorus peaked in 2005 and remains around 15 ppb, which is similar to the levels in East Pond (Figure 1.8). Chlorophyll A has also increased slightly, though more data are needed to confirm this trend (Figure 1.9). North Pond and East Pond have similar TP levels; however, East Pond blooms more frequently.

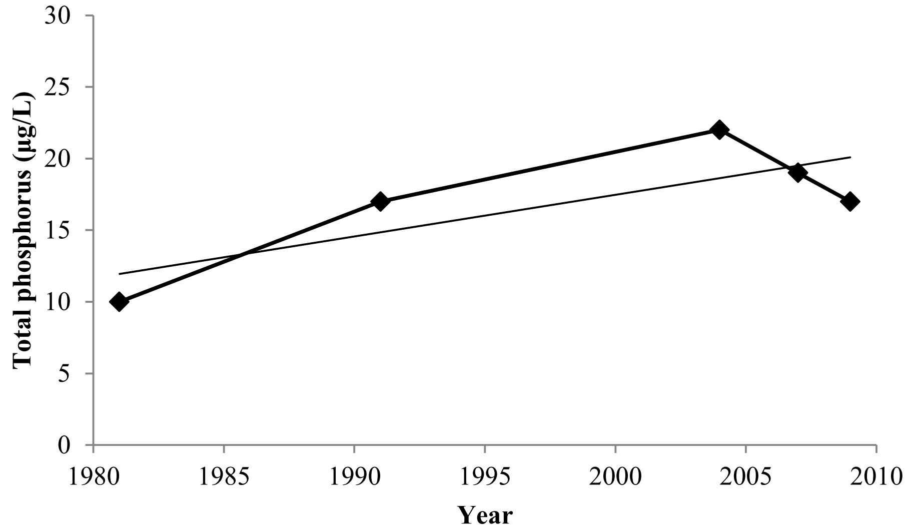

Figure 1.8. Phosphorus concentration (μ g/L) in North Pond water from 1980 to 2010. Data from http://www.lakesofmaine.org/**, collected through a collaboration of the Maine DEP and the Volunteer Lake Monitoring Program (VLMP) (y = 0.2903x – 563.2, r^2 = 0.62161).**

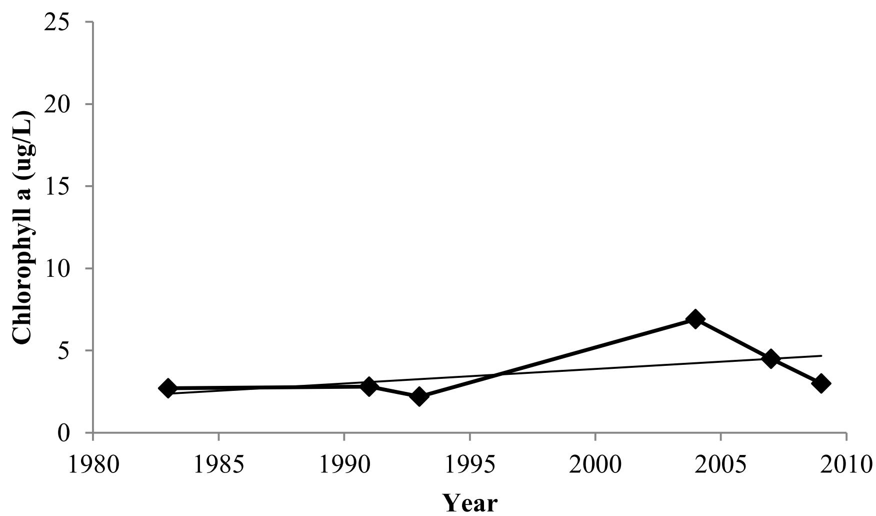

Figure 1.9. Chlorophyll a concentration (μ g/L) in North Pond water from 1980 to 2010. Data from http://ww.lakesofmaine.org/**, collected through a collaboration of the Maine DEP and the Volunteer Lake Monitoring Program (VLMP) (y = 0.0885x – 173.03, r^2 = 0.27222).**

Serpentine Stream

Geological Characteristics

The Serpentine Stream, shaped like an inverted 'Y', connects the northern end of East Pond to the eastern end of North Pond. At the northern vertex of the stream, water flowing north from East Pond merges with water flowing south from several tributary streams. The first half of the stream bisects a peat fen ecosystem, while the second is surrounded by densely wooded forest interspersed with residential development. The Serpentine has two main tributary streams, Sucker and Clark Brooks, which run through the northern portion of the marsh before entering the main Serpentine Stream. Sucker Brook passes though agricultural lands and beneath Maine State Highway 8, while Clark Brook runs through wooded and residential areas. These streams have been known to carry high nutrient loads during heavy rain events (CEAT 1991).

The Serpentine fen is 66.4 ha in area, underlain by organic soil, formed by millennia of peat growth (CEAT 1991). In 1991, the Colby Environmental Assessment Team surveyed the fen, dividing it up into three ecological communities. The western and eastern sections were classified as ombrotrophic (precipitation-fed) peatlands. This area makes up 63% of the wetland, experiences water flow, and consists of a bed of Sphagnum moss, with ericaceous shrubs and small trees growing from it (CEAT 1991). The central section was classified as a raised bog. It comprises 12% of the total 66.4 ha fen, is less permeable to water, and contains black spruce (*Picea mariana*) and Eastern larch (*Larix laricina)* (CEAT 1991). The northern area, where the tributaries enter, is a marsh. It makes up 25% of the wetland and the plant community includes cattails, sedges, rushes, and grasses, along with emergent and floating vegetation on the water's edge.

The Serpentine watershed comprises 1,628 ha in the town of Smithfield, ME (MDEP 2001). This watershed is slightly larger than that of East Pond.

Historical Data

In 1947, Central Maine Power Company built Coffin Dam at the outlet of the Serpentine into North Pond. The East Pond Association soon acquired the dam and has overseen it ever since (MDEP 2001). The East Pond Association regulates the water level in East Pond by 12.0 in, and is traditionally open from Labor Day to May 5th to prevent ice damage and allow spring runoff to escape.

The Serpentine stream can receive high phosphorus inputs from cleared land bordering tributaries, and the fen surrounding the main stream may contribute to or buffer those inputs (CEAT 2000). The Colby College Environmental Assessment Team (CEAT) studied the Serpentine as part of the 1991 and 2000 East Pond surveys. Backflows have historically been observed after heavy rains which could serve to wash phosphorus into East Pond (CEAT 1991). In their 2000 survey, CEAT estimated that over 2.5 inches of rainfall over 6 hours was necessary to initiate backflow. The same CEAT survey found that excessive nutrient loading of East Pond caused by Serpentine backflow was unlikely, because TP levels were not significantly different in the Serpentine and East Pond. The Serpentine seldom blooms far downstream from East Pond, and CEAT surmised that, due to the plants, the fen ecosystem usually acts as a nutrient sink (CEAT 2000).

As depicted in Figure 1.10, this study sampled data from 11 sites. The sites, go from East Pond to North Pond; their notations are as follows: one site in East Pond (EP), two sites between East Pond and the confluence of the Serpentine (S1 and S2, respectively), one site at the confluence (SC), three sites in the input streams that feed into the confluence (I1, I2 and I3), one site between the confluence and the dam (S3), one site above the dam near North Pond (AD), one site below the dam (BD) and one site in North Pond (NP).

Objectives

Spatial Analysis Objectives

- Display visually the physical parameters of our study area
- Quantify environmental factors that contribute to the ecosystem health and processes using Geographic Information System
- Model the dynamic environmental processes in a watershed scale

Water Chemistry Objectives

- Compare the concentrations of elements (Al, Ca, Fe, Mg, Mn, N and P) in the Serpentine and North and East Ponds
- Compare the concentrations of DO, DOC, pH and temperature
- Determine the impact of the input streams on the water chemistry of North Pond, East Pond, and the Serpentine

Figure 1.10. Sample site locations used in this study.

- Infer if the fen impacts water chemistry

Sediment Objectives

- Determine flow of the Serpentine
- Determine the nutrient composition of the sediments in the Serpentine
    - Study aluminum, iron, phosphorus, calcium, magnesium, and total organic carbon
    - Determine change throughout the Serpentine

Fish Objectives

- Understand which fish species are found in the Serpentine and which are dominant
- Understand how these relate to species found in East and North Ponds
- Understand how fish might affect trophic relationships in the Serpentine through diet analysis
- Understand how trophic relationships might be influencing algal blooms

- Compare habitat requirements for fish species from literature to collected water chemistry data
- Explore whether the Serpentine is playing a role in the ineffectiveness of the 2008 biomanipulation project in East Pond

Algae Objectives

- Establish a baseline for future studies of algal species found in the Serpentine, East, and North Ponds
- Target and record algae species that are bioindicators

Plants Objectives

- Discover what wetland plant species characterize the Serpentine
- Figure out influence of those species on the nutrients and vice versa
- Determine the composition of species change as you move away from open water
- Determine how the two sides of serpentine differ and what effect it has on the ecosystem
- Classify as poor fen/transitional bog, investigate composition as you move away from open water

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2. SPATIAL ANALYSIS

Overview and Introduction

A Geographic Information System (GIS) is a widely used and powerful analytical tool that integrates computer hardware and software to help us enhance our geographic understandings (Bolstad 2008). We can use GIS to collect, manage, analyze, model and display all forms of spatially referenced data and information. GIS allows for visualization, understanding, and interpretation of data in a variety of ways that reveal relationships, patterns, and trends through maps, charts, and reports (ESRI 2011). CEAT used ArcGIS 9.3 and 10 developed by ESRI to create maps and models to characterize, synthesize, and analyze data for our study.

Map Projections and Coordinate Systems

To transfer locations from the curved Earth surface onto a flat map surface, points need to be projected through systematic renderings, known as map projections (Bolstad 2008). There are different map projections used in GIS that serve specific mapping objectives and regions of interest. Map projections are constructed to preserve one or more properties of the Earth's surface (i.e., area, shape, or direction). Transverse Mercator is a commonly used projection that can be conceptualized as enveloping the earth in a horizontal cylinder and projecting the Earth's surface onto the cylinder, minimizing distortions near the line(s) of intersections. Choosing the right map projection is important for obtaining the correct measurement for the properties of interest.

A standard coordinate system based on the transverse Mercator projection is the Universal Transverse Mercator (UTM) coordinate system (Bolstad 2008). The most prevalent plane grid system used in GIS, the UTM is adopted for remote sensing, topographic map preparation, and natural resource databases. It is a global coordinate system and is widely used in the U.S. The UTM divides most of the earth into zones that are 6° wide in longitude; areas that are above 84° north latitude and below 80° south latitude are excluded. The zones are numbered from 1 to 60 in an easterly direction, starting at 180° west longitude. Zones are further divided into north and south of the equator. All maps for this project were made using NAD 1983 UTM 19N projections.

Data Models

Spatial data are a conceptualization of the real world phenomena or entities. There are two main conceptualizations used for digital spatial data: vector and raster data models (Bolstad 2008).

Vector data models use sets of coordinates and associated attribute data to represent discrete elements such as points, lines, or polygons. Frequently used for objects with well-defined shapes and boundaries, vector data allow users to calculate geometry, display and analyze respective attributes, and also represent continuous variations.

In contrast, raster data models describe the world with a set of square cells with associated values in a grid pattern. Raster data are most useful for continuous data and images like elevation and precipitation. They can also be used to represent discrete data, for example, land use type. However, complications may be implied for discrete features like points and lines with low image resolution. Raster data models are often used for multi-factor analysis.

Watershed studies often require geographically referenced data. GIS is a powerful tool that allows users to analyze and represent complex information. We created maps and models to visually display the physical parameters of our study area, to quantify environmental factors contributing to ecosystem health, and to simulate and model environmental processes.

Land Use

Introduction

Nutrient loading is largely the result of urban development and increased agricultural land use patterns (Carpenter et al. 1998). A landscape perspective is critical for acquiring a comprehensive understanding of stream ecosystem health. Degradation of the landscape by humans affects the biological diversity of streams along with its overall diversity. These disruptions are also linked to the larger stream system and its surrounding landscape (Alan 2004). Land adjacent to water bodies has a disproportionately high influence on lake health and eutrophication (Carpenter et al. 1998). Furthermore, riparian wetlands along larger rivers and lakes fill important roles in capturing sediments and nutrients flowing into water bodies and serving as buffers between the entire watershed and other water bodies (Mitch 1995). Wood removal during the development of lakeside residences has detrimental impacts on water bodies. Experimental removal of wood allowed sediment and organic matter export rates in the first year

of observation to exceed baseline natural erosion rates by several hundred percent (Naiman and Décamps 1997).

The Serpentine is unique because of its direct connection to East Pond and the Coffin Dam, which flows into North Pond (Figure 2.1). East Pond has a smaller area than North Pond but is deeper on average (Table 2.3).

Table 2.1. Size of entire watershed, East Pond, North Pond, and the serpentine. The volume (m^3) of East Pond and the Serpentine are also given.

	Size (m^2)	% Total	Volume
Watershed	74,931,000	1	-
East Pond	6,902,740	0.09	25,129,613
North Pond	9,027,960	0.12	*
Little Pond	1,183,230	0.02	*
Serpentine	123,509	0.002	152,274

* Bathymetric data was not available for North Pond, and a volume calculation could not be performed

The Serpentine, best described as a fen ecosystem, connects these two ponds. As a stream through a wetland, it holds a large quantity water near the surface that can be cycled by wind and currents. The Serpentine is large in land area (12.35 ha) and is characterized by a thick organic layer made up largely of peat and sphagnum moss, like a bog. However, unlike an ombrotrophic bog that receives only rainwater, the Serpentine's hydrology is complicated by the addition of groundwater sources, streams, and two connecting lakes. Hajek et al. (2006) indicated that there is a difference in plant species between less biologically productive fens and ombrotrophic bogs. Certain fen plants benefit from rather high ammonium and phosphate concentrations while other species serve as nutrient indicators due to their nitrogen use efficiency, with bog plants having the highest efficiencies (Aerts et al. 1999, Hajek et al. 2006). To understand how the low nutrient environment and the accumulating organic matter of the Serpentine can influence the surrounding region, we must quantify land use types.

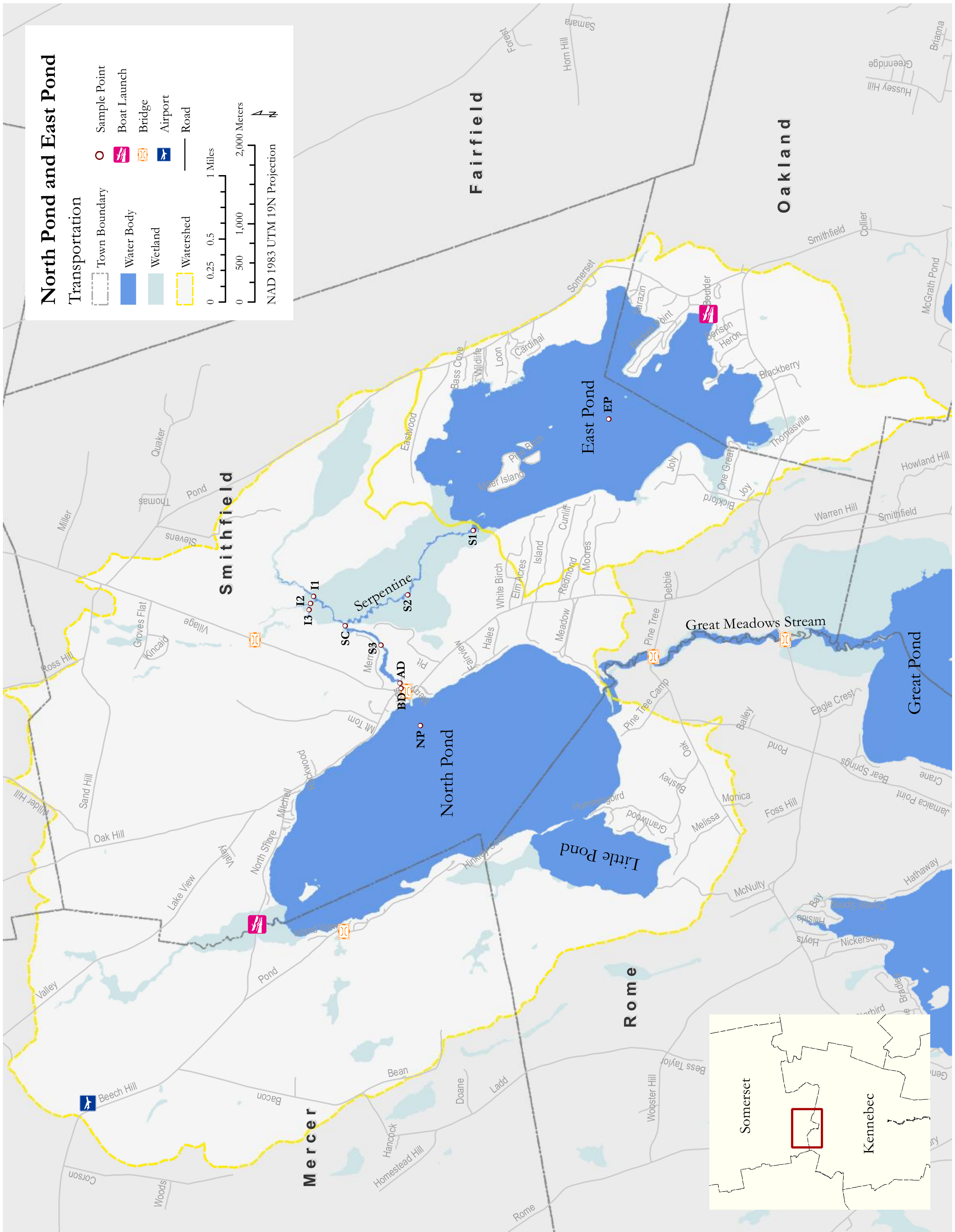

Figure 2.1. Transportation and political map of the East and North Pond watersheds. Our sample sites are displayed with a two character designation (e.g., NP).

Wetland ecology in our study area is heavily influenced by interface with larger bodies of water. These fringe wetlands at the periphery of large water bodies can serve to improve water quality and habitat while reducing nutrient input (Mitch 1995). Mwanuzi et al. (2002) conducted a study on Lake Victoria in Africa to examine the buffering capacity of connected wetlands, specifically their ability to absorb nutrients, sediments and pollutants. Lake Victoria has also been under siege from human development, and this pressure could be mitigated by a proportionally larger wetland and increase in buffering capacity. The parameters used to explain the characteristics of nutrient flow within the wetland systems in the study's erosion model included vegetation type and distance from water body, the latter of which implies a connection to wetland size. The Serpentine is large in comparison to East Pond, thus its interactions are likely similar to those between Lake Victoria and its wetlands.

The effects of adjacent land-use on wetland sediment and water quality can extend over thousands of meters (Houlahan and Findlay 2004). High water quality in wetlands therefore requires not only a narrow buffer zone between wetlands and land use, but also a heterogeneous landscape of forest and wetlands to reduce surficial inputs that could lead to eutrophication. Houlahan and Findlay (2004) observed statistically significant bivariate relationships between water and sediment nutrient concentrations and many land-use variables, including forest cover, road density, building density, and proportion wetland. Notably, all nutrients except NO_3 showed a negative correlation with forest cover, reinforcing the importance of extensive riparian zone vegetation. This information along with information from the Maine Department of Environmental Protection (MEDEP) regarding waterfront development was used as the framework for the land use analysis.

The buffer zone extending one hundred feet from the shore onto land is highly regulated by Maine state law. Maine's Mandatory Shoreland Zoning Act (MSZA) applies to the shoreline zone which includes land within 250 ft of the normal high water line of any natural pond over 10 acres or 75 ft of a stream. It states that structures built within 100 feet of a water body prior to the 1989 zoning laws cannot be expanded by more than 30%. Additionally, septic systems must be set back at least 100 feet from perennial water bodies. This ensures that the negative contribution of septic systems to lake nutrients is minimized. MSZA also requires that within any 10-year period, the 100 ft buffer zone adjacent to a pond or connected rivers remains 60% uncleared in volume and openings in the forest canopy do not exceed 250 ft^2. Additionally, any vegetation

less than 3 ft may not be cut, except for winding paths whose widths do not exceed 6 ft. These measures ensure that additional residential development is unlikely to be a major contributor of nutrients in lake systems.

Due to construction restrictions near wetland ecosystems, the Serpentine has little streamside residential development. However, it is directly connected to East Pond, which is highly developed. Yet, the contributions of other inputs cannot be ignored, as East Pond is not the only inlet to the Serpentine. Groundwater sources aside, two of the largest inputs to the Serpentine are the pair of feeder streams to the north. These streams are adjacent to farmland, wetlands, and forested land. Each of these land uses has a different ability to contribute nutrients to the lake system. Our analysis of land use within a specific zone adjacent to the perennial water bodies quantifies land use by type within this critical zone.

Our analysis of land use varies slightly from previous CEAT reports in that it is less focused on land use changes over time and more focused on land use change between ecosystems (CEAT 2009, 2010). It is valuable when working with historical trends to have many land use classes to compare over time. Many of these divisions are superfluous as they have the same ecosystem function. Therefore, land use classification with seven consolidated classes is appropriate for characterizing the effectiveness of each type of nutrients that could be contributed to the specific water body (Table 2.2).

Table 2.2. Original land use classifications (McCollough 2010) that are now nested within the new consolidated and reclassified land use types

Reclassified Land Use Type	Original land use classifications
Agriculture	Cropland/Farm, Orchards
Forest	Coniferous forests, Deciduous forests, Mixed forests, Transitional forests, Tree farms, Logging areas, Reverting lands or Regenerating land.
Commercial/Road	Commercial/Municipal, Dirt Roads, Paved Roads, State Road
Open Land	Golf Courses, Open Fields, Parks, and Cemeteries
Wetland	Wetland
Residential	Non-shoreline residential, Shoreline residential, and Streamside residential
Barren land	Bare ground, Cleared land, and Gravel pits

Barren land is characterized by having little to no living vegetation present and is a strong contributor to runoff and surface flow. Open land is similar to barren land because it lacks vertical growth in vegetation and consists almost entirely of ground cover like grass, which is often mowed, reducing runoff abatement potential. The high prevalence of fertilizer application and a weak ability to abate runoff flow renders open land and manicured lawns strong contributors to non-point source pollution (King et al. 2007). Residential land use types contain building development along with planted and natural vegetation. As a whole, residential land use is a primary contributor to lake nutrient loading due to its lake adjacency and potential for fertilizer application and selective vegetative clearing.

Commercial and road land use type is characterized by a highly developed land use with high levels of impenetrable surfaces with a strong potential for runoff. It was important to differentiate agriculture from other land uses because traditional farming practices grow monoculture crops with heavy fertilizer applications along with irrigation, which can disproportionately affect nutrient loading. In Vermont, Meals (1996) showed that phosphorus was 1500% higher than controls when it was winter spread, indicating farmland’s strong contributing potential. Farmland characterizes landscapes that are homogeneous in terms of their vegetation and are highly modified. They support a low diversity of vegetation and as a result, have a minimal ability to abate surface water flow. Finally, forested lands comprise the greatest land area within the watershed (61.1%). Ultimately, each land use classification and its original subdivisions have similar amounts of vertical vegetation stratification. Increased stratification along with a developed canopy layer is critical in dissipating rain droplets as they fall to the ground and reducing surface runoff and erosion, primary agents of nutrient transport (MEDEP).

Bathymetric maps are the topographic maps of the inland water bodies and the marine environment. They are particularly useful for identification of underwater features and dangers during navigation. Furthermore, and with increasing pertinence to our study, a bathymetric map will allow us to calculate lake volume. Lake volume is an important attribute to consider when comparing inland water systems as Anthony and Hayes (1964) showed that for 150 North American lakes, fish productivity could be directly related to mean depth and surface area.

Methods

Bathymetry and Thermometric Maps

A 16 ft bass boat was equipped with a GPS sensor and water thermometer interfaced with a Lowrance© LCX-27C Sonar/GPS Chartplotter Combo. Thermometric and bathymetric data for the Serpentine were collected on 19-September 2011. Data were imported using Lowrance Sonar Viewer 2.1.2 and exported as useable X,Y coordinate data for import into ArcGIS. These points were used to display the bathymetric and thermometric data as a continuous surface using the kriging method of spatial interpolation (ESRI 2009).

Volume was calculated using the raster image of the bathymetry for East Pond and the Serpentine. North pond bathymetry was not available. To calculate a discrete volume, depth values for each raster cell were summed for both water bodies separately using the Zonal Statistics as Table tool in ArcGIS and resulting value was multiplied by the area of the raster cells.

Land Use Categorization and Types

To characterize the 100-ft wide buffer zone on East Pond, North Pond, and the Serpentine, a digital buffer was created in ArcGIS and overlaid on existing land use information. Using the extent of buffer zone, the original land use classifications were separated from the entire land use. The area of land use in square meters was calculated for each polygon within the buffer and summarized based on its percent composition of the buffer by land use. This excluded any water that may have overlapped the buffer zone (Table 2.3).

Existing land use was reclassified into seven land use categories, each comprised of several land use types created during the initial classification (McCullough 2010, Table 2.2). Land uses were grouped based on the similarity of vegetation and development between each of the classes.

Results

Residential development within the 100-foot buffer zone between East (40%) and North (39%) Pond is remarkably similar (Figure 2.2).

Table 2.3. Land area (m^2) by land use types within the 100-foot buffer in East Pond, North Pond, and the Serpentine, including its feeder streams.

Land Use Type	East Pond	North Pond	Serpentine and feeder streams
Agriculture	0	15,028	3,268
Barrenland	0	903	0
Commercial/Road	7,895	14,463	657
Forest	234,057	298,840	89,869
Openland	1	1,097	0
Residential	216,938	252,847	21,906
Wetland	83,530	59,351	185,120

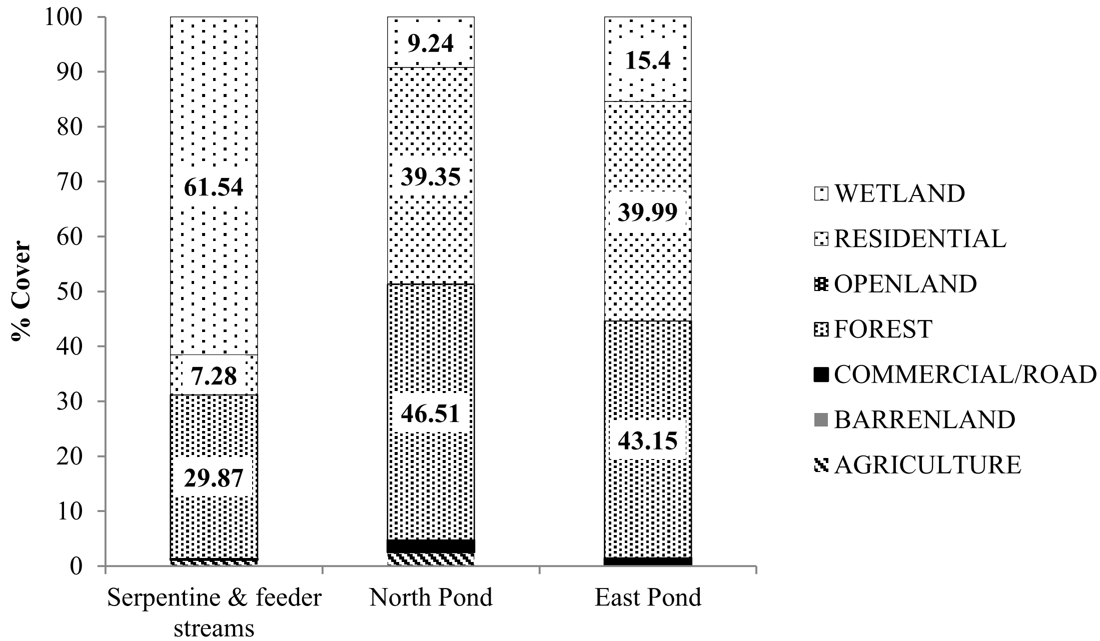

Figure 2.2. The percent cover of seven land use types by water body within the 100 ft buffer.

East Pond and North Pond also have similar levels of forested land, 43.15% and 46.51% respectively, within the buffer. Not surprisingly, the Serpentine has a higher percentage of wetland buffer (61.54%) and development along the Serpentine is comparatively low (7.28%) in relation to its connecting ponds. Agricultural land use was apparent in North Pond's buffer and watershed, and was also within the buffer zone of the Serpentine, because North Pond's watershed includes the Serpentine.

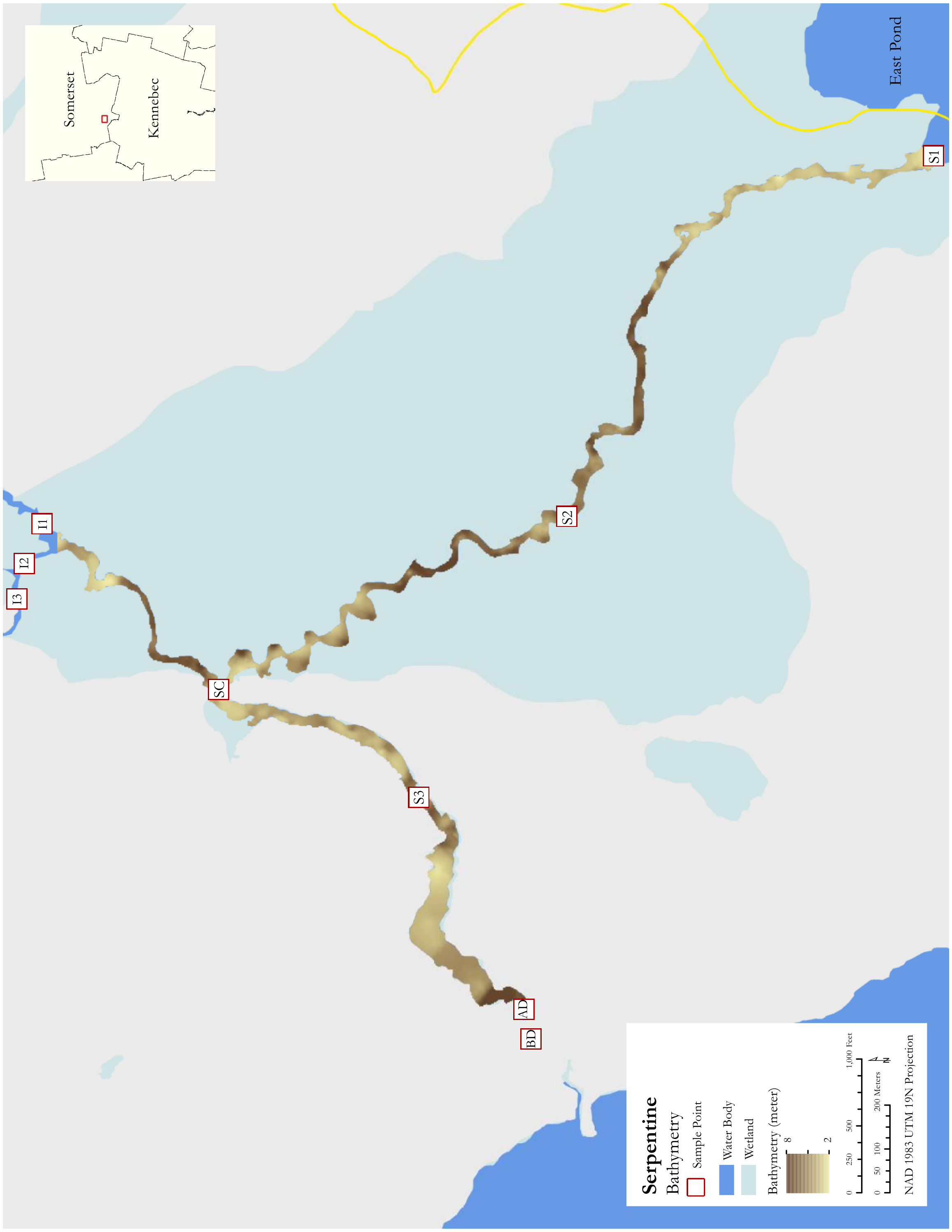

Figure 2.3. Bathymetry map of the Serpentine based on a kriging interpolation in ArcGIS 10 of over 3,000 data points. Depth was recorded on September 19, 2011 with the Lowrance© LCX-27C Sonar/GPS Chartplotter Combo and projected as a color gradient.

Using the bathymetry data, the volume of the Serpentine was calculated as about 150,000 cubic meters, roughly an order of magnitude smaller than East Pond. The bathymetry map displays the depth change moving from East Pond into the Serpentine (Figure 2.3).

For most of the first third of the passage from East Pond into the Serpentine (to site S2), the depth hovers around one foot. Depth subsequently increases, indicating the higher volume of water that is held in the middle of the Serpentine. The thermometric data also displays a decrease in water temperature while traveling from East Pond into the Serpentine (Figure 2.4).

It must be noted that these data are limited to one sampling date and therefore are subject to seasonal changes. Data collected throughout the year could be used to compare the temperature dynamics of the Serpentine to those of East Pond, or to other large water bodies that are more closely documented.

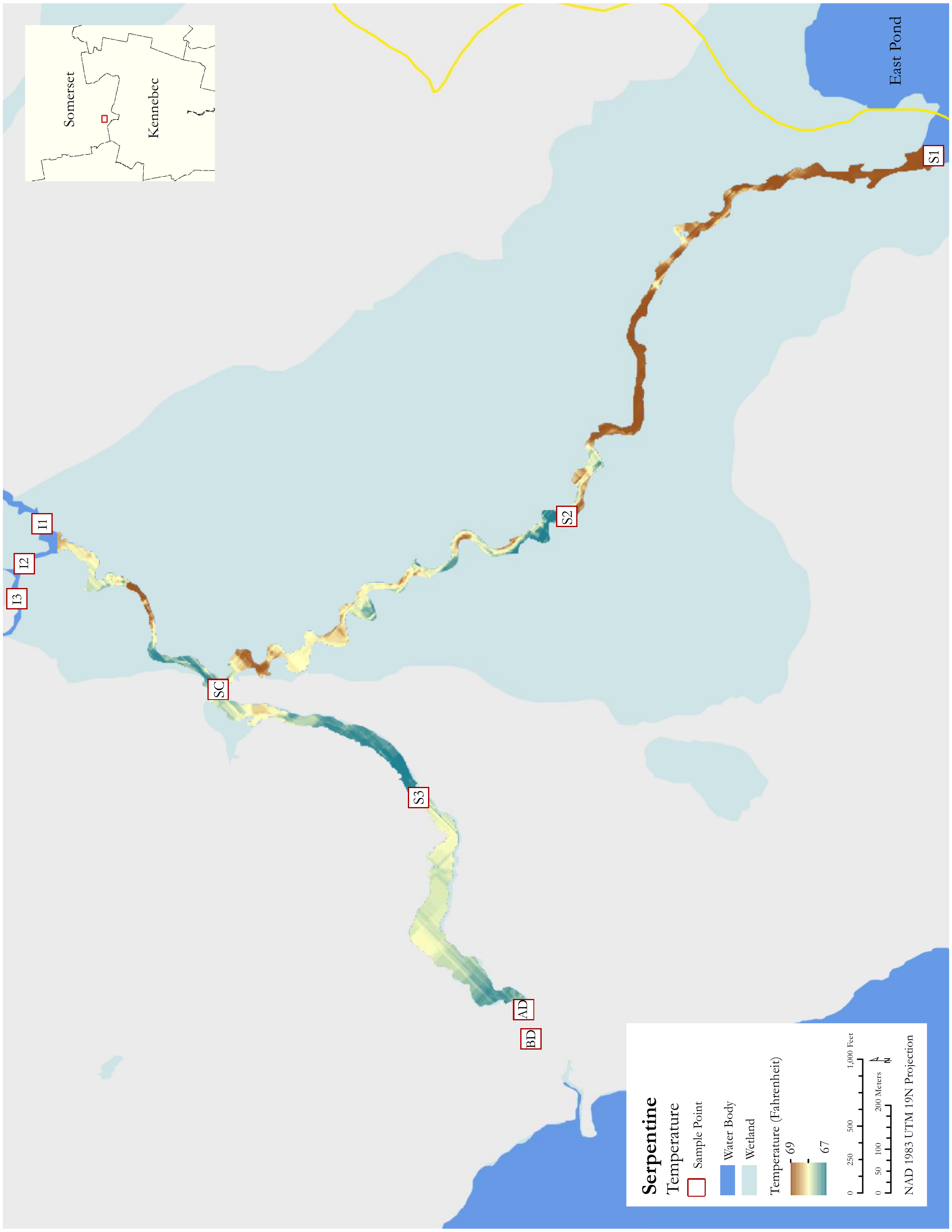

Figure 2.4. Thermometric gradient along the Serpentine based on a kriging interpolation in ArcGIS 10 of over 3,000 data points. Temperature was recorded on September 19, 2011 with the Lowrance© LCX-27C Sonar/GPS Chartplotter Combo and projected as a color gradient.

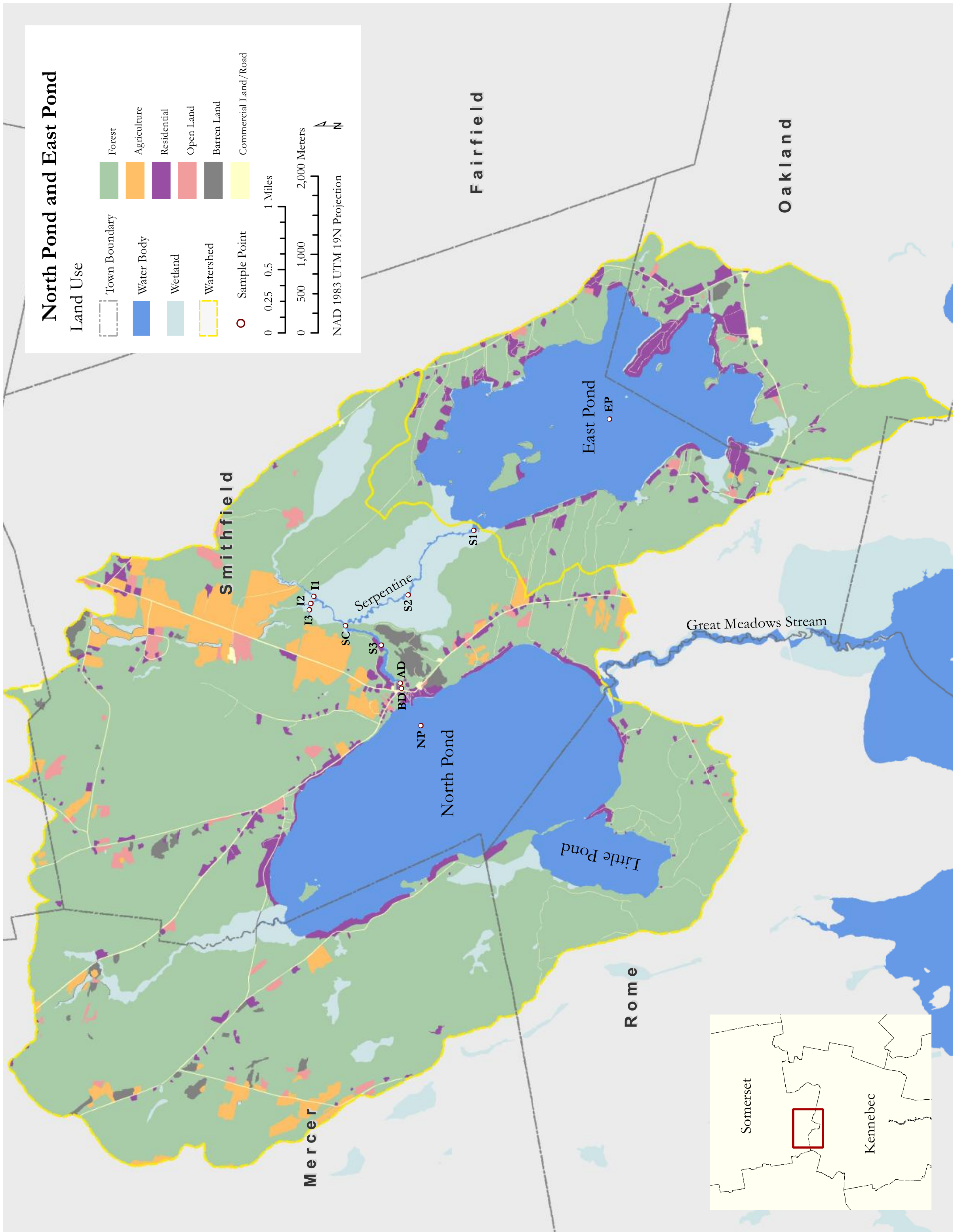

Figure 2.5. Land use within the East and North Pond watersheds. Land use designations were determined using a previously established classification scheme. Aerial imagery used in this classification was obtained from publicly accessible NAIP (National Agriculture Imagery Program) satellite imagery.

Discussion

Bathymetry and Thermometric Information

Before the dam was installed, the deeper section in the middle of the Serpentine (Figure 2.3) may have been filled with water year round while the shallower section close to East Pond would have acted as a natural dam when water levels were low. However, we do not have any local evidence to support this. The decrease in water temperature moving from East Pond into the Serpentine may indicate a lack of stratification and some stagnation of the water, which would allow it to warm. This temperature gradient influences species composition and distribution (see Table 6.1). Temperature also has an influence on oxygen consumption rates (higher in warmer water). Therefore those areas that are less shaded will have greater consumption rates. Increased organic matter and the consumption of dissolved oxygen will ultimately lead to greater stress on stream biota (Sand-Jensen and Pedersen 2005). Groundwater sources cool water bodies locally and therefore will reduce oxygen consumption rates. A more complete survey of this ecosystem would include temperature sampling multiple times throughout the year to compare it with pond data already gathered (CEAT 1991) and to monitor potential groundwater inputs along the Serpentine.

Land Use

The similarity between the ponds within each of their buffer zones, with respect to the amount of residential development, is surprising. It suggests that shoreline development on East Pond is not the major contributor to phosphorus loading, and thus does not lead to algal blooms in East Pond, the differentiation in trophic status between North and East Pond nor the differentiation in trophic status between East and North Pond. A previous study in 1991 by CEAT on East Pond did not categorize land use within a specific area. When comparing land use over entire watershed areas, East Pond included a substantially greater residential development than North Pond while North Pond included a larger area of agricultural development than East Pond (Table 2.4).

Table 2.4. Land area (m^2) of various land use types within the East and North Pond watersheds.

	North and East Pond	Percent total	East Pond	Percent total	North Pond	Percent total
Agriculture	2,807,218	3.7%	11,888	0.1%	2,795,328	4.9%
Barren Land	657,423	0.9%	58,555	0.3%	598,868	1.1%
Commercial/Road	909,601	1.2%	278,122	1.5%	631,480	1.1%
Open Land	860,031	1.2%	93,095	0.5%	766,937	1.4%
Residential	2,557,563	3.4%	1,289,266	7.2%	1,268,297	2.2%
Wetland	4,045,063	5.4%	360,697	2.0%	3,684,365	6.5%

*Forest land area dominated both watersheds and was ignored in this table

To best understand the land use discrepancies within the watersheds of East and North Pond, it is helpful to conceptualize the size of the watersheds (see Figure 2.5). East Pond's watershed is considerably smaller than that of North Pond. With this in mind, the greater productivity in East Pond compared to North Pond may be attributed to a greater level of residential development as a percent total watershed in East Pond. This suggests that greater development within the entire watershed is, in addition to the size of buffer zone, an important indicator of lake health. Land use types other than residential have potential to contribute negatively to the health of East and North Ponds. Agricultural lands were also examined in the context of the watershed context.

Farmland represents a small land area within the watershed (Table 2.4, Figure 2.5). When examining our study area, the proportion of total land use occupied by farmland was greater in the less eutrophic North Pond watershed. The larger forested area within the watershed of North Pond may explain this if the forest rate is able to slow and absorb surface nutrient flow. With the knowledge that farmland has the potential to facilitate considerably greater surface flow rates and that much of the farmland is adjacent to the feeder stream near sampling point I1, we suggest that nutrients are being added from this agricultural land. Peterjohn and Correll (1984) showed that groundwater sources of phosphorus are a small flux compared to surface transport, especially in agricultural and urban areas, further confirming our focus on the importance of surface water flow. Not surprisingly, the calculated phosphorus retention by the riparian forest was 80% (Peterjohn and Correll 1984). This value is twice as high as the retention by the cropland and slightly lower than the calculated total nitrogen retention for the riparian zone. With greater rainfall, landscapes comprised of agricultural areas characterized by a homogeneous

land cover and crop fertilization will contribute a considerable portion of nutrients into perennial water bodies.

Ever since the dam's construction in 1947, there have been many opportunities to change the hydrology and nutrient cycling of the Serpentine and East Pond watershed. Freeman et al. (2007) suggest that suspended particulates like silica from clay could result in cumulative and detrimental impacts on a hydrologic scale by restricting the ability of downstream diatoms to uptake CO_2. This system-wide flow widens the scope that must be studied to understand any number of ecosystem processes. A lake system's connections within its landscape have implications for periodic nutrient cycling, and both wetland and lake ecosystem health.

It must be recognized that while the size of our buffer zone was chosen based on the tight control of the land within 100 feet of perennial water bodies, the effectiveness of this buffer zone can change yearly due to precipitation variability and non-point phosphorus loading. Ubiquitous urban development contributes to decreased water quality. Extensive land conversion to urban use patterns in the future is expected to negatively impact water quality. The buffering capacity of the riparian zone is a critical determinant of P levels and water quality, and provides a strong incentive to characterize land use adjacent to lake and river systems in this study.

Erosion Modeling

Introduction

Soil erosion is the transportation of soil and organic matter away from its original location as a result of energy transmitted from rainfall, wind and overland flow (Pimentel et al. 1995, Merritt et al. 2003, CEAT 2008). Raindrops hit exposed soil and launch soil particles into the air; wind can transport airborne soil particulates long distances (Pimentel et al. 1995). Soil detachment is also influenced by overland flow when the shear stress to the soil surface exceeds the cohesive strength of the soil (Merritt et al. 2003). Detached soil can carry large amounts of nutrients and chemicals (from the application of fertilizers and pesticides) to water bodies, which can often lead to pollution and health problems (Pimentel et al. 1995).

Important factors influencing the potential of erosion include rainfall, slope, land use type, and soil type. The intensity and amount of rainfall affects soil erosion as it contributes to the overall runoff and disturbs the soil surface. Erosion increases dramatically on steep land; steeper slopes allow water to gain more speed and erosive energy with a greater gravitational

pull thus washing down soil faster and in larger particles (Pimentel et al. 1995, CEAT 2008). Land use type also contributes to erosion potential in relation to vegetation cover. Living and dead plants can reduce soil erosion and water runoff by capturing and dissipating raindrops and wind, while increasing soil stability with their roots (Pimentel et al. 1995). In contrast, activities such as construction and farming, which disturb land and expose soil, decrease soil stability. Barren land loses soil at a higher rate than that of land covered with vegetation (Pimentel et al. 1995 and Merritt et al. 2003).

Soil type is another important factor that affects erosion potential. Both the texture and structure of soil influence its susceptibility to erosion (Pimentel et al. 1995). Large particles are more resistant to transportation because they require more energy to move; very fine particles are also resistant because have great cohesiveness (Morgan 2005). Silts or sands are easily eroded as they are not as cohesive as clay and are small enough to facilitate transport. Organic matter in the soil presents varying levels of erodibility as some material increases soil stability while others decreases aggregate strength (Morgan 2005).

Different locations of erosion in a watershed result in variable impacts on the wetland system. Erosion that occurs near the lakes or the streams has a greater impact on the water than erosion that occurs far away, as sediment travels from further away is more likely to be absorbed or deposited before reaching the water body (CEAT 2008). In addition, erosion that takes place near overland flow paths poses a greater influence on the receiving water than that which occurs away from the paths (CEAT 2008, USDA 2010).

Based on the above factors, we developed a model for erosion potential and erosion impact of the East Pond and North Pond watersheds.

Methods

Erosion Potential

An erosion potential model was developed to indicate the level of risk for erosion in the watershed. The model was created by combining soil type, slope, and land use layers, according to their respective erosion potential ratings on a scale from 0 to 10, with 0 being the lowest and 10 being the highest potential of erosion. Rainfall was considered to be similar across the whole region.

Soils

Soil data for the East Pond and North Pond watersheds were downloaded from the Soil Data Mart managed by the Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The soil survey database associated with the spatial soil map is a complicated database with more than 50 tables. We used Soil Data Viewer, an extension tool to ArcMap developed by NRCS, to access soil interpretations and soil properties.

Soil erosion potential is indicated by the K factor (USDA 2010). The K factor is an empirical factor that represents the combination of detachability of the soil, runoff potential, and the transportability of the eroded sediment. The main properties affecting K factor include soil texture (i.e. the amount of very fine sand, silt, and clay percentage, organic matter), structure, and runoff potential as related to permeability in the soil profile. A higher K factor indicates higher erosion potential.

The study area consists of two survey locations: Somerset County, Maine, Southern Part (ME602) and Kennebec County, Maine (ME011). Due to survey discrepancies, soil property data for the two units showed considerable differences across the border between the survey areas (Appendix A.1). K factor information is missing for approximately 70% of the two watersheds, all of which lie in the ME602 survey area. The existing K factor data for our study area ranged from 0.02 to 0.49. For the missing data areas CEAT prepared three K factor scenarios: assigning the lowest K factor value of 0.02 (LOW), the median K factor value of 0.24 (MID), and the highest K factor value of 0.49 (HIGH). These three K factor scenarios were used to create three erosion potential models, indicating the lowest, mid, and highest erosion potential in the area.

The K factor values for the grid cells were converted to an erosion potential rating on a scale from 0 to 10, with a rating of 0 associated with the smallest K factor value and a rating of 10 associated with the largest K factor value.

Slope

Slope data were generated from the digital elevation model (DEM) in a 10x10 m grid format from the Maine Office of GIS (MEGIS). The slope values in East Pond and North Pond watersheds ranged from 0 to 35.5°. As noted, erosion increases as slope becomes steeper. Therefore, the slope values for the grid cells were converted to an erosion potential rating on a

scale from 0 to 10, with a rating of 0 associating with the flat ground and a rating of 10 associating with the steepest slope in the watersheds.

Land Use

Ian McCoullough (2010) prepared the land use types for the study area. According to the different impact of land use type on soil stability as discussed in the introduction, each of the land use type was assigned an erosion potential value (Table 2.5, CEAT 2008, CEAT 2010).

Table 2.5. Erosion potential ratings assigned to the land use types in the East Pond and North Pond watershed, with 0 being low and 9 being high erosion potential.

Land Use Type	Erosion Potential Rating
Wetland/Water body	0
Mature Forest	1
Commercial/Road	2
Regenerating/Reverting Land	3
Open Land	6
Barren Land	7
Agriculture	8
Residential	9

Wetlands and waterbodies were assigned an erosion potential value of zero because they are generally sediment sinks, where plants help capture and slow sediment transport (Morgan 2005). Mature forests, including coniferous, deciduous, and mixed, were rated 1, because root systems helps hold soil in place while the canopy shields soil from raindrop impacts of raindrops. Commercial land and roads are paved and impervious and thus are not easily eroded or disturbed. These land use types were given a low rating of 2. Regenerating land and reverting forests, although covered by vegetation, have yet to develop substantial root systems and dense vegetation and therefore were given a higher rating of 3. Open land, including golf courses, fields, parks, and cemeteries, was given a relatively high rating of 6, because of the presence of exposed paths. Although clear land is similar to open land, it rated 7 due to its reduced soil stability from recent disturbances. Agricultural land is comprised of croplands, farms, and orchards and was assigned a rating of 8. Farming and livestock grazing disturbs the soil and limited vegetation is present to protect the soil from weathering. The highest rating, 9, was given to residential land, as residential areas are often maintained and cleared, which increases the

disturbance to soil. In addition, limited vegetation cover, exposed land, and driveways increase potential of erosion.

Weighted Overlay

The erosion potential ratings of soil type, slope, and land use type were integrated using a weighted overlay (Figure 2.6). Soil type is the most important factor in erosion potential, so it was weighted at 40% (Morgan 2005). Slope and land use type were each given 30% weight respectively in the model. Three erosion potential models were created using the LOW, MID, and HIGH K factor scenarios.

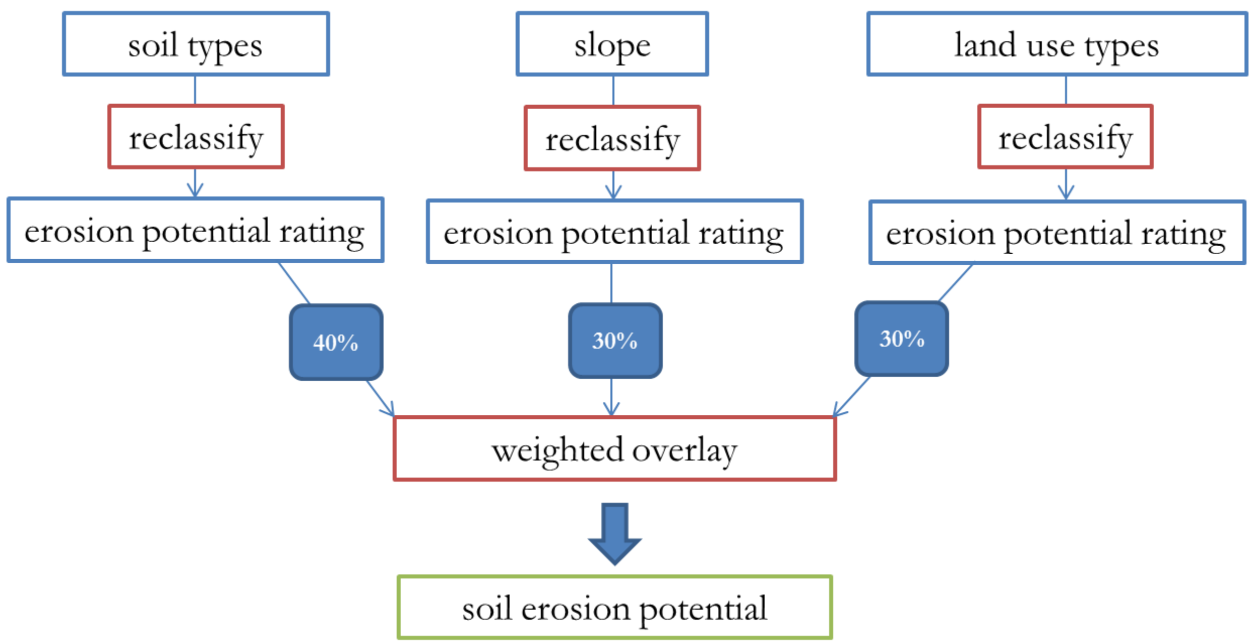

Figure 2.6. Generalized components, processes, and relative weights used in the erosion potential model built for the North Pond and East Pond watersheds.

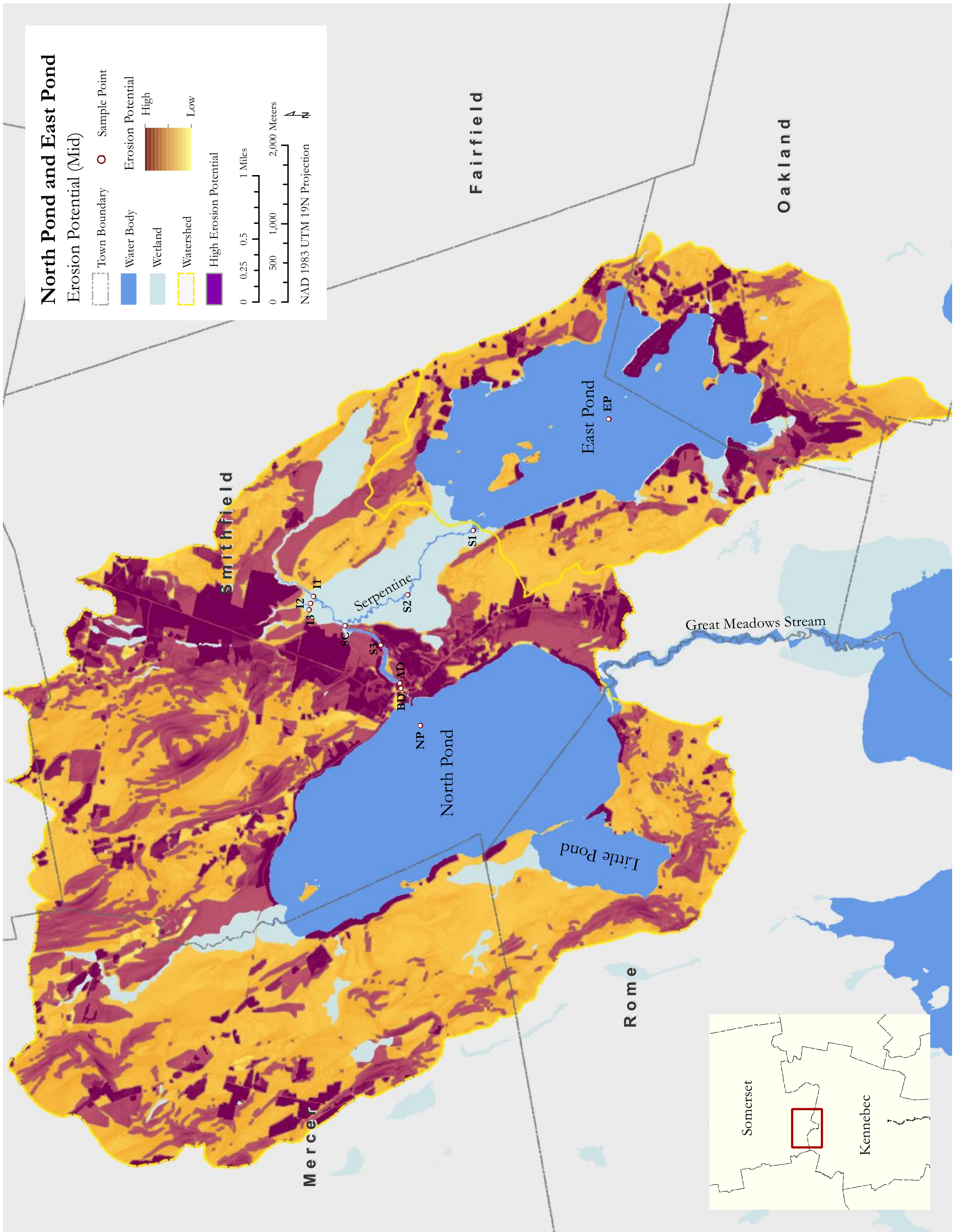

Figure 2.7. Erosion potential model to the extent of the East Pond and North Pond watersheds. This model is a weighted function of slope , soil type, and land use types within the watershed using the medium K factor (K factor = 0.24 for missing data) scenario. High erosion potential zones are presented.

High Erosion Potential Zone

The high erosion potential zones were generated to visualize areas with significantly elevated erosion potential. The grid cells of the two watersheds were divided into three classes using the quantile method. The top one-third tier was then smoothed using the focal mean method to generate the high erosion potential zones. Zones were created for all three models.

Erosion Impact

The erosion impact model was created by combining the soil erosion potential model, lake proximity, and flow route proximity, according to their respective erosion impact ratings on a scale from 0 to 10, with 0 being the lowest and 10 being the highest impact of erosion.

Erosion Potential

The erosion potential model was created to show different levels of erosion risk. This model corresponds to the erosion impact directly, and was built into the erosion impact model without further alteration.

Lake Proximity

The location of potential erosion was taken into consideration as we evaluated its impact on the wetland system. Land within 60 m (about 200 ft) from waterbodies was given the highest erosion impact rating of 10. The ratings for areas lying outside the 60 m buffer decreased by 0.167 for every 100 m. The outer edges of the watersheds received the lowest ratings (CEAT 2008, CEAT 2010).

Flow Route Proximity

Overland flow path is the route taken by surface water as it concentrates and flows overland downhill following the path of least resistance towards the stormwater network, streams or the coast (USDA 2010). The overland flow routes were generated using the Terrain Analysis Using Digital Elevation Model (TAUDEM). It is a suite of DEM extension tools to ArcMap for the extraction and analysis of hydrologic information from topography as represented by a DEM (Tarboton 2009).

Land within 60 m (about 200 ft) from the flow routes was given the erosion impact rating of 6, as sediment entering the flow paths has a higher likelihood of entering the wetland system. However, because are still possibilities that the sediment will be captured or settle out before reaching the aquatic system, so the area was not given the highest rating. The rating for area that lies outside the 60 m was 0, since the area was accounted for the lake proximity parameter.

Weighted Overlay

The erosion impact ratings of erosion potential, lake proximity, and flow route proximity were integrated using a weighted overlay (Figure 2.8). Based on previous CEAT studies in the region, erosion potential was rated most heavily at 50% (CEAT 2008, CEAT 2010). Lake proximity was given 40% weight. Overland flow path proximity was given 10% weight due to the high possibility of sediment being trapped or settling out and the empirical nature of the generated flow path routes based on DEM. Three erosion impact models were created using the three erosion potential models created with the LOW, MID, and HIGH K factor scenarios respectively.

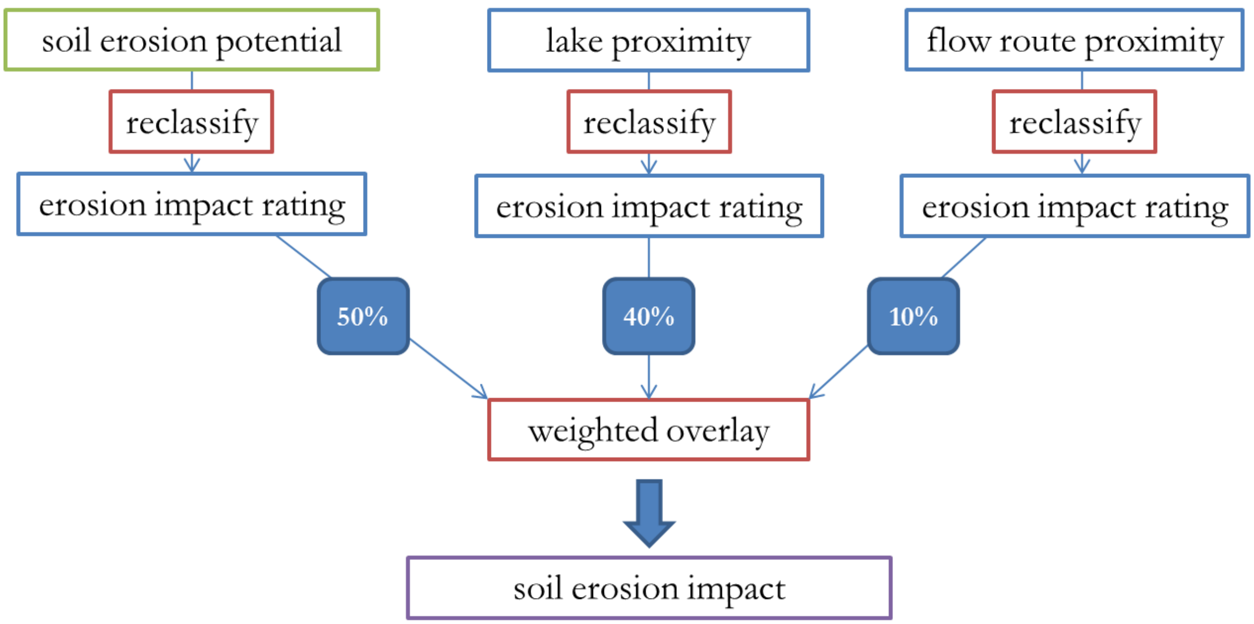

Figure 2.8. Generalized components, processes, and relative weights used in the erosion impact model built for the North Pond and East Pond watersheds.

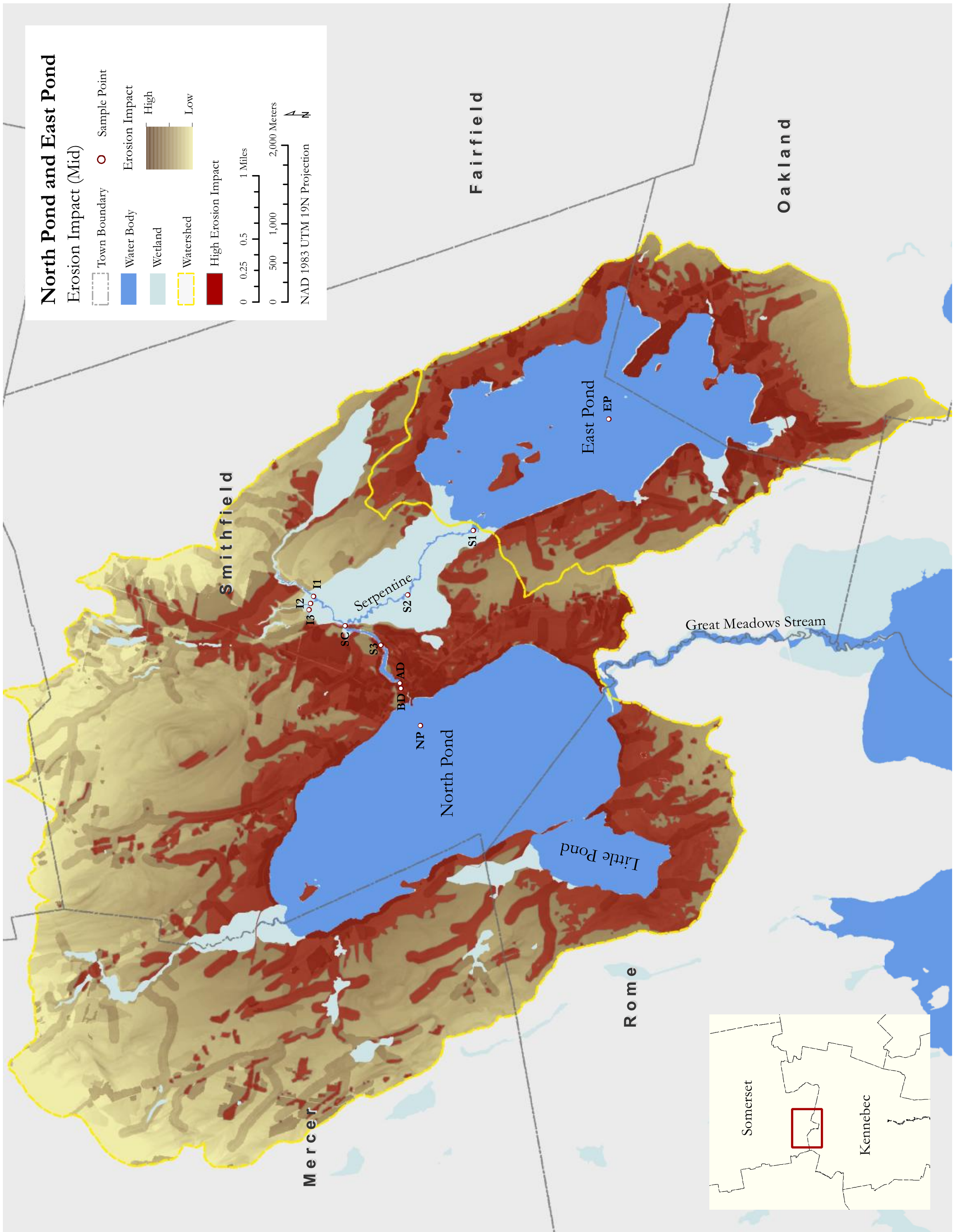

Figure 2.9. Erosion impact model of the East Pond, North Pond and Serpentine watersheds based on a weighted combination of the soil erosion potential model, lake proximity, and flow route proximity using the medium K factor scenario (K factor = 0.24 for missing data). High erosion impact zones are presented.

High Erosion Impact Zone

The high erosion impact zones were generated to visualize area with the highest erosion impact. The grid cells of the two watersheds were divided into three classes using the quantile method. The top one-third tier was then smoothed using the focal mean method to generate the high erosion impact zones. The zones were created for all three models.

Erosion Results and Discussion

Three erosion potential maps and three erosion impact maps were created to present erosion information in the North Pond and East Pond watersheds, which include the lowest, mid, and highest erosion potential. When applying the LOW K factor scenario, erosion potential and impact is the lowest in the North Pond watershed; when using the HIGH K factor scenario, erosion potential and impact in North Pond watershed are the highest. Additionally, the high erosion potential and impact zones are shifted towards the North Pond watershed.

The erosion potential map (Figure 2.7) displays the combined weighted erosion potential ratings of the soil K factor (MID scenario), slope, and land use in the North Pond and East Pond watersheds. Areas with darker color indicate higher erosion potential while areas with lighter color indicate lower erosion potential. The high erosion potential zone is displayed with transparency to show the original erosion potential. A comparison of results from the three models is summarized in Table 2.6. Erosion potential maps for LOW and HIGH scenarios are in the appendix.

Table 2.6. High erosion potential area as percent of the East Pond and North Pond watersheds according to the high, medium, and low K factor scenario.

	East Pond	North Pond
High	23%	39%
Mid	25%	36%
Low	35%	29%
Mean	27%	35%

The erosion impact map (Figure 2.9) displays the combined weighted erosion impact ratings of the erosion potential (MID scenario K factor), lake proximity, and flow route

proximity in the North Pond and East Pond watersheds. Areas with darker color indicate higher erosion impact with while areas with lighter color indicate lower erosion impact. The high erosion impact zone is displayed with transparency to show the original erosion impact. Comparison of results from the three models is summarized in Table 2.7. Erosion impact maps for LOW and HIGH scenarios can be found in the appendix.

Table 2.7. High erosion impact area as percent of the East Pond and North Pond watershed according to the high, medium, and low K factor scenario.

	East Pond	North Pond
High	39%	29%
Mid	41%	28%
Low	38%	27%
Mean	39%	28%

There is higher erosion potential in the North Pond watershed, as 35% of the watershed on average indicates high erosion potential, compared to that of the East Pond watershed, where 27% of the watershed shows high erosion potential. In comparison, erosion impact is greater in the East Pond watershed with 39% of the watershed indicating high erosion impact. In the North Pond watershed, 28% of the watershed shows high erosion impact. The increased impact mostly stems from the relatively small size of the East Pond watershed, since locations are inherently close to the water body.

There are high erosion potential zones concentrated between the two major water bodies (Figure 2.7), where the Serpentine is located. The overland flow direction, generated using TAUDEM, shows that sediment from high erosion potential zones around East Pond and North Pond is most likely to be transported toward its adjacent water body (Figure 2.10). Areas with land use types like agriculture, residential, barren land, and cleared land showed particularly high erosion potential around the Serpentine.

Future studies on the erosion potential and impact are needed to develop more refined models. Special efforts should be made to incorporate more complete data sets, develop models with other potential factors, e.g., seasonality and rainfall difference, and improve factor parameterization and ratings.

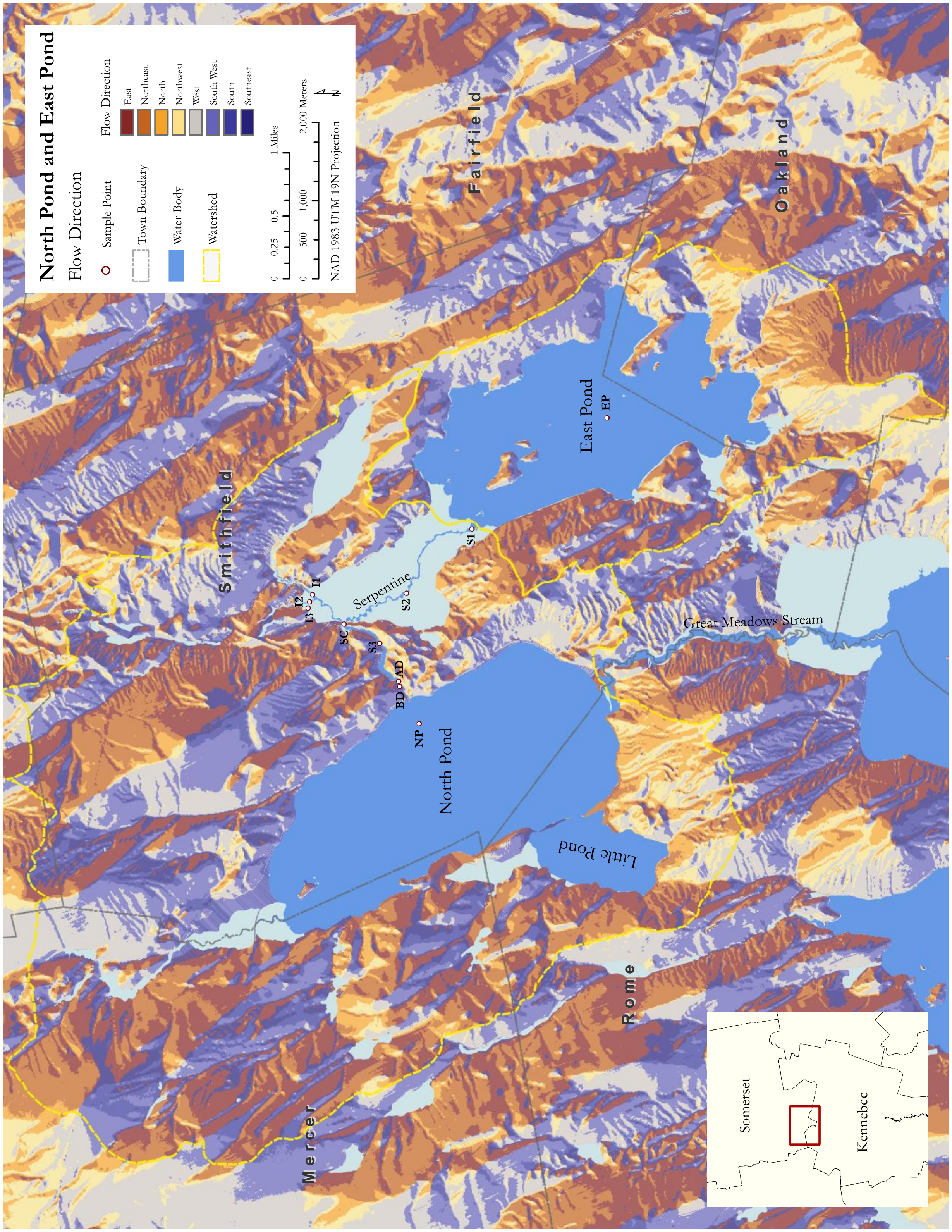

Figure 2.10. Flow direction generated using TAUDEM in East Pond, North Pond and Serpentine watersheds.

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3. WATER CHEMISTRY

Introduction

Earth's freshwater ecosystems are currently threatened by anthropogenic inputs that can degrade water quality (Carpenter et al. 2011). Monitoring water chemistry gives researchers information about the ecological health of a watershed, which inputs threaten the watershed, and how close the watershed is to certain threshold limits. Understanding anthropogenic inputs and their potential environmental and human health impacts is especially important when looking at water bodies that have been significantly affected by human development, such as East Pond, North Pond, and the Serpentine. Anthropogenic inputs can include heavy metals, radioactive wastes, industrial wastes, and agricultural runoff. These waste products can produce low quality water with bad taste, odor, turbidity, or toxicity that impacts the quality of life of homeowners and aquatic organisms (Carpenter et al. 2011). Anthropogenic inputs can also lead to cultural eutrophication where elevated nutrient levels in the water column cause algal biomass to increase, degrading the quality of the water (Havens et al. 1996). Water chemistry can also give researchers a better idea of how nutrient cycling occurs in an ecosystem. Understanding nutrient cycling and the interactions between an aquatic and the terrestrial ecosystem around it is important in determining the what sorts of life can live in an ecosystem and can give a broad understanding of how an ecosystem functions.

Phosphorus and Nitrogen

Phosphorus (P) is a limiting nutrient in aquatic ecosystems. Humans have greatly altered the global phosphorus cycle through mining, use of fertilizers, use of animal feeds, and a variety of other products (Bennett et al. 2001). P typically enters a water body through external loading primarily due to anthropogenic sources, namely as agricultural runoff from fertilizer. (Bennet et al. 2011). Substantial mobilization of external inputs has been found to occur following significant precipitation or erosion events (Bennett et al. 2001). P can also be present in the water column from internal loading from sediments (Sondergaard et al. 2002). Understanding the roles of these sources is important when considering implications for management. In lakes where external loading has been reduced, improvements in lake quality may still be hindered due to substantial internal loading (Sondergaard et al. 2002). The extent of the internal loading can be influenced by season, and certain characteristics of the sediment, particularly the abundance of

redox-sensitive compounds in the sediment (Sondergaard et al. 2002). When found in excess concentrations, P contributes to eutrophication, leading to algal blooms, contaminated drinking water, depletion of oxygen, fish kills, and the creation of dead zones (Carpenter 2008).

Nitrogen (N) is a limiting nutrient in aquatic ecosystems. During the past few centuries, humans have greatly altered the nitrogen cycle, increasing the mobility and availability of nitrogen globally (Galloway and Cowling 2002). It can be present in many forms, including nitrate. Nitrates primarily enter into aquatic ecosystems through sewage from treatment plants or personal septic systems. Nitrates can also be introduced as runoff from fertilizers and cattle feedlots. When nitrate concentrations are high, they contribute to eutrophication of lakes and streams (McIsaac et al. 2001). High nitrate levels are toxic to some freshwater organisms including many invertebrates, fish, and amphibians (Camargo et al. 2005). Nitrates are toxic as they convert oxygen-carrying biomolecules, such as hemoglobin, to forms incapable of carrying oxygen (Scott and Crunkilton 2000). This can also have implications for humans living near the lake or stream. Ingestion of nitrates can cause methemoglobinemia in infants by inhibiting the ability of hemoglobin to take up oxygen (Sandstedt 1990).

Although when present in excess both N and P can greatly threaten water quality, these nutrients are essential for plant growth. Their significance in an ecosystem is described by the molar ratio of N to P. The calculated ratio can be compared to the Redfield ratio, which has an N:P ratio of 16:1, as an indicator of nutrient limitation. Higher ratios are found in ecosystems where P is limiting, whereas lower ratios are found in ecosystems where N is limiting (Koerselman and Meuleman 1996). P is typically the limiting nutrient in freshwater ecosystems (Elser et al. 2000). This ratio impacts the types of organisms that live in an ecosystem. In particular the ratio can have an impact phytoplankton community structure because some algae are better suited to N limited environments whereas others are better suited to P limited environments (CEAT 2012).

Aluminum, Iron, Manganese, Phosphorus, and Dissolved Oxygen

Aluminum (Al), iron (Fe), and manganese (Mn) can all form complexes with P, sequestering P in the sediment (Figure 3.1). P present in the water column can bind with all three forming precipitates. Al binds P nearly irreversibly acting as a permanent sink for P (Wilson et al. 2008). Conversely, Fe and Mn bind P during oxic conditions, but release it under anoxic conditions due to the ability of Fe and Mn to act as reducing agents in oxidation-reduction

chemistry. Reduction-oxidation chemistry is characterized by the redistribution of electrons in various species in a chemical reaction which can result in a shift in the chemical properties of the oxidized and reduced species. When oxygen is abundant, Fe and Mn are in their oxidized forms, Fe3+ and Mn3+ respectively, and are able to form P binding complexes. Under anoxic conditions Fe3+ and Mn3+ are reduced to Fe^{2+} and Mn^{2+}, inhibiting the P binding complexes from forming (Lake et al. 2007).

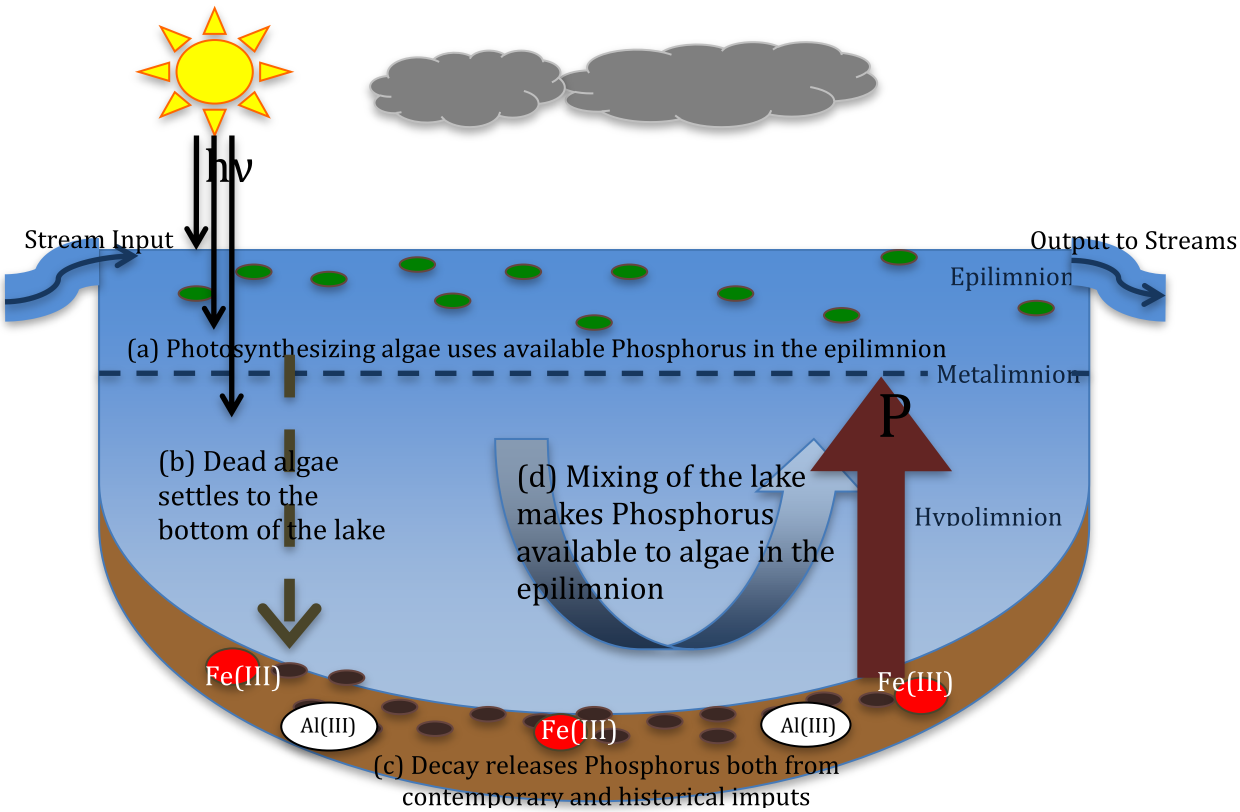

Figure 3.1. shows how phosphorus cycling occurs in freshwater ecosystems that have aluminum, iron, and manganese in the sediment. Manganese can be substituted for iron in this diagram.

The abundance of oxygen in an ecosystem is affected by a variety of factors. Many stratified freshwater lakes undergo semiannual mixing events that redistribute nutrients and oxygen throughout the entire lake. Cultural eutrophication can cause algal blooms that significantly impact oxygen levels (Anderson et al. 2002). When algae die they sink to the bottom of the lake and undergo decomposition, a reaction that requires oxygen, often creating

anoxic conditions. Eutrophication is often positively correlated with concentrations of P, with higher P concentrations leading to lower dissolved oxygen (DO) concentrations (Fisher et al. 2006). This cycle is therefore a positive feedback loop that in turn results in increased P as it is released from Fe or Mn complexes in the sediment. Additionally, low DO concentrations can cause fish kills, and significantly reduce the potential for biological diversity (Fisher et al. 2006). Determining the concentrations of Fe, Al, Mn, and P in the water column, and understanding events that can affect the abundance of oxygen are essential to understanding a freshwater ecosystem and can have serious implications for the system's health.

Calcium and Magnesium

Calcium (Ca) and magnesium (Mg) are both indicators of groundwater inputs. Water bodies in the Belgrade Lakes Watershed have significant inputs from groundwater (Nesbeda 2004). When concentrations of these elements are high, it can be inferred that groundwater is a major source at a particular site (Stauffer 1985). Groundwater inputs can have major implications for a water body. Ca and Mg both contribute to the hardness of the water; certain organisms can only survive in specific ranges of hardness. Hardness can be used to estimate the ameliorating effects of the water on metal toxicity (Naddy et al. 2009). Groundwater inputs can also affect the temperature of a water body, as groundwater inputs are typically colder than surface water or precipitation inputs (Constanz 1998). Again, this can have an impact on which organisms can live in a freshwater ecosystem. Finally, the complexes Ca and Mg form, can affect the pH of a lake or stream through their impact on alkalinity, or pH buffering capacity of a system (Schindler et al. 1989). Ca and Mg typically enter a water body as calcium carbonate or magnesium carbonate complexes from the weathering of limestone. Both of these complexes are water-soluble and dissolve as they enter the water. Mg and Ca therefore do not directly impact pH, but the carbonate ion functions as an excellent pH buffer. High Mg and Ca concentrations imply high carbonate concentrations, and therefore a high alkalinity and buffering capacity. This is important when considering environmental issues such as acid rain, as a water body with a high alkalinity will be more resilient to pH change in response to acid rain inputs, maintaining a viable habitat for the organisms living in it (Schindler et al. 1989).

pH

pH is a measure of the activity of the hydrogen ions present in a solution and is influenced by a variety of factors including alkalinity and vegetation type. Alkalinity impacts pH, as it indicates the buffering capacity of the lake or stream (Schindler et al. 1989). Vegetation type also influences pH. Much of the Serpentine can be classified as a wetlands ecosystem with high sphagnum moss coverage. Sphagnum moss is a peat moss that contributes to the acidification of the surrounding water body. Sphagnum acidifies the surroundings by taking up positive cations and releasing hydrogen ions into the water. Several studies have found that pH can also influence nitrogen cycling. One study found that when pH values fell below 5.6, nitrification of ammonium ceased (Rudd et al. 1990). Another study found that nitrogen fixation ceased at pH values below 5, but no effects on nitrification were noted (Vitousek et al. 1997). Finally, the pH of a water body is very important in determining which organisms are able to live in the ecosystem.

Dissolved Organic Carbon

Dissolved organic carbon (DOC) plays an important role in the carbon cycle and can affect chemical, biological, and physical characteristics in lakes and streams. DOC provides protection to organisms from the damaging effects of UVB radiation and also complexes heavy metals by influencing the acid-base chemistry of the water, making heavy metals less bioavailable to phytoplankton (Winch et al. 2002). This is important because bioaccumulation is a huge problem in aquatic ecosystems, especially those with multiple links in their food webs. High concentrations of DOC have been found to depress primary productivity and decrease lake transparency, causing shallower euphotic zones and thermoclines (Gergel et al. 1999). DOC can enter an ecosystem through a variety of sources including precipitation, leaching, and decomposition. Additionally, highly productive wetlands are able to generate substantial amounts of DOC that enter the lake or stream as tea-colored tannins and lignins (Gergel et al. 1999).

Arsenic

Arsenic is often found in aquatic ecosystems, as it is a byproduct of mining and chemical waste. It is of interest in this study because arsenic is common in Maine lakes and streams, likely due to relatively high concentrations in the bedrock. The current EPA standard for arsenic in drinking water is 10 ppb, however studies looking at domestic wells across Maine have found

that 12% of wells have concentrations exceeding 10 ppb, and 1-3% of wells have concentrations exceeding 50 ppb (Ayotte et al. 2003). As arsenic is considered to be a possible carcinogen, the findings of this study could have potential implications for the health of residents of East Pond, North Pond, and the Serpentine who use these water bodies as sources of drinking water or spend extensive amounts of time in them recreationally.

Measuring these variables will provide information about the chemical profile of the Serpentine ecosystem. With this information, inferences can be made about the health of the system and the flora and fauna it can support. Conclusions can also be drawn about the impacts of human development and what, if any, effects water quality has on recreation and human health. Currently East Pond experiences regular algal blooms, while algal blooms appear rarely and with less severity in North Pond (CEAT 2012). Therefore, of particular interest are the P, Fe, and Al data as inferences can be made about eutrophication and algal blooms from these concentrations. Obtaining information about where different chemical inputs are coming from and how strongly they impact the North Pond and East Pond ecosystems will also help with the development of management strategies.

Methods

Sampling Methods

Plastic Erlenmeyer flasks, glass vials, syringes, and filter holders were washed with 5% trace metal grade sulfuric acid for 72 hours prior to sampling. Both the flasks and vials were rinsed three times then filled with deionized water after the acid wash. Ashed 0.45 μm GF/F Whatman filters were used to collect filtered samples. One filtered and one unfiltered sample was collected at each site in the Erlenmeyer flasks (CEAT 2012). For both the filtered and unfiltered samples the flasks were washed out three times with filtered and unfiltered water respectively before being filled with the sample to be analyzed. Immediately after sampling each sample was acidified to a pH of less than 2 (using concentrated trace metal grade sulfuric acid), and then refrigerated at 40° C. At each site, two additional filtered samples were taken and put in the glass vials. The samples were then stored in a refrigerator until analysis. Temperature, pH, and DO were measured at each site. These were taken either with a YSI 6820 Multi-Parameter Water Quality Monitor or with a handheld Mettler-Toledo SevenGo SG2 pH meter and a

handheld YSI 55 DO meter. Samples were taken on four different days, although not every site was sampled each sampling day due to time constraints (Appendix 3.A). Samples were taken on Sept. 22, Sept. 29, Oct. 3, and Oct. 6 in 2011.

Methods of Analysis

The samples collected in the Erlenmeyer flasks were analyzed using a SPECTRO ARCOS inductively coupled plasma atomic emission spectrometer (ICP-AES). Before analysis could be performed, standards were created in order to generate calibration curves. Blanks, 50 ppb, 100 ppb, 500 ppb, and 1000 ppb standards were created using 5% trace metal grade nitric acid as a diluent and an IV-ICPMS-71A multi-element stock solution that included all of the elements analyzed in the study. Calibration curves were created using these standards. After the calibration curves passed regression checks by the ICP-AES, both the filtered and unfiltered samples were analyzed to determine the concentrations of Mg, Ca, P, Al, Fe, and Mn in each sample.

The samples collected in the glass vials were analyzed using a Shimadzu TOC analyzer. The samples were first acidified to eliminate inorganic carbon present in the samples, leaving behind only DOC. The analyzer then determined DOC and total nitrogen (TN) in each sample. The same samples were then analyzed using a Lachat auto-analyzer that measured nitrate concentrations in each sample using a cadmium reduction process.

Rainfall data obtained from a weather station near site Serpentine 3 (S3) was then examined to determine if any of our sampling dates were preceded by significant precipitation events.

Statistical Analysis

All graphs were made in Microsoft Excel. Graphs were made looking at unfiltered P, filtered Al, and filtered Fe samples by both site and date while also looking at the weather station data in order to determine if precipitation events impacted the concentration of these elements. Filtered Fe and Al concentrations were used in analysis as these samples represent the amount of each element found in the water column only. The unfiltered P samples were used in analysis, however, because they represent the amount of P in the water column plus the amount of P tied up in aquatic microorganisms. This is considered to be total phosphorus (TP). Graphs showing concentrations of Mg, Ca, Mn, TN, DO, DOC, and nitrate by site were also created. These data are averaged across each of the sampling days; concentrations did not vary widely between

sampling dates. Scatter plots were created to determine if several of the variables measured were correlated. To determine if the differences found between sites were statistically significant, T-Tests and ANOVAs were performed for Ca, Mg, Al, Fe, P, TN, DO, DOC, and nitrate concentrations.

Results

pH, DO, DOC, and Temperature

The pH of the Serpentine was found to be relatively uniform, with a mean of 6.19 during sampling (Figure 3.2). The mean pH over sampling days in North Pond (NP) was 7.34, higher than the mean pH of East Pond (EP), which was 5.75 (Figure 3.2). The mean DO concentration was 7.50 mg/L overall, ranging from 13.1 mg/L in EP to 3.9 mg/L at the confluence of the Serpentine (SC) (Appendix 3.A). DO did not vary significantly between any two sampling locations due to high variability in abiotic factors between sampling dates (Figure 3.3). The temperature of the water was measured with all samples, ranging between 12° C and 19.5° C with a mean of 16.9° C for all samples (Figure 3.4). Temperature averages and bounds exclude some sampling events (10/6 - I2, NP) due to recorder error. DOC concentrations ranged between a high of 19.89 mg/L at I1 to a low of 4.43 mg/L at S2, with a mean of 13.99 mg/L (Appendix 3.A). DOC did not vary significantly between sampling sites (Figure 3.5) (ANOVA, p=0.14).

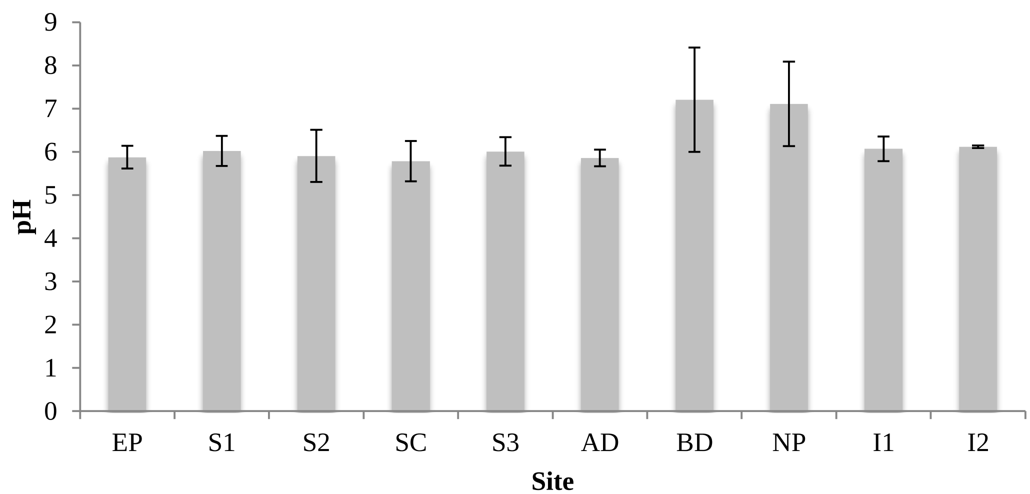

Figure 3.2. pH (± SD) by site averaged over sampling days is relatively uniform with slightly higher averages found at BD and NP.

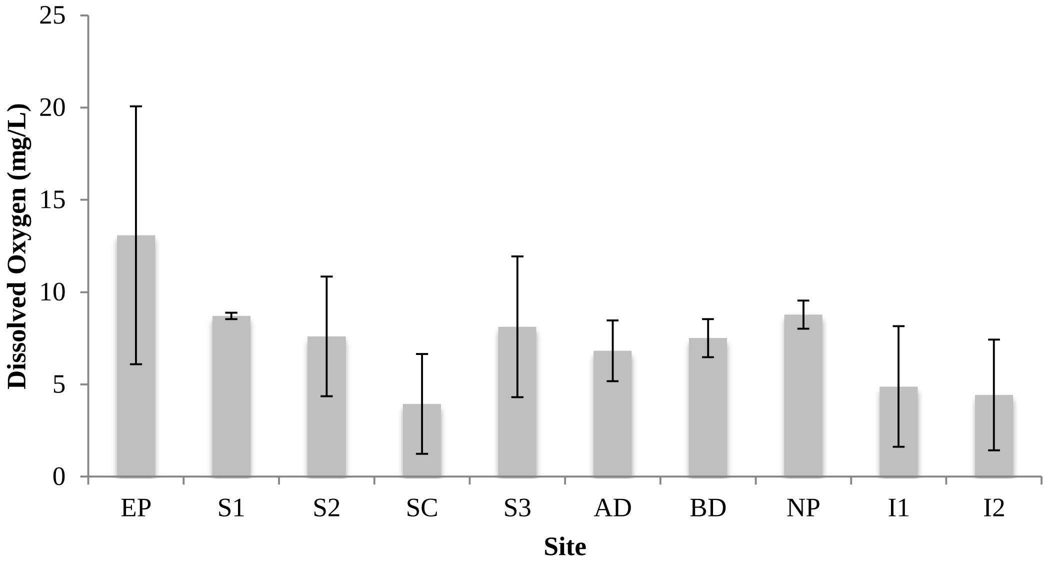

Figure 3.3. Dissolved oxygen concentrations (± SD) by site averaged over sampling days.

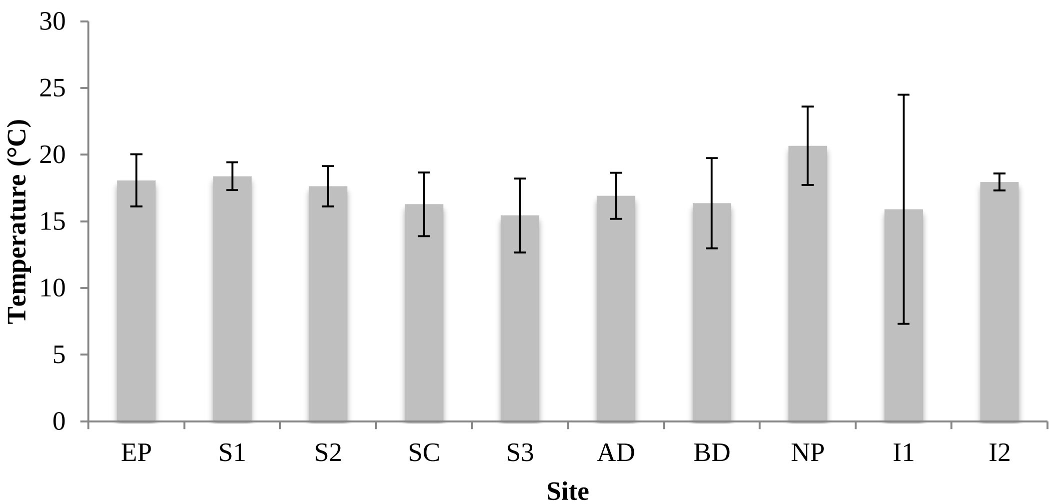

Figure 3.4. Temperature (± SD) by site averaged over sampling days.

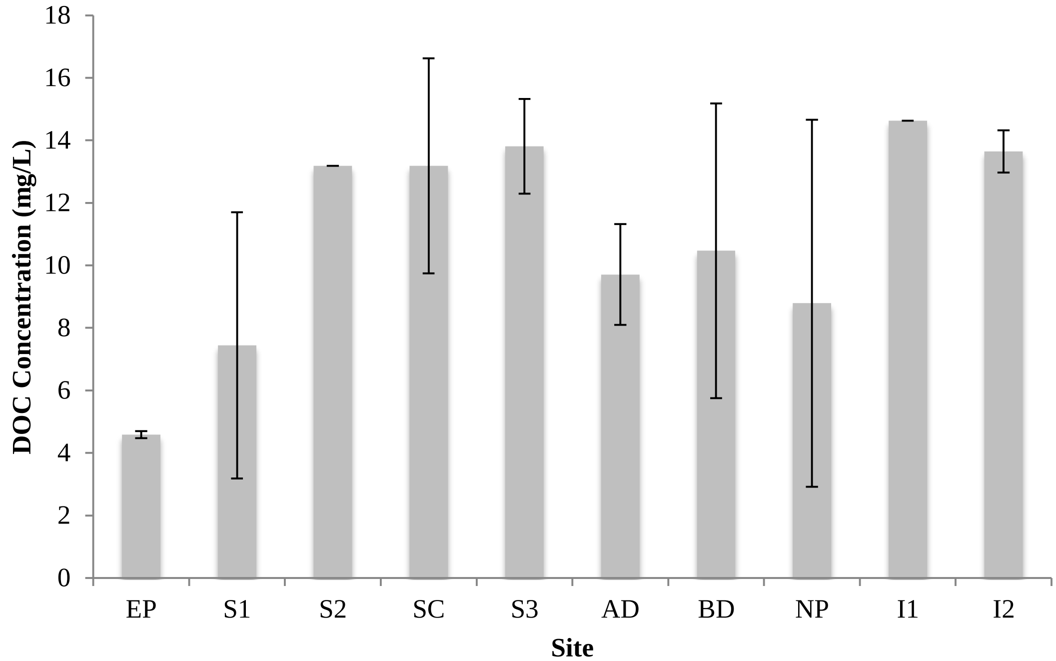

Figure 3.5. Dissolved organic carbon concentration (± SD) by site averaged over sampling days (ANOVA, p=0.14).

TN, TP, and Nitrate

Nitrate concentrations were notably low and varied, ranging between 0.107 mg/L at SC and 0.006 mg/L in NP (Appendix 3.A). There was no significant difference in concentration of nitrate between sites (Figure 3.6) (ANOVA, p=0.451). Total nitrogen was also very low and did not significantly differ among sites (Figure 3.7) (ANOVA, p=0.601); the highest concentration was reported below the dam (BD) at 0.467 mg/L, while the lowest was at NP at 0.043 mg/L (Appendix 3.A).

TP concentrations were low at EP and at S1 and S2, with concentrations of 10.61 ppb, 3.69 ppb, and 3.20 ppb respectively (Figure 3.8). TP was highly variable among sites, where I2 had the highest mean concentration, 320.20 ppb, and S2 had the lowest of 3.20 ppb (Figure 3.8). TP concentrations were relatively high in input streams, averaging 103.2 ppb for all input streams (I1, I2) over all sampling events (Figure 3.8). SC and I2 both had elevated P on October 3, 2011 following a rain event in the preceding 48 hours, with concentrations of 69.8 ppb and 320.2 ppb respectively (Figure 3.8).

Utilizing TN and TP concentrations, the ratio of molarities of TN to TP was calculated for each site where data were available, with the highest ratio of 89.9:1 present at NP (Figure 3.9). The lowest N:P ratio was 2.2:1, found at I2 on October 3, 2011 (Figure 3.9).

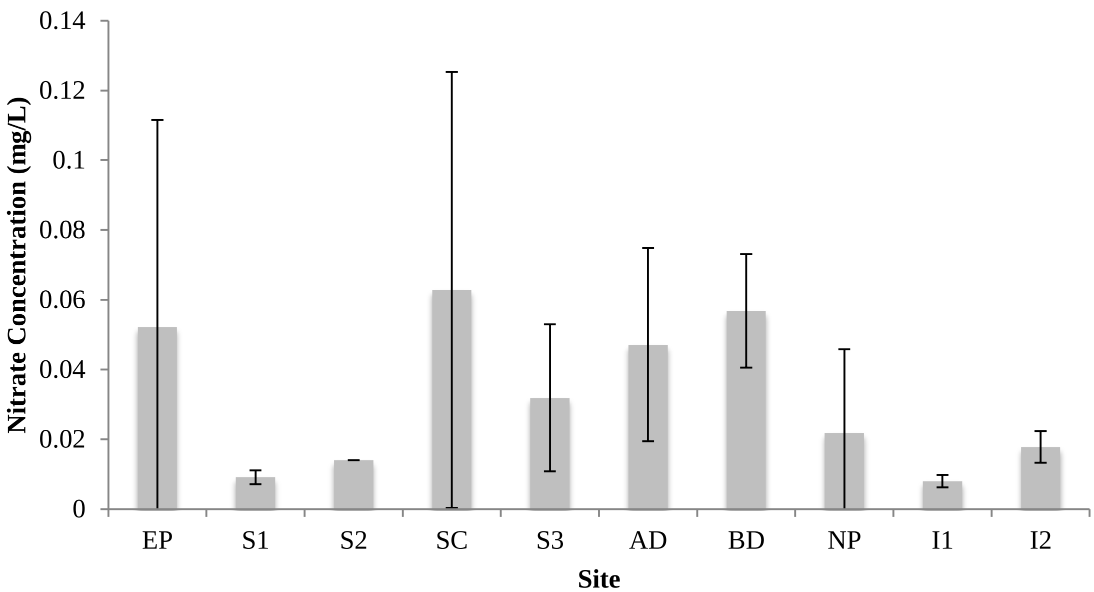

Figure 3.6. Nitrate concentration levels (± SD) by site averaged over sampling days (ANOVA, p=0.451).

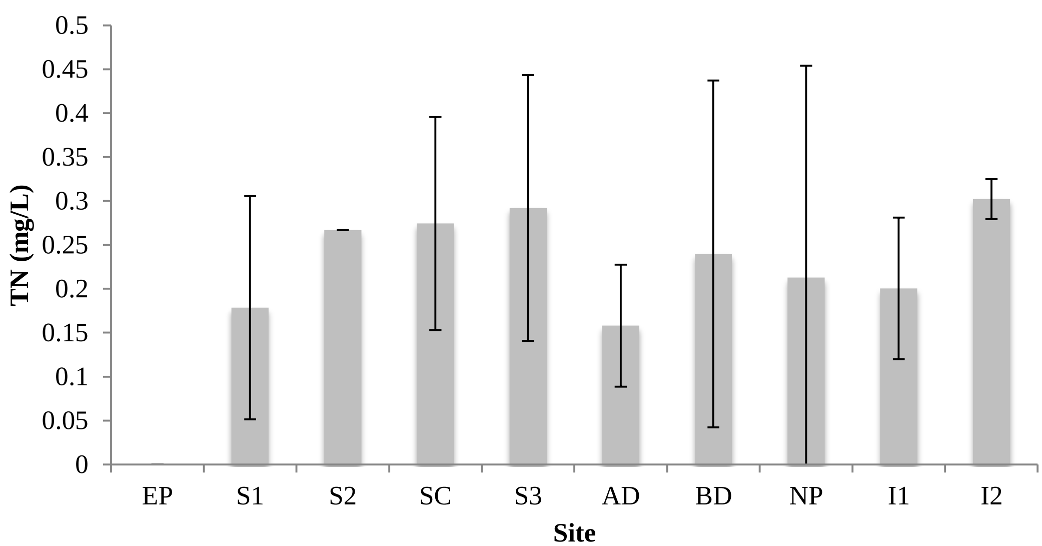

Figure 3.7. Total nitrogen concentration levels (± SD) by site averaged over sampling days (ANOVA, p=0.601).

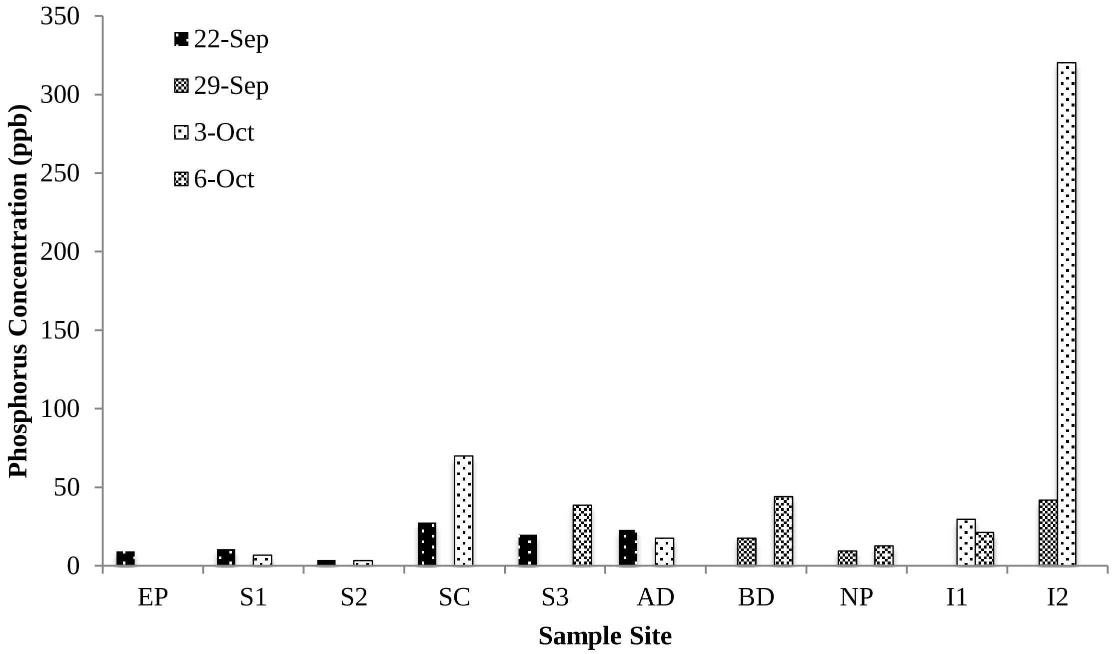

Figure 3.8. Unfiltered phosphorus concentration measured at each sample site on four sampling dates.

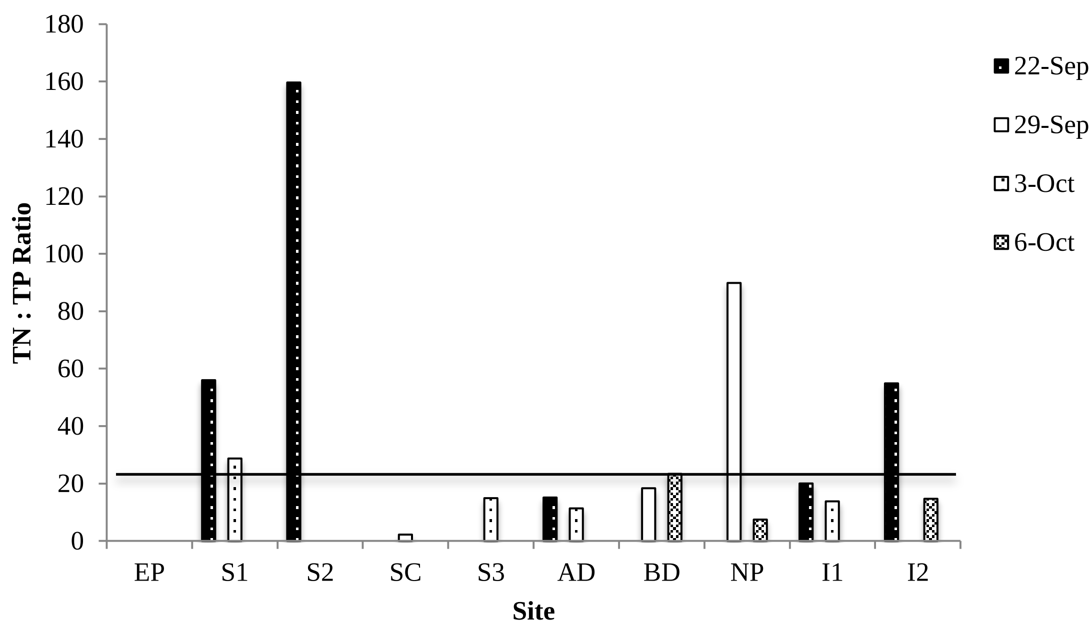

Figure 3.9. Total nitrogen: Total phosphorus ratio measured at selected sites on four sampling days. The horizontal line on the graph represents the Redfield Ratio of 16:1. Ratios greater than this value typically indicate a P limited ecosystem whereas ratios less than this value indicate an N limited ecosystem.

Magnesium and Calcium

Magnesium concentrations also displayed inter-site variability, with I2 containing the highest concentration of 2163 ppb, and Serpentine 1 (S1) the lowest at 556.6 ppb (Figure 3.10). Mg tended to have lower concentrations between EP and S2 than in input streams or between SC and above the dam (AD). The highest Mg concentrations occurred in input streams (I1, I2), while the Mg concentrations had a declining trend as distance from the input streams increased (Figure 3.10). Mg differed slightly between I2 and EP (T-test, $p=0.0579$), as well as between I2 and NP (T-test, $p=0.0959$).

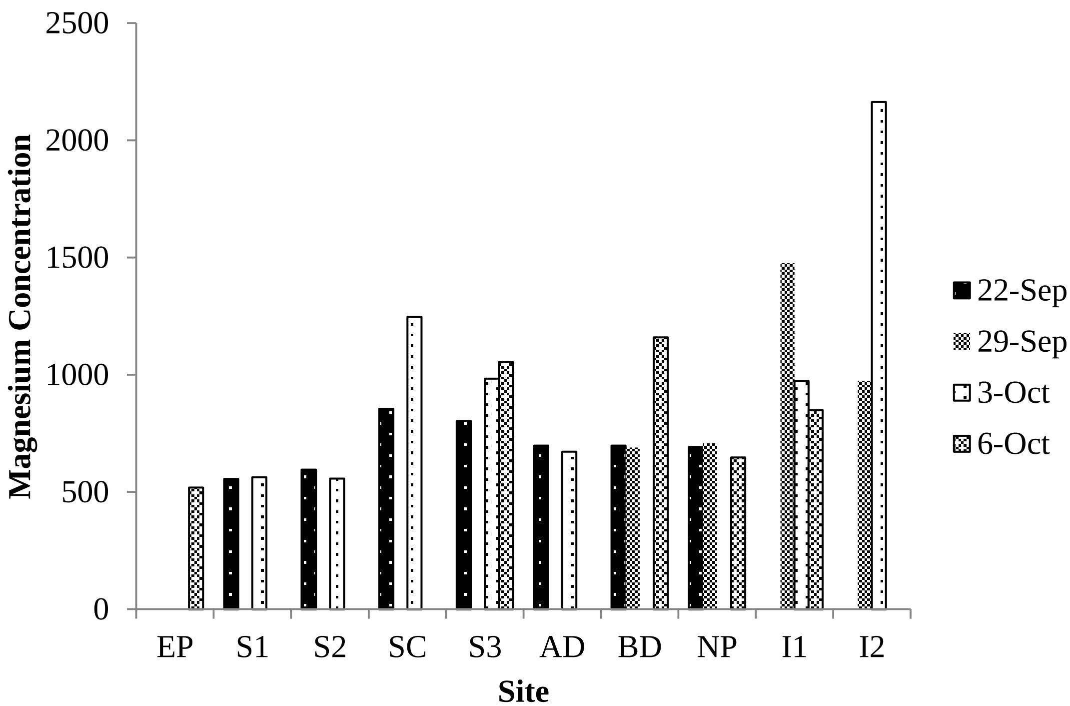

Figure 3.10. Magnesium concentration measured at each sample site on four sampling dates (Mg differed slightly between: I2 and EP (T-test, $p=0.0579$), I2 and NP (T-test, $p=0.0959$)).

Calcium was present in the Serpentine, North Pond and East Pond with concentrations ranging from a low of 2129 ppb in NP, to a high of 4144 ppb at SC (Figure 3.11). Ca had lower concentrations between EP and S2 than in the input streams (I1, I2) (Figure 3.11). Ca also displayed some trending in decreasing concentrations between SC and AD (Figure 3.11). BD had higher concentrations of Ca than AD, while NP had significantly lower Ca concentrations than S3 (T-test, $p<0.05$; Figure 3.11). Figure 3.12 indicates a strong significant correlation ($y = 0.4649x - 533.08$, $R^2 = 0.65252$, $p < 0.001$) between Mg and Ca.

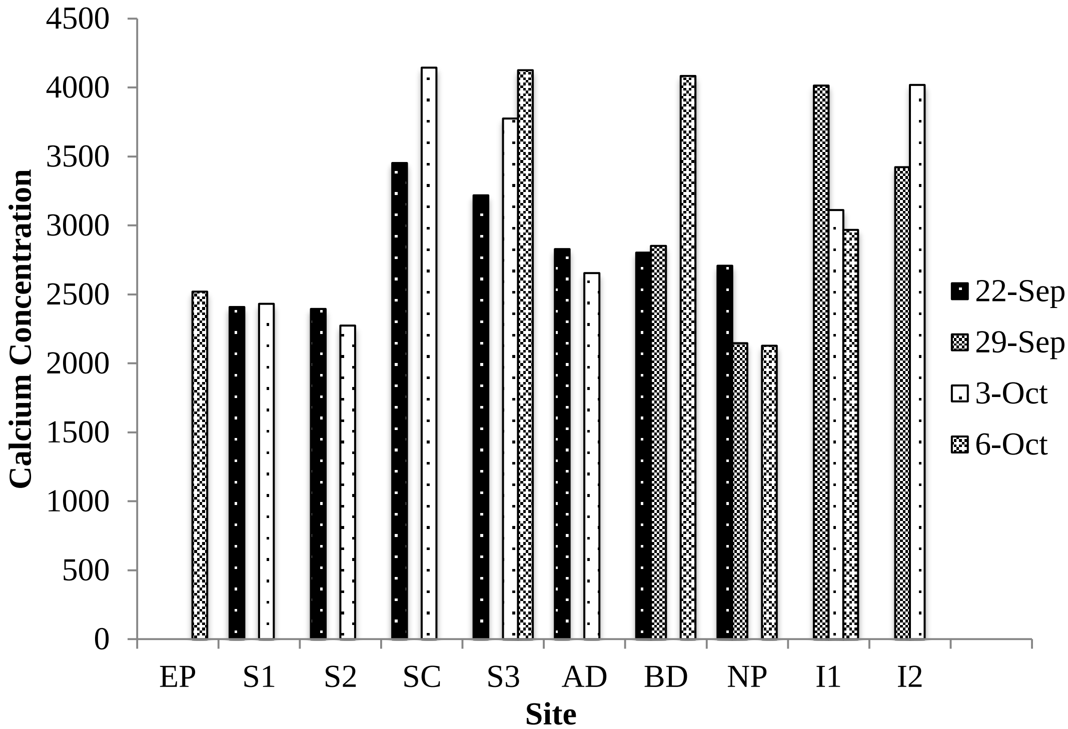

Figure 3.11. Calcium concentration measured at each sample site on four sampling dates NP significantly lower than S3 (T-test, $p<0.05$).

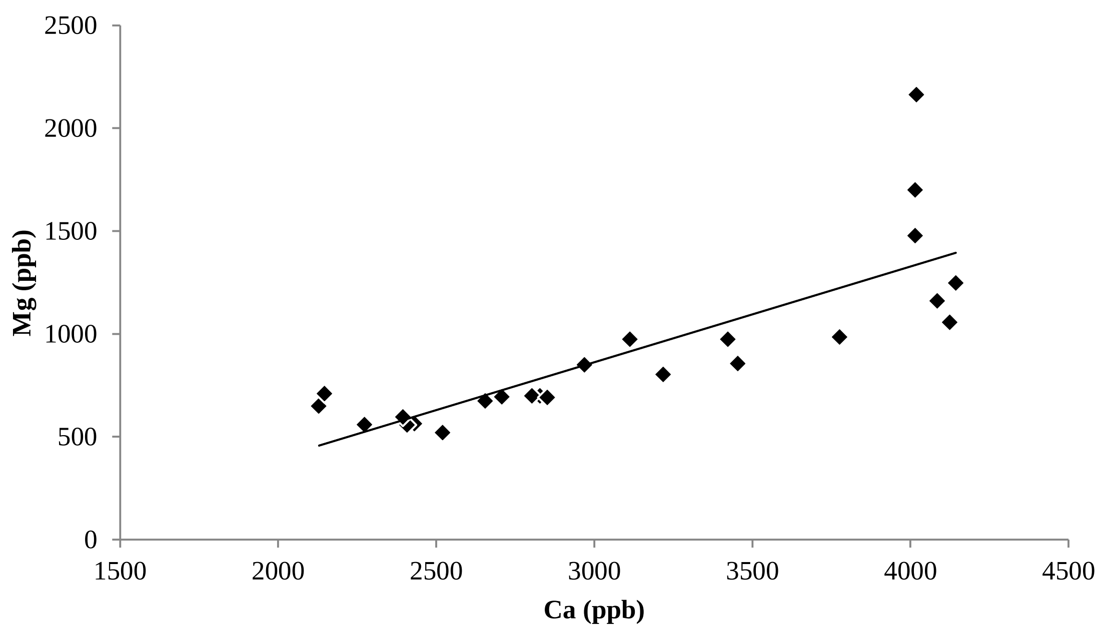

Figure 3.12. Scatterplot of magnesium and calcium across all sample dates and sample sites. A regression line ($y = 0.4649x - 533.08$, $R^2 = 0.65252$, $p < 0.001$) is included.

Aluminum, Iron, and Manganese

Iron concentrations displayed high variability between sites and sampling dates (Figure 3.13). The concentration of Fe was lowest at S1, 13.74 ppb while highest at I1, 856.86 ppb (Figure 3.13). Fe concentrations were relatively low at EP, S1 and S2, while all of the input streams had relatively high concentrations. Between SC and AD, a decreasing trend in iron concentrations was observed (Figure 3.13). NP had higher concentrations of Fe than EP (Figure 3.13). When DO is compared to Fe across all sites and sample dates, there is a highly significant correlation (ANOVA, $p < 0.01$) (Figure 3.14). When P is compared to Fe, a significant correlation is present ($y = 0.0217x + 8.8547$ $R^2 = 0.30$, $P < 0.01$).

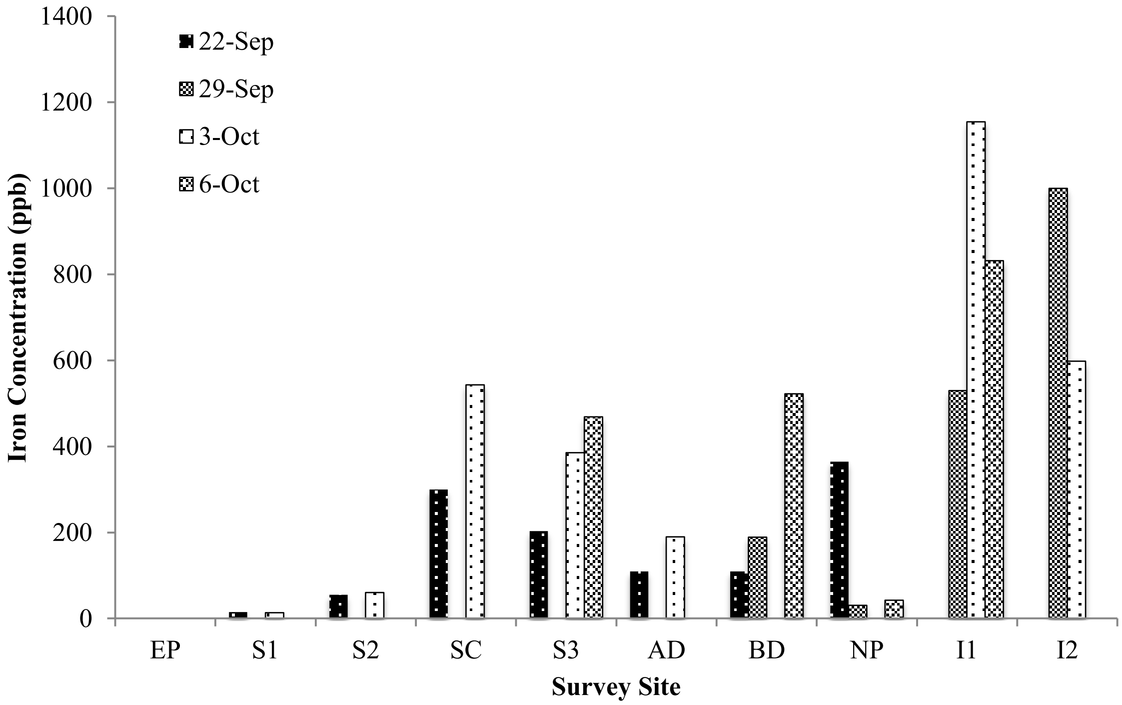

Figure 3.13. Filtered iron concentrations measured at each sample site on four sampling dates.

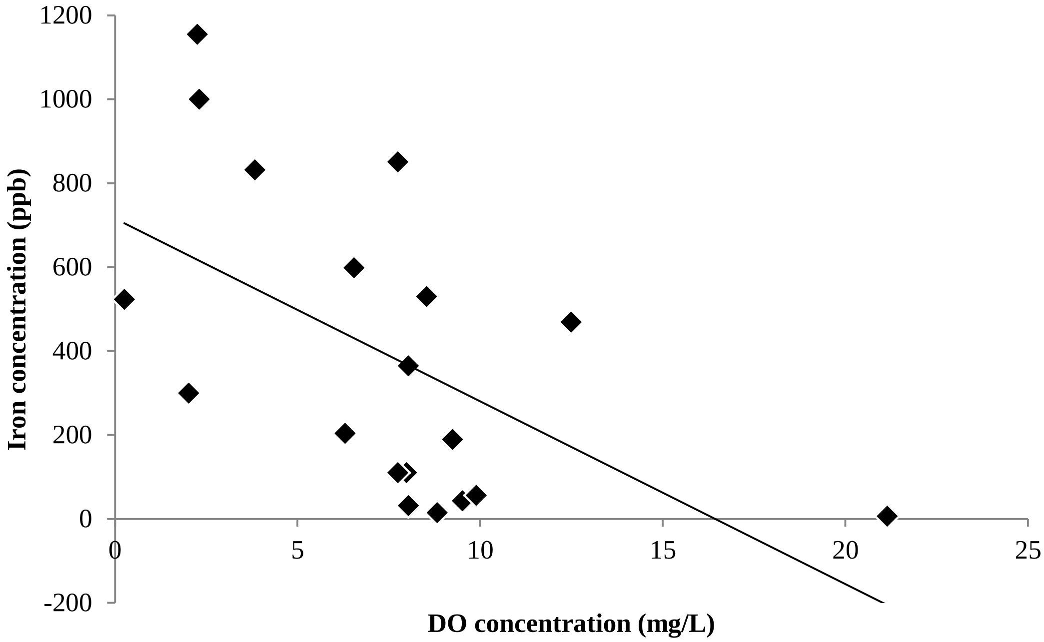

Figure 3.14. Scatterplot of iron and dissolved oxygen concentrations across all sample dates and sample sites. A regression line ($y = -43.565x + 716.02$, $R^2 = 0.30871$, $p < 0.01$) is included.

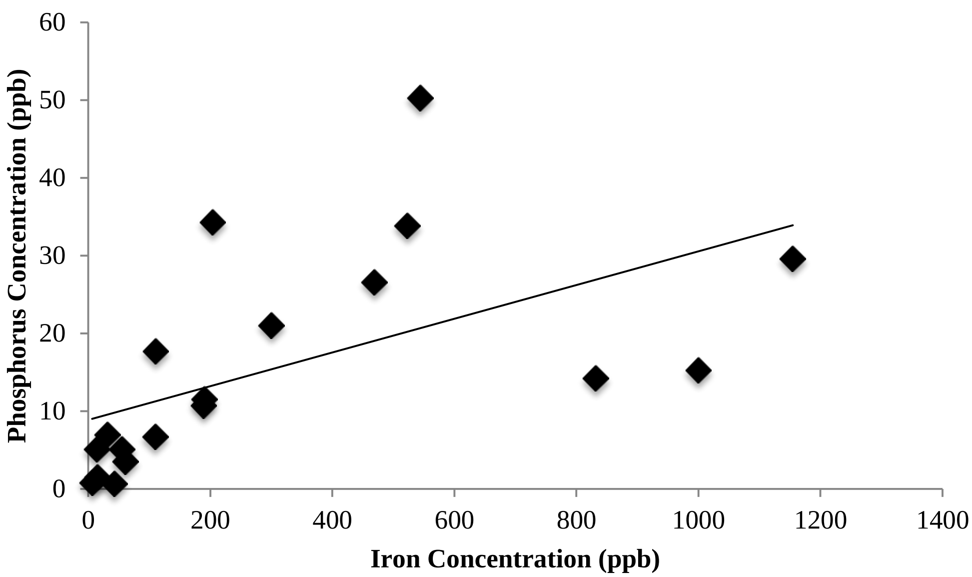

Figure 3.15. Scatterplot of iron concentration versus phosphorus concentration across all sample sites and dates. A regression line ($y = 0.0217x + 8.8547$ $R^2 = 0.30798$, $p < 0.01$) is included.

Aluminum concentrations were highly variable in the Serpentine, the input streams (I1, I2) and North Pond; the lowest concentration of Al was 13.51 ppb at NP on October 6, while the highest concentration of Al was 543.53 ppb at I2 on October 3 following the rain event (Figure 3.16). Trends in Al concentration indicate consistently low concentrations in EP, S1 and S2. The input streams had higher concentrations than SC, while all sites between the input streams and NP tended to have elevated and highly variable concentrations (Figure 3.16). A declining trend in Al concentration is observed between SC and AD (Figure 3.16).

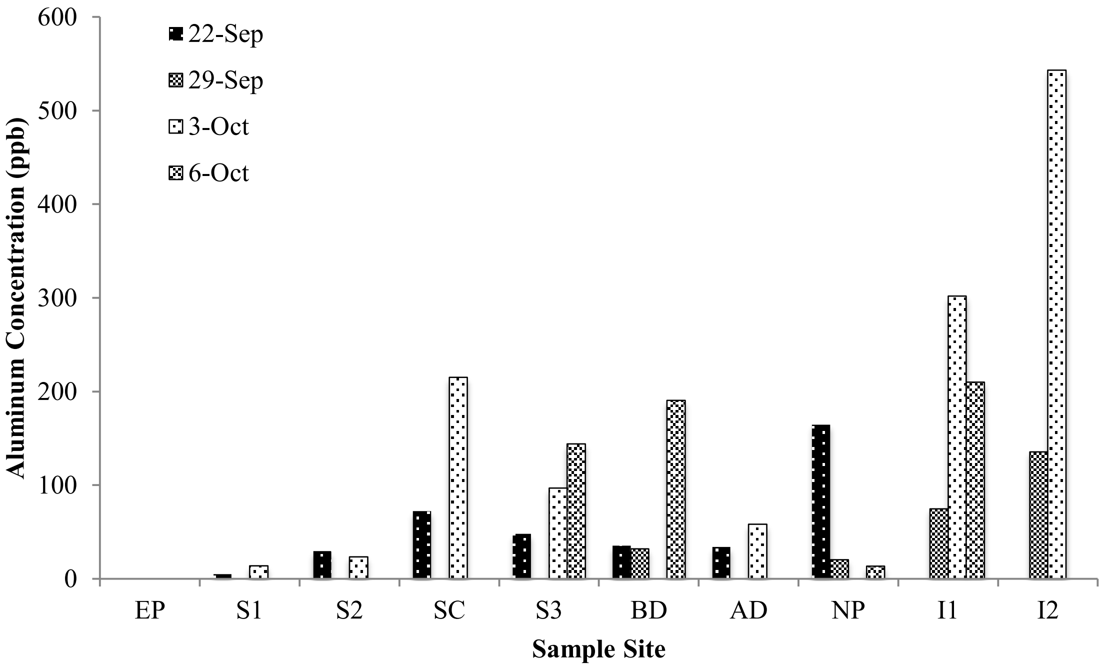

Figure 3.16. Filtered aluminum concentrations at each sample site on four sampling dates.

Manganese varied in concentration with the lowest concentration of Mn being 5 ppb at S2, while the highest was 123 ppb at I2 (Appendix 3.A). Between EP and S2 the concentrations of Mn are relatively uniform, whereas between SC and AD there is a decreasing trend in concentration (Figure 3.17). The highest and most variable Mn concentrations were in the input streams (I1 and I2), BD, and NP (Figure 3.16).

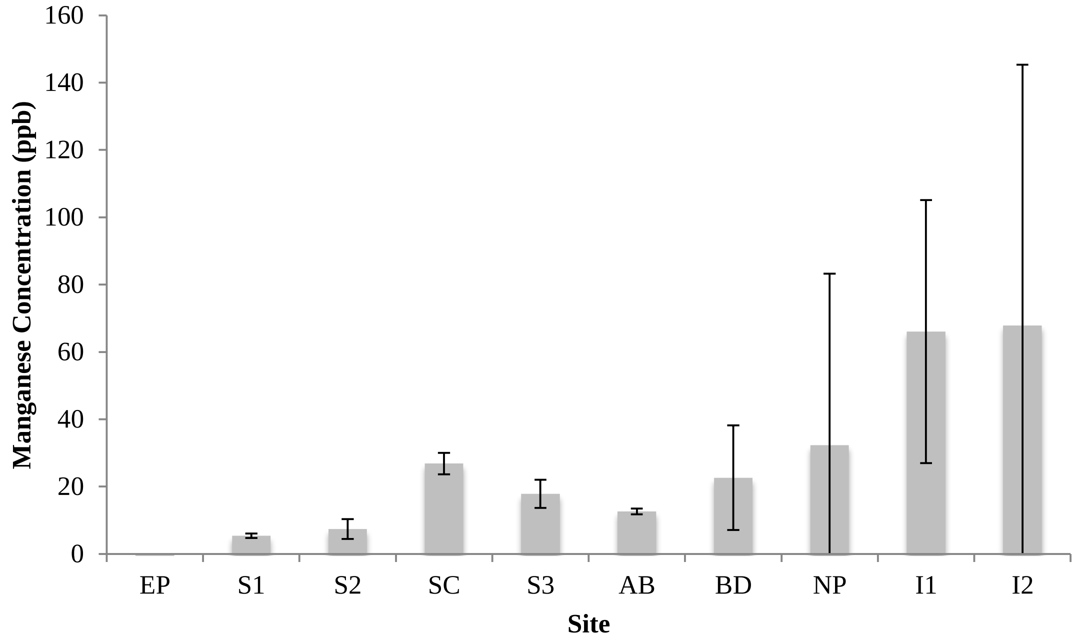

Figure 3.17. Manganese concentrations (± SD) by sample site (ANOVA, p=0.352).

Arsenic

The concentration of arsenic was below the detection limit for the AES-ICP in several instances, indicating that the concentrations of arsenic were below 4.99 ppb in the sample. The maximum concentration of arsenic was found at SC at 10 ppb (Appendix 3.A). The lowest detectable concentration of arsenic was found at I1 at 5 ppb (Appendix 3.A). In general arsenic concentrations were fairly consistent across all sites (Figure 3.18).

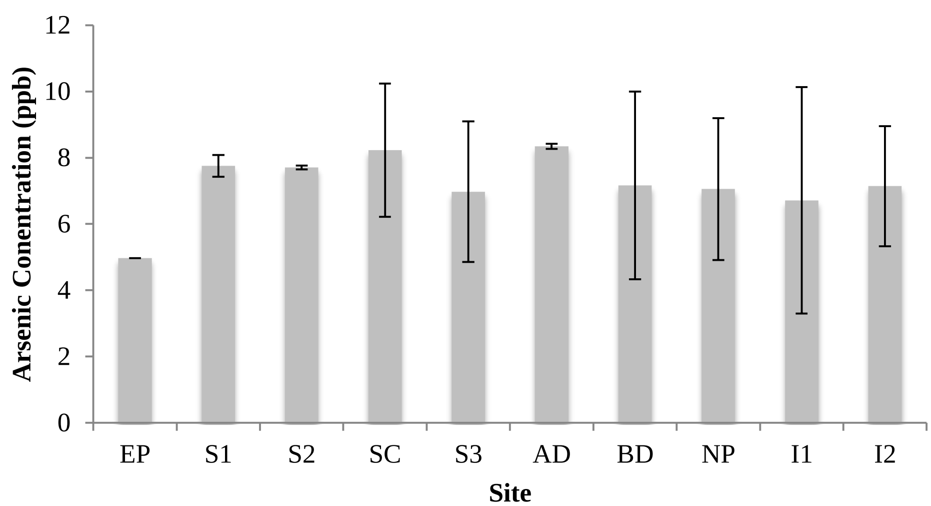

Figure 3.18. Arsenic concentrations (± SD) by sample site.

Discussion

The importance of water chemistry to the Serpentine stems from the interconnected nature of the system, namely the linkage of East Pond to North Pond (Figure 1.2). As this study seeks to determine the impacts of the Serpentine upon NP and EP, a comparative survey of water quality parameters is essential. The explanation for the occurrence of algal blooms in EP and absence of blooms in NP is linked to Water Chemistry, Sediment and Algae teams (Chapters 4 and 6 respectively). Our findings indicate significant nutrient inputs to the Serpentine, while EP and NP show little response in elevated nutrient concentrations in the Serpentine. Elevated concentrations of P, Al and Fe in input streams on October 3 correspond with a rain event, indicative of significant nutrient inputs from surface flow. The elevated concentration of elements in the input streams and absence in NP following rain events has significant implications for the relation of the Serpentine to EP and NP.

The trend towards decreasing concentration with proximity to the dam for all elements was fascinating, as the decreased concentrations reflect the effects of biological or chemical processes. For the elements Fe, P, Al, Ca and Mg, the input streams and sites downstream from the input streams (SC, S3 and AD) generally had higher concentrations than EP or NP. Trends in Fe, Al, P, Ca and Mg indicate decreasing concentrations between the SC and AD. This may be the result of one or more of three hypothesized processes acting upon nutrient concentrations in the Serpentine. DO concentrations remained relatively uniform, declining notably in the input streams and at SC. As this study was concerned with algal blooms, the relation of P to Fe, Al and DO is noteworthy, however the relation of DO to element concentrations is unremarkable.

pH

The mean pH of the Serpentine, 6.19, is comparable to the pH values found in a similar study of small Maine streams (Figure 3.2). A study by Nelson and Johnson (2003) during September and October sampling events found an mean pH for streams in central Maine of 6.31. The Serpentine is slightly more acidic, however the presence of large quantities of Sphagnum moss may explain this discrepancy. This is due to the release of hydrogen ions (H^+) by Sphagnum moss during sorption of cations from the water column. Across all sampling events there was little variation, however NP tended to have a higher pH than EP or the Serpentine (S1, S2, SC, S3, and AD) as a whole [Appendix 3.A]. This could indicate additional inputs to NP, however further study is required to determine individual input contributions to overall pH. The

pH of the Serpentine is able to support the biota of EP. The pH in EP and NP do not preclude the residence of any biota.

DO

The mean concentrations of DO remained above anoxic concentration (<2.5 mg/L) across all sample sites, however at times SC, I1, and I2 exhibited hypoxic conditions (DO <5 mg/L; Figure 3.3). The confluence of the Serpentine has previously displayed such trending towards anoxia (King Personal Communication). Sampling events with DO concentrations above 5.0 mg/L were considered to be oxic, indicating well oxygenated water (Loeb et al. 2007). The decreased concentrations at SC could indicate a stagnation of the water column or an increased rate of decomposition by bacteria, utilizing DO faster than mixing is able to replenish it. DO concentrations were, on average, above the minimum levels required by fish to survive in the Serpentine, however SC at times precluded habitation by certain fish (Fish Chap, CEAT 2012).

Dissolved oxygen concentrations can be significantly correlated with the level of Fe present in the water, with lower levels of DO indicative of higher levels of Fe present in the water ($y=-43.872x+692.09$, $R^2=0.34637$, $p<0.01$; Figure 3.14). As DO decreases, use of Fe as the principal reducing agent for biologic processes increases (Andrews 1998). This results in the release of Fe and P from insoluble complexes with subsequent increases in the concentration of Fe and P in the water column (Figure 3.14, Figure 3.8). Because Fe may also bind with other elements, not all compounded Fe will release P (Andrews 1998).

DOC

The concentration of DOC (13.99 mg/L) was similar to concentration reported by Nelson and Johnson (2003) for streams in central Maine of 10.37 mg/L during sampling events in September and October (Figure 3.5). The DOC concentration also appears consistent with streams from Minnesota, with mean concentrations of 11.28 mg/L (Lottig et al. 2011). Concentrations at EP varied little across sampling events, while NP had high variability between sampling events. The uniformity of EP is likely due to the limited inputs from inflowing streams and the smaller watershed area compared to the diversity of inputs and large watershed area in NP (GIS Team, CEAT, 2012). As DOC is readily decomposed under oxic conditions, low DOC is expected in NP, EP and the Serpentine. While low in EP, DOC concentrations increase in the Serpentine between S1 and SC; however, by the dam DOC concentrations again begin to decrease. This increase in DOC upon entering the Serpentine could indicate that Sphagnum

moss impacts decomposition rates through the release of sphagnol (CEAT 2012). In releasing sphagnol, Sphagnum slows decomposition of all organic matter. The prevention of decomposition could thereby increase DOC concentrations upon entering the Fen. This is correlated with the decreased DOC at AD in the forested ecosystem of the Serpentine, supporting the theory that spahgnol is limiting decomposition (CEAT 2012).

Total Phosphorus

TP remained low and relatively uniform in EP, S1 and S2, while I2 had a considerably higher concentration. Between SC and AD, the concentrations of TP exhibited a decreasing trend, with a maximum concentration observed on October 3 at SC following a rain event. BD likely had higher concentrations as a result of increased weathering and sediment disturbance due to the increased flow velocity of water falling over the dam. In North Pond, the concentrations of phosphorus were not considerably different from East Pond. The high levels of TP present at I2 may be the result of runoff from agricultural land abutting the stream (CEAT 2012).

The trend of decreased phosphorus between SC and AD could be indicative of chemical or biological processes present in the Serpentine. Compounding by Fe or Al could explain the decline in TP concentrations. Further, uptake of P by flora in the Serpentine could also explain the decreasing trend. Finally, the dilution of nutrient rich inflow (from input streams) with nutrient poor water (from EP) could explain the decreasing trend.

Iron

The concentration of iron in the input streams was higher than in the Serpentine, while the concentration of iron exhibited a decreasing trend between SC and AD (Figure 3.13). Following the rain event on October 3, the downward trend in iron concentrations is apparent (Figure 3.13). This trend was mirrored by concentrations observed on September 22. This decrease in concentration may be due to the dilution of nutrient rich water (from input streams) with nutrient poor water (from EP). Alternatively, Fe may be precipitated out of the water column upon forming complexes with P; however, sediment data does not appear to support this conclusion (Figure 4.3; McDowell et al. 2004, Lake et al. 2007).

Over all sample sites in the Serpentine, North Pond and East Pond, the comparison of P to Fe indicates that P and Fe are not well correlated. The decreasing concentration of iron with decreasing phosphorus is predicted in ecological systems, however the lack of increased

sediment iron-phosphorus concentrations with decreased water column concentrations indicates an absence of correlation (Lake et al. 2007). In I2, the highest concentrations of P occurred concurrently with the lowest concentration of Fe following the rain event. As agricultural land drains into I2, the decline in Fe could indicate compounding of P; unfortunately, sediment data does not support this conclusion (McDowell et al. 2004, Lake et al. 2007). If concurrent introduction of Fe and P took place during a rain event, the binding reactions may be more favored, as the DO concentrations in input streams should increase with increased input.

Aluminum

Aluminum concentrations averaged 107.1 ppb; this is similar to the mean reported concentration of 135.9 ppb by Nelson and Johnson (2003). Al was at its highest concentration in I2, most likely due to surface runoff or possibly from the agricultural land abutting the stream (Bryan et al. 1999). Al was consistently low in EP, S1 and S2, while the highest concentrations were found on October 3 in I2, following the rain event. The high concentration following a rain event lends credence to the theory that Al is introduced with surface water from adjacent agricultural lands (McDowell et al. 2004, Lake et al. 2007). Between SC and AD, a trend of decreasing Al concentration is present. As with Fe, there are hypotheses explaining the decreasing trend. The first hypothesis is that Al binds with P and precipitates from the water column (Lake et al. 2007). This theory is supported by sediment data showing increased concentrations of Al-P in sediment between SC and AD (Figure 4.3). This could be beneficial when considering the management of P as Al has the ability to permanently sequester P permanently. Secondly, dilution of nutrient rich waters (input streams) with nutrient poor water (EP) is supported by the decrease in all element concentrations between SC and AD.

The mean concentration of Mn in the Serpentine is 29.9 ppb. Mn was found to have extremely variable concentrations in input streams and in NP. The concentration is essentially uniform between EP, S1 and S2. Between SC and AD, the concentration of Mn exhibits a decreasing trend, similar to Fe. The extreme variability of Mn in NP is unexpected and variability in DO concentrations do not predict such change; however, NP also has many additional inputs and a comparatively large watershed. Mn can act as a reducing agent, however it is utilized before Fe by bacteria. The decreasing trend can be explained by the hypothesis of dilution, in which nutrient poor waters (from EP) dilute nutrient rich waters (from input streams).

Nitrate

The level of nitrate was highly variable between and within some sites; however, sites were statistically significant from one another overall (ANOVA, p=0.451). Overall, nitrate was low in comparison to other Maine streams. The mean level of nitrate was 0.20 mg/L by Nelson and Johnson (2003), while this study found 0.036 mg/L. Nitrate concentrations at such low values could indicate extensive biological processing or high forest cover at the Serpentine site. Low levels of nitrate are preferred in drinking water as excess nitrate can cause blue-baby syndrome, potentially leading to infant mortality (EPA). Overall, the concentration of nitrate in the Serpentine was well below the mean concentration found in similar small streams.

TN

The levels of TN found in the Serpentine are similar to, but consistently lower than TN in Maine streams reported by Nelson and Johnson (2003). Further confounding is that for sampling events in October and September alone, Nelson and Johnson (2003) had a higher mean of TN than when all data are considered. The lower TN concentration in the serpentine could indicate high uptake by flora in the Serpentine. The exceedingly low concentrations of TN could negatively impact plant growth at sites limited by N. TN was not significantly different between sites (ANOVA, p=0.601), however concentrations were highly variable between sites and showed no discernible trend in any area of the Serpentine. TN varied significantly both between sampling dates and within single sampling instances in which replicate sample vials were tested.

TN:TP Ratio

With both the levels of TN and TP, a ratio of the molarity of TN to the molarity of TP was calculated for each site and is highly variable (Figure 3.9). The line in Figure 3.9 is the Redfield ratio of 16:1 TN:TP. Above this line systems are considered P limited, while ratios below are generally N limited. The presence of N limited sites in the Serpentine indicates sites that would be conducive to cyanophyta growth, as these algae can fix N from the atmosphere, blooming under conditions other algae are unable to tolerate.

Calcium

Calcium concentrations were variable; however, all were below the mean reported value by Nelson and Johnson (2003) of 6842.6 ppb, with the maximum Ca concentration of 4143.8 ppb present at SC. Between SC and AD calcium concentrations displayed a decreasing trend between SC, S3 and AD. In EP, S1 and S2 the concentration of Ca remained relatively uniform and

sampling events were of distinctly lower concentration compared to SC and AD. This disparity is explained by the tendency for water from short groundwater flow paths and precipitation to contain less than 10 ppm of Ca. Given the input, our data is indicative of precipitation or groundwater input from short flow paths as the majority contributor of water to the Serpentine (Loeb et al. 2007, Nadim et al. 2007).

Magnesium

The concentration of Mg was lower than the mean reported for Maine streams by Nelson and Johnson (2003), mean of 892.3 ppb. The concentration reported by Nelson and Johnson was above 4000 ppb. In EP, S1 and S2 the concentration of Mg remains lower than concentrations in SC, S3 and AD. The concentration of Mg in input streams (I1 and I2) was variable between sampling dates, however mean concentrations are relatively uniform across all sample sites. As with Ca, Mg at lower concentrations could be indicative of different water sources (Wels et al. 1991, Bryan et al. 1999, Nadim et al. 2007). When the concentrations of Mg and Ca are compared and a regressive trend line is applied, a correlation is visible ($p<0.001$). This correlation implies a significant relationship between Ca and Mg concentrations in the Serpentine ecosystem (Figure 3.12).

Arsenic

As was found in several samples, the concentration of arsenic was always below the EPA limit of 10 ppb for drinking water (EPA). Arsenic concentrations were highest at SC and had a concentration of 9.6 ppb.

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4. SEDIMENT

Introduction

Phosphorus naturally occurs in low concentrations in lake ecosystems, making it a crucial limiting nutrient for plant growth. However, over the past hundred years, humans have increased phosphorus inputs to lake systems through a host of non-point sources such as bad septic systems, fertilizer use, and road runoff. Once phosphorus is introduced to a system, there are no immediate means for it to dissipate. Increased levels of phosphorus result in large algal blooms which may lead to eutrophication, decreased property values, and in extreme cases, fish kills (Hoagland et al. 2002).

Internal loading (the input of nutrients from within the system) of phosphorus from sediment is important for determining phosphorus in the water column. The model for internal loading in lakes starts with lake stratification. During the summer months, most lakes become stratified with warm water in the epilimnion and cold water in the hypolimnion. When the lake is stratified, it cannot mix. The cold, dense water of the hypolimnion is too heavy to rise to the top without a disturbance of some kind. Without mixing, oxygen cannot be replenished at the bottom of the lake. Meanwhile, the bacteria on the bottom continue to use dissolved oxygen as they decompose dead organic matter. If the lake remains stratified long enough, the bottom of the lake will become anoxic, as a result of consuming all the available dissolved oxygen, causing a nutrient release (Wilson et al. 2010). This internal loading is one of the primary drivers of phosphorus cycling.

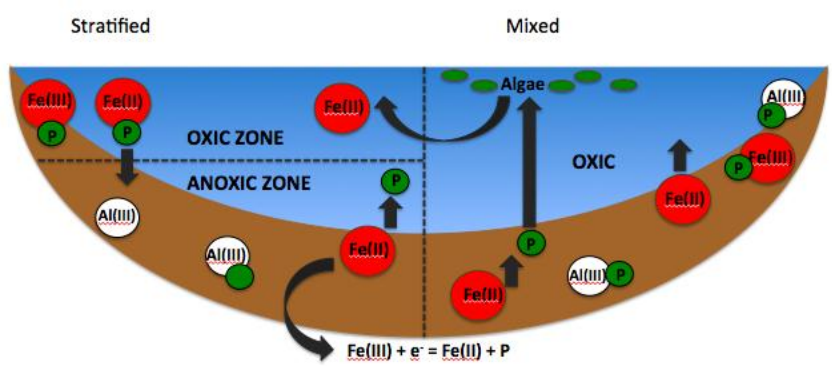

Figure 4.1. Diagram of the reduction-oxidation chemistry of phosphorus, iron, and aluminum in stratified and mixed lakes (delineated by vertical line in the middle).

Internal loading can be explained by redox chemistry within the sediments. When phosphorus is introduced to the sediment, it can either bind to iron hydroxide, $Fe(OH)_3$, or aluminum hydroxide, $Al(OH)_3$. Under anoxic conditions, the iron in $Fe(OH)_3$ is reduced from its oxidized state, Fe(III), to its reduced state, Fe(II). During this reduction the phosphorus is released from the iron. Now both Fe(II) and phosphorus are soluble in the water and can enter the water column. Aluminum is significant because it does not react under anoxic conditions. Therefore, once phosphorus binds to $Al(OH)_3$ in the sediment, it will be permanently sequestered (Lake et al. 2007, Wilson et al. 2008; Figure 4.1).

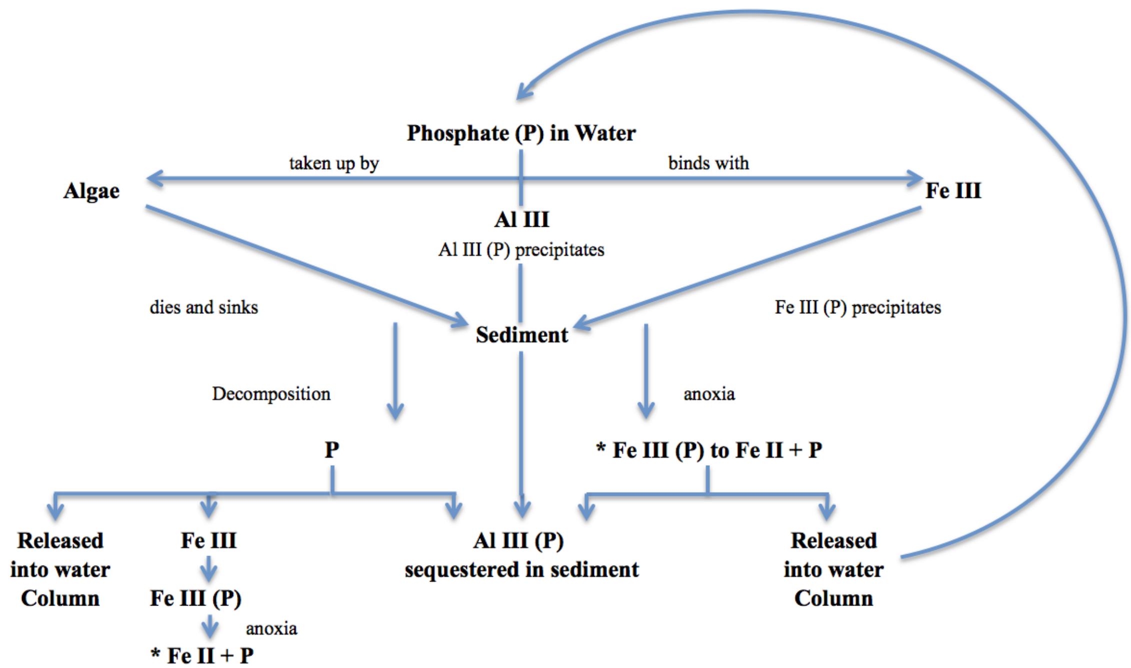

Figure 4.2. Potential pathways for phosphorus cycling in an aquatic ecosystem.

Once phosphorus is released into the water column, it will stay at depth due to the stratification of the water column. However, at certain times in the summer and at the start of the fall, the water column will mix. This mixing is mainly the result of weather events but is also dependent on the bathymetry of the lake. Shallower lakes are mixed more easily by wind, and penetrated more evenly by sunlight. Once the lake is a uniform temperature, the phosphorus at the bottom can rise to the epilimnion. In the epilimnion and hypolimnion, algae take up phosphorus. Once the algae die, they fall to the bottom of the lake where they are decomposed and the phosphorus is released again into the sediment. In addition, when Fe(II) enters the water

column, it encounters oxygen and undergoes oxidation becoming Fe(III). Any free floating phosphorus that is not taken up by algae will bind to Fe(III) and precipitate out of the water, fall to the bottom, and resume the cycle.

Over the past 10 years, scientists at the University of Maine have conducted studies on Maine lake sediments to further undersyand the trends of phosphorus cycling in sediment (Kopacek et al. 2001, Kopacek et al. 2005, Lake et al. 2007, Norton et al. 2008, Wilson et al. 2008, Wilson et al. 2010). Kopacek et al. (2005) determined that ratios of aluminum to iron (Al:Fe) and aluminum to phosphorus (Al:P) were the most important factors determining phosphorus release into the water column in acidic lakes. They did not find a significant correlation between iron and phosphorus (Fe:P). The Al:Fe and Al:P ratios are important only for lakes that become anoxic. There is also less of a correlation between the Al:Fe ratio and phosphorus in the water column when the lake is non-acidified (Kopacek et al. 2005). From graphing these correlations, Kopacek et al. (2005) found that the optimal ratio for Al:Fe in the sediment is greater than 3 and the optimal ratio for Al:P is greater than 25 (Appendix 4.A)**.** In acidic conditions, ionic aluminum will form aluminum hydroxide, which has a high absorptive capacity for phosphorus (Kopacek et al. 2001). Consequently, phosphorus that has been released from decomposing organic matter or iron hydroxide in anoxic conditions will bind with the aluminum hydroxide on the top layer of the sediment (Kopacek et al. 2001). Lastly, high concentrations of organic carbon may inhibit the absorptive capacity of aluminum hydroxide. Kopacek et al. (2005) hypothesize that an Al:P ratio greater than 25:1 and Al:Fe ratios greater than 3 will overcome the effect of high levels of organic carbon. If the ratio of aluminum to phosphorus is low, it will not be able to effectively sequester significant amounts of phosphorus. These ratios emphasize that simply analyzing the total concentrations of each element is not enough to understand the true dynamics of phosphorus cycling.

There are a few key differences between East Pond and North Pond that govern the nutrient cycling in each lake. Dr. Whitney King (Colby College) has been monitoring summer lake mixing events in these lakes since 2007. King uses data loggers dispersed throughout the water column to collect continuous temperature data throughout the summer. Graphs of these data show periods of stratification and mixing (Appendix 4.B).

Generally East Pond is stratified until July 29th (Day 210). Additionally, during the greatest stratification, the difference between the surface water temperature and the bottom water

temperature is 4.8° C on average (King, unpublished data). This contrasts with North Pond, which shows weak stratification but overall is relatively mixed throughout the summer. On average North Pond is only stratified by 3°C (King, unpublished data). The data are consistent with past reports, which show that North Pond is polymictic, and does not stratify seasonally (CEAT 1997). These data indicate that North Pond does not reach anoxic conditions, or only reaches anoxic conditions for very short periods of time compared to East Pond. Thus, the release of phosphorus from $Fe(OH)_3$ may occur only at a reduced rate in North Pond (Temperature graphs for East Pond and North Pond since 2006 are available in Appendix 4.B).

The lack of stratification in North Pond can be explained by its bathymetry. North Pond is shallower than East Pond by approximately 1 meter on average. In addition it has a more basin-like bathymetry compared to East Pond's vase like bathymetry (Appendix 4.C) (King, unpublished data). Since North Pond is shallower, light can penetrate farther into the water column keeping the lake a more uniform temperature. In addition, North Pond experiences stronger cross winds along the surface water, allowing it to mix many times throughout the summer, not only with storm events.

Ground Water Indicators: Calcium and Magnesium

Calcium and magnesium are ground water indicators (Lottig et al. 2011). While magnesium does not play a role in nutrient cycling, calcium is a potential source of phosphorus to the system. When calcium enters the system it may be bound up in apatite, $Ca_5(PO_4)_3OH$, or calcium carbonate, $CaCO_3$, from the underlying bedrock. Phosphate is released into the system from calcium due to weathering and acidic conditions (Schlesinger 1997).

Total Organic Carbon

TOC in sediment is a measure of both detritus from dead plant and animal tissue, as well as living biota within the sediment. This carbon is a central part of the carbon cycle in freshwater ecosystems. Carbon may have its source in atmospheric inputs of CO_2, groundwater, or surface water inputs; it also becomes sequestered in living organisms (Myrbo and Kelts 1999). This organic form of carbon may be decomposed by bacteria in the sediment or act as a source of dissolved carbon in the water column. Organic carbon levels sre related to sedimentation rates in eutrophic lakes (Nesbeda 2004). Increased runoff from agriculture and development may also contribute to sedimentation. Levels of organic carbon in the sediment are indicative of decomposition rates. Decomposition occurs in a series of reactions involving a variety of biota.

The basic formula for decomposition in the presence of sufficient oxygen (aerobic) is as follows: O_2+ Organic Carbon → CO_2 +H_2O.

In anoxic environments, decomposition of organic carbon may occur through a variety of other processes, including denitrification, manganese-reduction, iron-reduction, sulfate-reduction, and methanogenesis (Richards et al. 1965). The iron reduction process, from Fe(III) to Fe(II), causes phosphorus to be released into the water column. These alternative processes are increasingly energy deficient. Thus, higher levels of organic matter in sediment should indicate slower rates of decomposition, and therefore may be used as a partial indicator of oxygen levels in the sediment and water column.

Materials and Methods

Sediment Sampling

In late September 2011, sediment samples were taken from East Pond, North Pond, and the Serpentine using a Wilco grab-sampler. One sample was taken from each of the 11 sites. After collection, the samples were stored in sealed Ziploc bags and refrigerated in the lab. The samples were then dried at 100º C for at least 24 hours.

Sequential Extraction

The sediment samples were analyzed using the sequential chemical extraction procedure developed by Psenner and Pucsko (1988) (Table 4.1). In accordance with this procedure, approximately 1 gram of dried sediment was weighed from each sample.

Table 4.1. Sequential sediment extraction procedures.

Step	Solution	Time	Nutrients Released
Step 1	1 M NH_4Cl	1 hour	Ion Exchangeable
Step 2	0.1M $Na_2S_2O_4$ and 0.1M $NaHCO_3$	0.5 hour	Reducible metal hydroxides
Step 3	0.1 M NaOH	16 hours	Organic matter
Step 4	0.5 M HCl	16 hours	Inorganic matter
Step 5	1M NaOH	24 hours at 80°C.	Residual

Step 1 extracted any nutrients that were ion exchangeable, or easily dissolved in water. Step 2 represents reducible metal hydroxides, which are released in anoxic conditions. More specifically, this represents the phosphorus bound to $Fe(OH)_3$. Step 3 extracted phosphorus

bound to $Al(OH)_3$, as well as any nutrients tied up in the organic matter. Step 4 extracted any nutrients dissolvable in acidic environments. This is especially important for any phosphorus bound to calcium. Step 5 extracted any residual phosphorus bound by rocks. Each fraction was centrifuged at 1500 rpm, and the supernatant was decanted for analysis. Each step was run twice, to ensure full extraction. Between steps, each sample was rinsed with deionized water and centrifuged for 15 minutes.

ICP

The samples were run through an Inductively Coupled Plasma Optical Emission Spectrometry machine, (ICP-OES). The ICP measures the wavelengths of light emitted by particular elements, in order to determine the specific concentration of each element in a sample. The supernatant from each step in the sequential extraction was diluted in 3% nitric acid (HNO_3) by a factor of 10 or 100 in order to attain the concentration levels that were able to be read by the ICP. Steps 1, 2, and 4 were diluted by a factor of 10. Steps 3 and 5 of the sequential extraction procedure were diluted by a factor of 100 because their concentrations were too high for the ICP to read properly.

Loss on Combustion

Levels of TOC were determined using mass loss on combustion. 1 gram of sediment for each site was combusted for 5 hours at 500-1000° C. The difference in weight before and after the combustion represents the proportion of total carbon (TC) in the sample. From the ICP results, the level of inorganic carbon in each sample was determined by the amount bound in $CaCO_3$. This inorganic carbon was subtracted from the TC to calculate TOC. These differences were negligible, indicating that the majority of carbon present was organic in composition.

Results

Total concentrations of phosphorus are the highest in EP, S3, NP, and I2 (Figure 4.3). A slight increasing trend is observed through the Serpentine. The concentration of releasable phosphorus is highest at EP, S1, S2, and SC (Figure 4.4). A decrease in releasable phosphorus is noticed starting in S3 through BD. The input streams also have relatively low concentrations of releasable phosphorus, as compared to S1, S2, and SC. The concentration of phosphorus bound up in organic matter is lower at S1, S2, and SC is notably high for sites S3, Ad, and I2 (Figure 4.5). BD has very low concentrations of phosphorus bound up in organic matter.

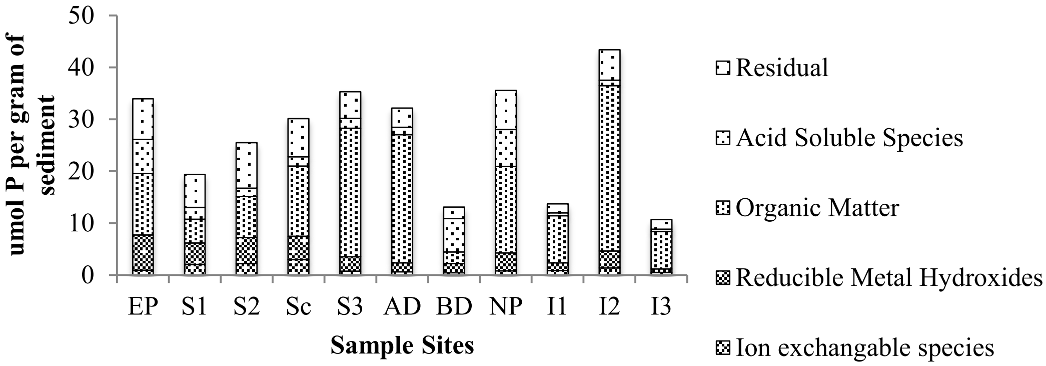

Figure 4.3. Total phosphorus measured in µmol P/g of sediment for all steps. The steps are in sequential order with step 1 on bottom and step 5 on top.

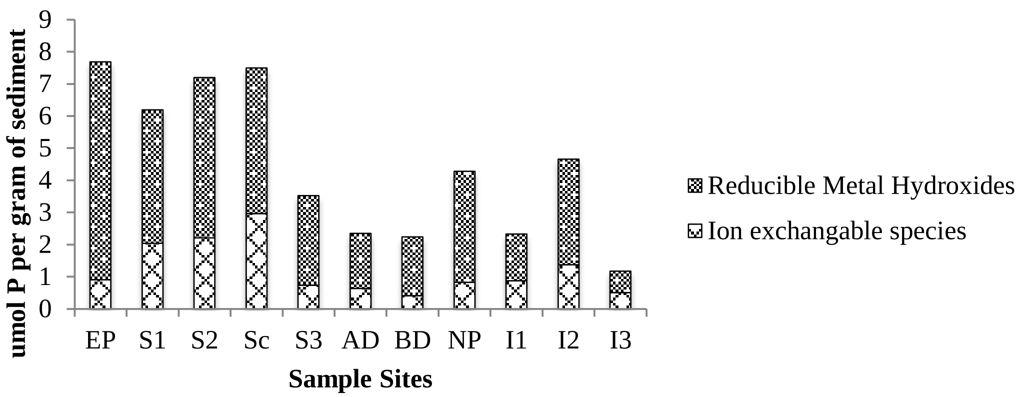

Figure 4.4 Phosphorus measured in µmol P/g of sediment for step 1 ([1M] NH4Cl) and step 2 (Bd), also known as releasable P.

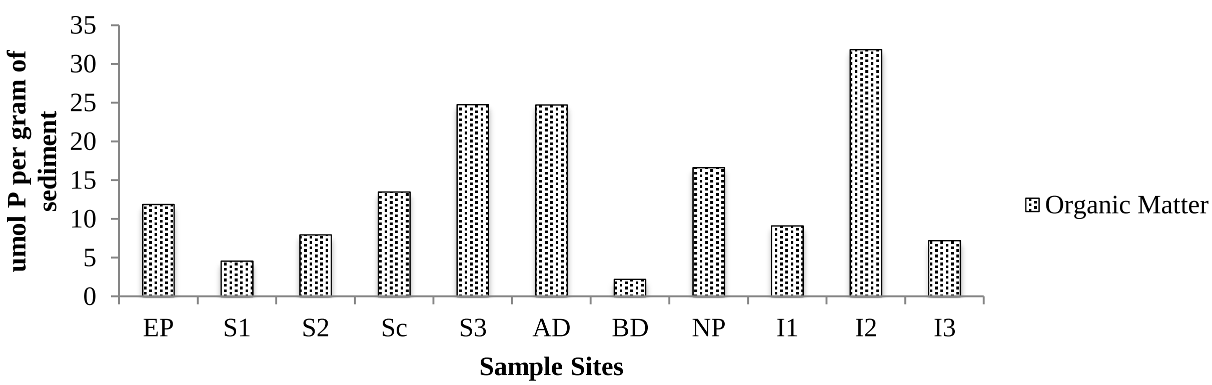

Figure 4.5. Phosphorus measured in µmol P/g of sediment for step 3 ([0.1M]NaOH). This represents the phosphorus bound up in the organic matter.

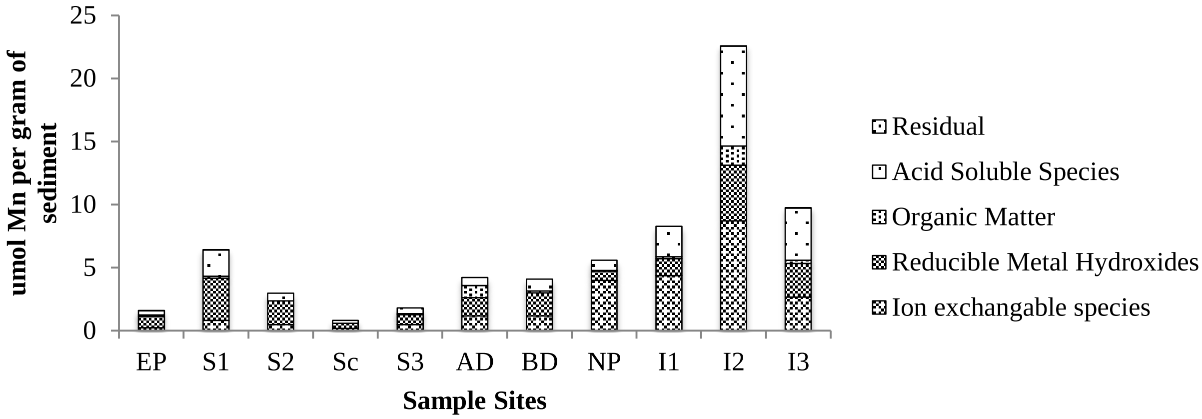

Figure 4.6. Total manganese measured in µmol Mn/g of sediment for all steps.

Total manganese levels are notably low across all sites (Figure 4.6). The highest concentration is found at site I2; however, it does not exceed 25 µmol Mn/g.

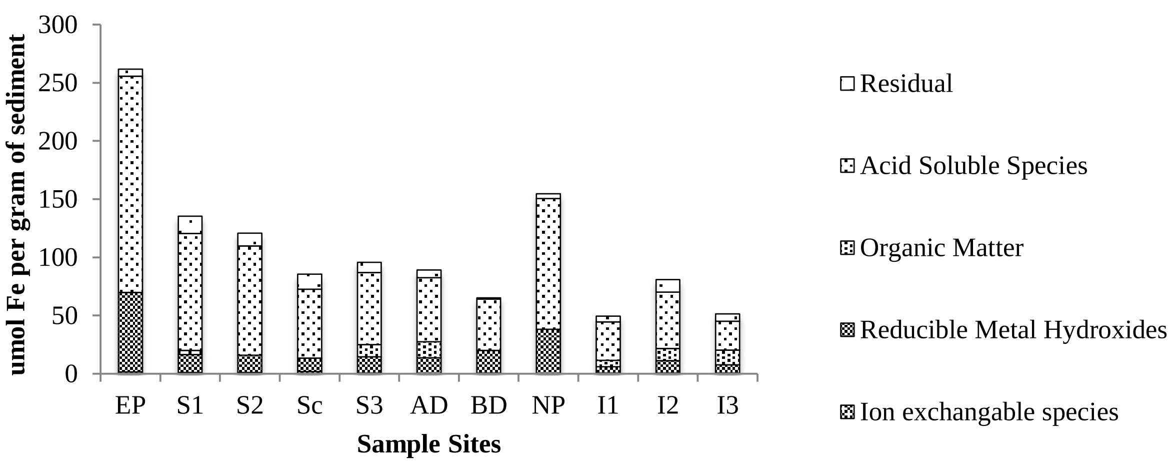

Figure 4.7. Total iron measured in µmol Fe/g of sediment for all steps.

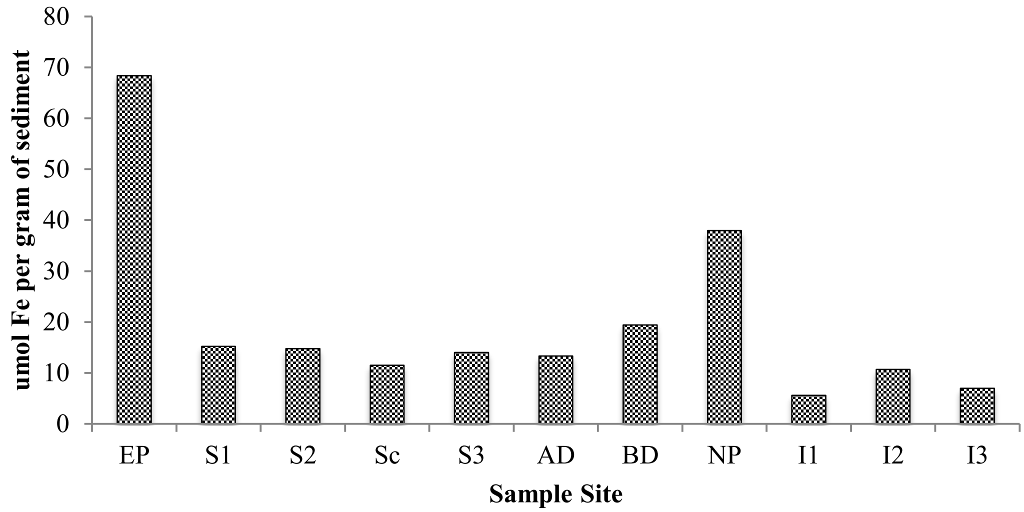

Figure 4.8. Reducible iron (Fe(III)) measured in µmol Fe/g of sediment from step 2 (Bd). This represents concentrations of $Fe(OH)_3$ in the sediment.

Total iron concentrations are notably higher in East Pond and North Pond, with the highest levels in East Pond. (Figure 4.7). This is also true for the levels of $Fe(OH)_3$ (Figure 4.8). The levels of $Fe(OH)_3$ throughout the Serpentine and its tributaries remain relatively constant, with an mean of 12.39 µmol/g of sediment among the Serpentine sites. East Pond levels of $Fe(OH)_3$ were 68.37 µmol/g of sediment. The concentration in North Pond was 37.97. These two sites exceeded the Serpentine mean by 55.98 and 25.58 µmol/g of sediment, respectively.

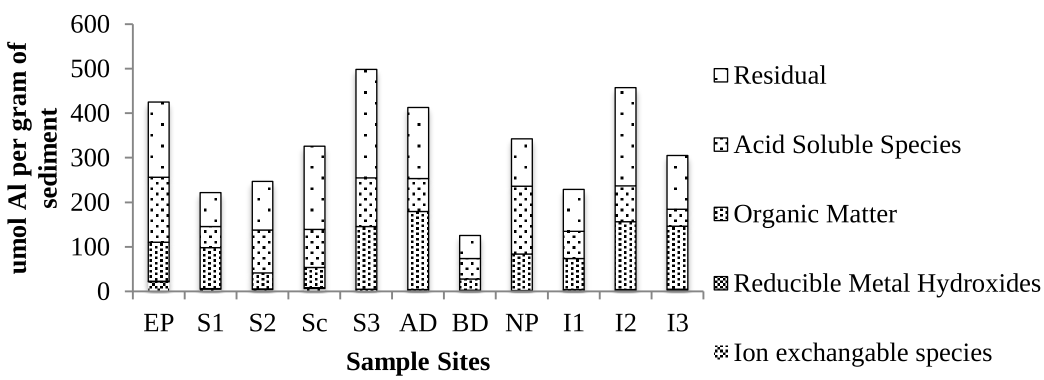

Figure 4.9. Total Al measured in µmol Al/g of sediment from all steps.

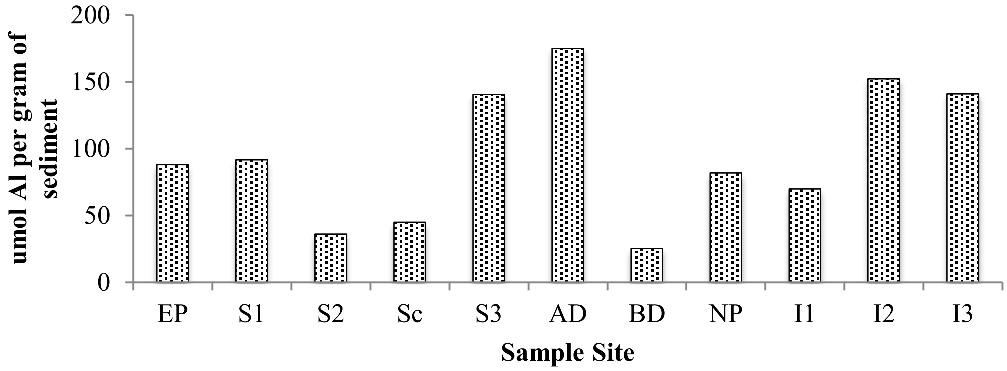

Figure 4.10. Aluminum measured in µmol Al/g of sediment from step 3 ([0.1M] NaOH). This represents concentrations of $Al(OH)_3$ in the sediment.

Total aluminum concentrations are much higher compared to the other elements (Figure 4.9). The highest aluminum concentrations are found in EP, S3, AD, and I2. Levels of $Al(OH)_3$ exhibit greater spatial variability than $Fe(OH)_3$ (Figure 4.10). Overall, the mean concentration of $Al(OH)_3$ is 95.15 µmol/g of sediment. Intermediate levels of $Al(OH)_3$ were found in EP, S1, NP, and I1. However, S3, AD, I2, and I3 greatly exceeded the mean. In site AD, the concentration of $Al(OH)_3$ was 174.92 µmol/g of sediment, which is 79.7 ppb greater than the mean. The concentration at site I2 was 152.3 µmol/g sediment, which is 57 ppb greater than the mean.

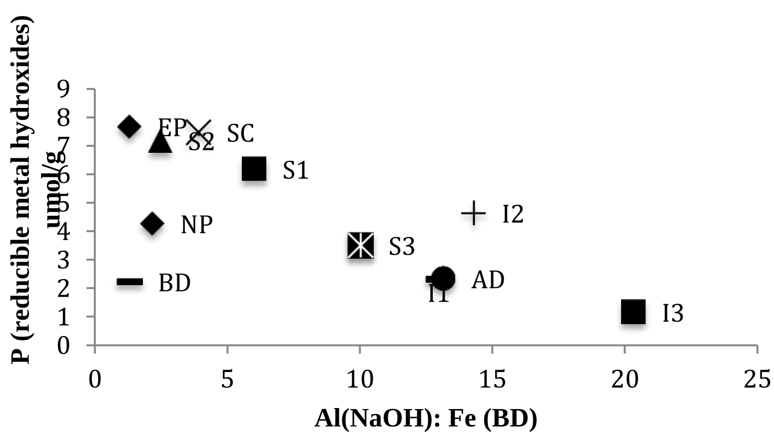

Figure 4.11. Phosphorus measured in µmol P/g of sediment for steps 1 and 2, plotted against the ratio of aluminum (step 3) to iron (step 2).

Sites EP, S2, BD, NP and I1 have Al:Fe ratios below 3 (Figure 4.11). The concentration of phosphorus is generally highest at these sites, as well, with the exception of BD and NP. At higher Al:Fe ratios, the phosphorus concentration generally decreases, and remains below 4μmol/gram of sediment.

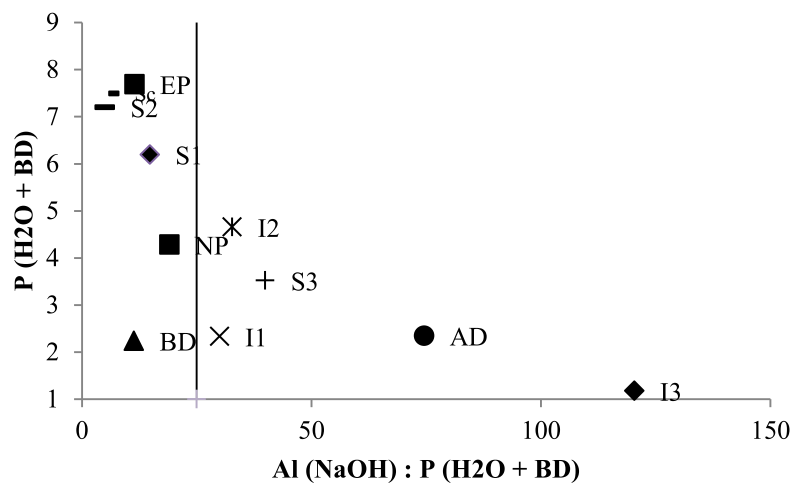

Figure 4.12. Phosphorus measured in μmol P/g of sediment for steps 1 and 2, plotted against the ratio of aluminum (step 3) to iron (steps 1 and 2).

A generally negative correlation between phosphorus concentration and Al:P ratios exists (Figure 4.12). Sites EP, S1, S2, SC, BD, and NP have Al:P ratios below 25. Of these sites, NP and BD have considerably lower concentrations of phosphorus. The remaining sites have ratios of Al:P greater than 25, and generally low phosphorus concentrations. Of those remaining sites, AD and I3 have phosphorus concentrations below 3 μmol/g of sediment and particularly high ratios of Al:P (74.56 and 120.38 respectively).

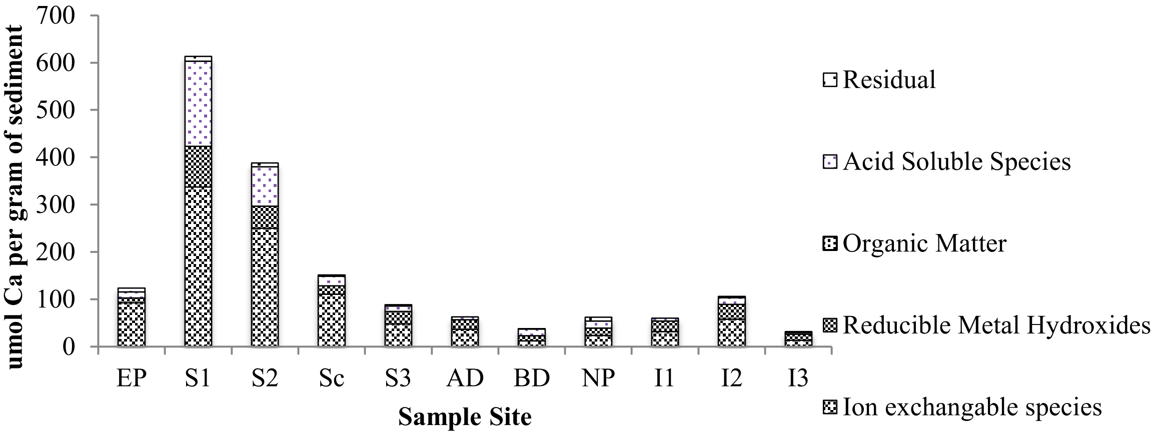

Figure 4.13. Concentration of Calcium in µmol Ca/g of sediment for all steps.

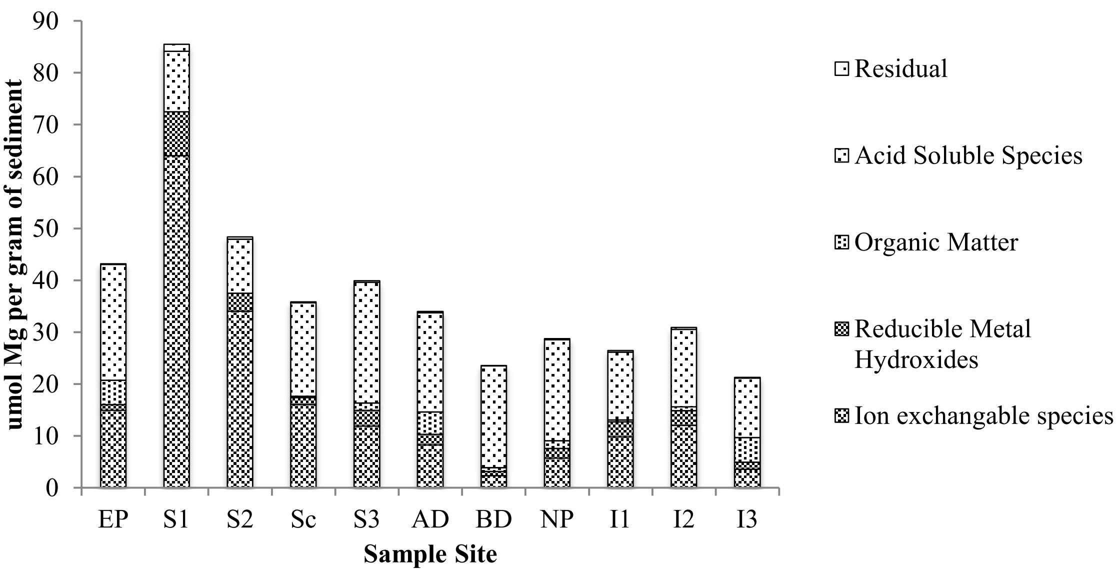

Figure 4.14. Concentration of total Magnesium in µmol Mg/g of sediment for all steps, across sites.

Calcium concentrations are mostly extracted from step 1, ion-exchangeable species (Figure 4.13). Total calcium levels are notably high at sites S1 and S2. The concentration of calcium extracted from step 2 is greater in S1 and S2 than in other sites. Total magnesium is primarily extracted from steps 1 and 4 (Figure 4.14). Magnesium is high at site S1, while remaining relatively constant throughout the other sites. The amount of acid soluble species (step 4) is relatively constant, with much of the variation among totals resulting from variation in ion exchangeable magnesium.

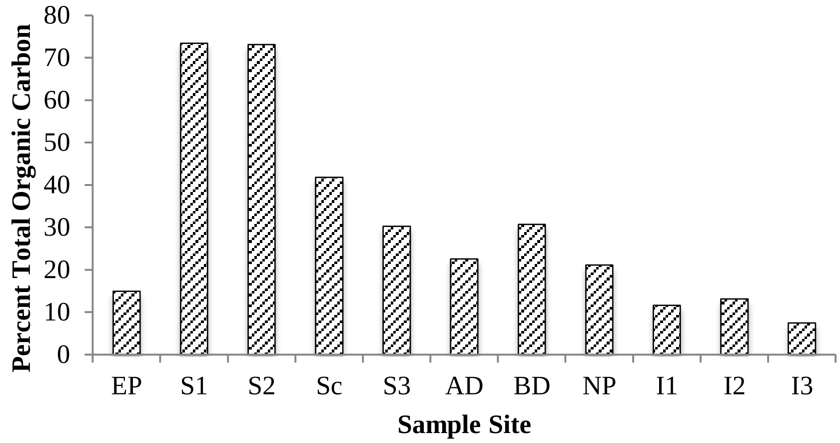

Figure 4.15. Percent TOC for each site as a result of the loss of combustion.

The mean TOC for all sites is 30.9 percent. S1 and S2 exhibit extremely high proportions of organic carbon, and SC substantially exceeds the site mean. This indicates higher proportions of TOC at fen sites, in comparison to lower proportions of TOC in the input streams and below the fen.

Discussion

Redox reactions in the soil: Nitrogen, Manganese, and Iron

Once oxygen becomes depleted due to bacterial respiration, decomposition continues to occur through a variety of redox reactions with other elements. Denitrification occurs first, followed by manganese-reduction and iron-reduction. Generally, phosphorus is the limiting nutrient in Maine aquatic ecosystems as opposed to nitrogen (Bjorn 2009). In accordance, low levels of nitrogen were found in the water column, as compared to iron (Figure 3.7, Figure 3.13). Manganese concentrations are also very low indicating that iron-reduction would occur soon after the anoxic conditions set in. This confirms the emphasis placed on iron and aluminum concentrations in East and North Pond in previous studies.

The same sediment analysis was performed on East Pond and North Pond during the summer of 2011. Sediments were gathered along a cross section of each lake at different depths. The sediment analyzed for East Pond was gathered in 2004 and stored in glass vials. On average the total iron concentration found in East Pond was 86.6 μmol/g and 135.5 μmol/g in North Pond (King, unpublished data; Appendix 4.D). The mean iron concentration gathered from East Pond

in the summer is lower than the mean gathered this fall, but that may be attributed to the fact that the actual sediment used in the past study was physically gathered a several years ago. Additionally, another study conducted on six Maine lakes using the same sediment extraction procedure gathered sediments in May, July, and September. For the six Maine lakes studied, iron concentrations varied from 150 μmol/g to 1070 μmol/g. The wide variance in iron concentrations was found between lakes and was found between sample dates. In other words, some lakes showed extreme variance in iron concentrations between May and July and July and September 9 (Lake et al. 2007, Appendix 4.E).

Iron concentrations in East Pond and North Pond exceed those in the Serpentine. Like phosphorus, iron is released into the water column and ultimately resettles on top of the sediment (Kopacek et al. 2001). Therefore iron would continue to accumulate in the lakes with sedimentation instead of being buried. Alternatively, because water flows through the Serpentine, the iron may not settle on the sediment, but be moved through the system to accumulate in the lakes.

Aluminum

On average, aluminum concentrations found during the summer of 2011 were 895.41 μmol/g for East Pond and 424.91 μmol/g for North Pond (King, unpublished data; Appendix 4.D). Again, North Pond concentrations are relatively consistent for the summer and fall data. However, East Pond levels were higher in the summer data. The study done by Lake et al. (2007) shows that there are variances in aluminum concentrations from month to month (Appendix 4.E), so it is likely that the data from the summer will not exactly match the data from the fall and even more so if sample dates vary by several years as it does for East Pond data.

Since there is no mechanism by which aluminum enters the water column, it stays in the soil and is continually buried with sedimentation over time (King personal communication). Hence, aluminum inputs are important for keeping the aluminum to iron ratio high, which keeps phosphorus low in the water column. Based on the data, higher amounts of aluminum are present in I1, I2, SC, S3, and AD. The variability of aluminum in the Serpentine may be explained in two ways. First, higher concentrations of aluminum at sites I1, I2, SC, S3, and AD is consistent with higher concentrations of aluminum in the water column at I1 and I2. The higher amounts in SC, S3, and AD may be the result of aluminum precipitating out as it travels down the Serpentine. Second, the high amount of TOC at S1 and S2 may dilute the aluminum

concentration at these sites. In other words, the accumulation of dead sphagnum moss, which is high in TOC, may be diluting any aluminum that is being introduced to the sediment. It is likely that both of these hypotheses play a role in aluminum variance across sites. Lastly, there is lower accumulation in the lakes because, unlike iron, the aluminum is being buried with sedimentation.

Phosphorus

Mean phosphorus concentrations across depths gathered in the summer of 2011 were 44.96 µmol/g for East Pond and 40.83 µmol/g for North Pond (Appendix 4.D). These concentrations are relatively consistent with the data gathered in the fall. Variances may be explained by sample date (Lake et al. 2007; Appendix 4.E).

East Pond

Al:Fe ratios were also calculated for East Pond in the summer of 2011. The mean Al:Fe ratio for East Pond is 0.1074 and is associated with 28.16 µmol/g of releasable phosphorus (Appendix 4.F). Lake (2009) found the Al:Fe ratio in East Pond to be around 1.75 for the top 10 cm of sediment.

Compared to the other lakes in the Belgrade Lakes watershed, East Pond has the most drastic algal blooms, turning the surface a milky pea green color at times (CEAT 2000). The explanation for these algal blooms is found in the biogeochemistry. East Pond has the highest amounts of releasable phosphorus (phosphorus from NH_4Cl and Bd) and a low Al:Fe ratio (Al:Fe for EP = 1.29). Additionally, the Al:P ratio is lower than 25. Thus, East Pond's sediments are conditioned for high nutrient release after periods of anoxia followed by mixing, potentially causing algal blooms. The temperature graphs (King, unpublished data) in Appendix 4.B show this cycle. The temperature data shows the lake stratifying and mixing. Years with a large difference between the temperature at the top and the temperature at the bottom of the lake (large stratification) are generally associated with large algal blooms, shown by a shallow secchi depth. Therefore a combination of the proportion of nutrients in the sediment, the event of stratification, and weather events are driving the algal blooms in East Pond.

North Pond

The mean Al:Fe ratio for the summer of 2011 data for North Pond is 7.43 and is associated with 3.49 µmol/g of releasable phosphorus (King, unpublished data; Appendix 4.F). Our data on the other hand was below 3, closer to the ratio that Lake (2009) found. Lake (2009)

found the Al:Fe ratio to be around 1.75 for the top 5 cm of sediment but the Al:Fe ratio is 2.72 at 10 cm depth in the soil.

North Pond also has an Al:Fe ratio below 3 and Al:P ratio below 25 indicating that its sediments will not efficiently sequester P. Overall concentrations of iron and aluminum do not vary greatly between East Pond and North Pond. However, North Pond does not go anoxic, so it would not experience the same frequency of algal blooms because Fe is not reduced. Thus, North Pond is not governed by the same mechanisms as East Pond.

The Serpentine

TOC was also calculated for the sediments gathered in the summer of 2011. On average, East Pond had 14.26% TOC and North Pond had 11.86% TOC (King, unpublished data). Nesbeda (2004) found 30.6% TOC near sites S1 and S2. The TOC data for the lakes is relatively consistent however it is interesting that Nesbeda (2004) found relatively low TOC in the mouth of the Serpentine compared to our data. This may be a result of our sampling position in the stream channel. Our samples may have been taken nearer to the shoreline of the fen, resulting in higher levels of deposited plant material.

The TOC is high at sites S1 and S2 but is relatively low for the rest of the Serpentine. There are several general differences between S1 and S2 that influence the high TOC. First, S1 and S2 are located in the fen, which is dominated by sphagnum moss. Sphagnum moss is known to produce a phenolic compound called sphagnol, which inhibits decomposition (Aerts et al. 1999). Therefore the high levels of TOC can be attributed to the sphagnum moss that is only very slowly decaying on the bottom. Additionally, relatively high DO in the water column may be a result of low decomposition rates. This supports the hypothesis that there is inhibited decomposition of organic material near the fen.

Second, the phosphorus data shows step 3 of our sequential extraction procedure is small at S1 and S2 while step 3 in SC, S3, AD, I1 and I2 is large. Step 3 represents phosphorus bound either in organic matter or bound to aluminum. Since S1 and S2 are so high in TOC, it is assumed that the amount of phosphorus in general is being diluted by the high amounts of TOC. This is logical as sphagnum is known to be a large carbon sink. The larger fractions of step 3 at SC, S3, and AD indicate that the phosphorus is binding to aluminum in the water column and precipitating into the sediment. This explains the slight increasing trend in phosphorus and aluminum from SC to AD.

Like North Pond, the Serpentine is shallow, indicating that it is probably well oxygenated. Therefore, once phosphorus binds with iron in the sediment, it will remain there since iron will not undergo a redox reaction in oxic environments. In other words, the sediment is not driving the nutrient chemistry in the Serpentine like it is in East Pond.

Calcium and Magnesium

The spike in calcium and magnesium at S1 indicates that there is a ground water input. At these sites, the concentration of Ca in the sediment greatly exceeded the concentration of 0.5 μmol/g found in the water column. It can thus be assumed that the calcium is not solely coming from the water column, because if the water were the only source of calcium to the sediment, then the sediment should only have around 0.5 μmol/g of calcium. Precipitation does not generally contribute calcium and magnesium, so it may be concluded that there is a ground water source. Additionally, while the high concentrations of calcium and magnesium are most likely coming from a ground water input, it is not flowing into the Serpentine at a high rate. If this were a major spring with high flow, more calcium would be dissolved in the water column and not found in the sediments.

Calcium is significant in nutrient cycling because it can be either a source or a sink for phosphorus depending on the pH and the solubility constant of calcium phosphate. Calcium can introduce phosphate to the system via the mineral apatite, which is easily dissolvable in acidic conditions. However, it does not appear that there is any apatite coming up through the ground water. Therefore, calcium would primarily impact nutrient cycling if the phosphate in the water column is binding with the calcium. If the calcium is taking up phosphorus, then the calcium would sequester the phosphorus in a manner similar to aluminum. Calcium is a Lewis acid and phosphate is a Lewis base. Using the solubility product constant (Ksp) for calcium carbonate ($Ksp = 2.6x10^{-7}$), it was determined that phosphate would dissolve into the water column and not precipitate with calcium at a pH of 6 (Harris 2010).

The acid soluble step of the sequential extraction represents phosphorus that is bound in apatite or calcium carbonate (Kopacek et al. 2001). The results from the ICP indicate that there is only a small amount of phosphorus associated with calcium. Regardless, this phosphorus concentration is interesting to consider, as it only takes a small amount of phosphorus to be ecologically significant in this ecosystem.

Magnesium is capable of the same interactions with phosphorus as calcium. However, it occurs in very low concentrations, resulting in a very small ecological affect.

Future studies may want to consider increasing the sampling size so that a statistical analysis can be run. Additionally Lake et al. (2007) displayed the variance that can occur as a result of sample date and seasonal changes. So sampling over a period of time may be something to consider. If sediment samples are taken somewhat regularly in conjunction with water samples, the direct of effects of internal loading may be more easily quantified.

More research should also be conducted on the flow in the Serpentine. In 2009 the East Pond Dam Association calculated the flow over the dam after heavy rain in order to project how long it would take for East Pond water levels to return to normal. East Pond drained at a much faster rate than was projected. Therefore it can be concluded that the water must be draining out of East Pond in more places than just the Serpentine. It is possible that the water is flowing underground through the esker to North Pond. However more research should be done before any conclusions are drawn.

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5. FISH

Introduction

Fish are an essential component of freshwater lakes and streams. Therefore, fish are not only important to consider in the context of their own habitat, but also in the context of their interactions across trophic levels and the powerful ways that these linkages can drastically affect community structure. Trophic cascades are the primary way that fish species can transform ecosystem composition. At the most basic level, trophic cascades occur when a species in the dominant trophic level reduces the abundance of a species in the mid-trophic level (Figure 5.1). This reduces grazing pressure on species in the lowest trophic level, allowing their populations to increase (Pace et al. 1999). Trophic cascades are not caused solely by increased abundance of species in the top trophic level, but can also result from drastic increases or decreases in species populations within any feeding ecology (Pace et al. 1999).

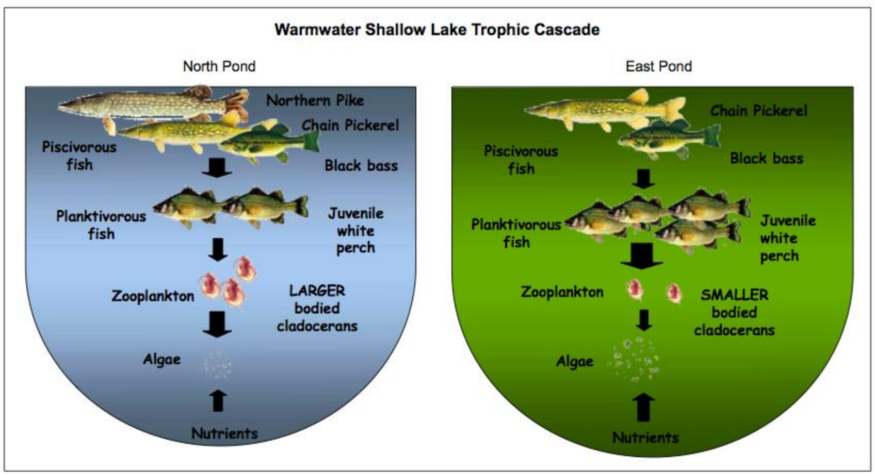

Figure 5.1. East and North pond trophic cascade (Source: Halliwell and Evers 2008).

Trophic Cascades

In freshwater ecosystems, such as lakes and streams, algal blooms are often associated with high nutrient inputs, but may also signal the occurrence of trophic cascades among fish species; a high abundance of zooplanktivorous fish can reduce zooplankton populations, leading to an increase in phytoplankton populations and increased likelihood of algal blooms (Vanni et al. 1997). Algal blooms result in a large accumulation of dead organic matter. The decay of algae consumes the majority of oxygen in the water column, leaving little for other species, and sometimes resulting in fish kills. While algal blooms can have deleterious effects on both

freshwater and marine ecosystems, trophic relationships can also be manipulated to mitigate the occurrence of algal blooms. Trophic manipulations are especially effective when algal blooms are more likely attributed to increased nutrient inputs, such as phosphorus. In these freshwater ecosystems, phosphorus is an extremely important limiting nutrient in biotic productivity. When there is an excess amount of phosphorus in the water column, algal populations are able to take advantage of this surplus resulting in algal blooms (Carpenter et al. 1987).

Biomanipulations

By removing predator biomass, it is possible to promote growth of zooplankton populations, causing the grazing pressure on algal populations to rise (Halliwell and Evers 2008). This process is known as biomanipulation, or the altering of an ecosystem through the removal or addition of species (Lathrop et al. 2002). There are many examples of biomanipulation projects to reduce the likelihood of algal blooms in freshwater lakes (Carpenter et al. 1987, Vanni et al. 1997, Lathrop et al. 2002, Halliwell and Evers 2008); understanding the basic results each of these projects can shed light on the current biomanipulation project applied to East Pond.

Carpenter et al. (1987) conducted a biomanipulation project in Michigan on three lakes: Peter, Paul, and Tuesday. Paul Lake was used as the reference ecosystem and remained undisturbed during the experiment. Peter Lake and Tuesday Lake both underwent reciprocal fish exchanges, 90% of adult bass biomass was moved from Peter Lake to Tuesday Lake and ~90% of minnow biomass was moved from Tuesday Lake to Peter Lake. As expected, no significant change was observed in Paul Lake, the undisturbed lake. However, fish manipulations significantly changed zooplankton community structure in Tuesday Lake with a 70% increase in zooplankton biomass, causing a decline in primary production. Conversely, with higher minnow abundance, Peter Lake experienced increased zooplanktivory, decreased zooplankton biomass, and increased phytoplankton biomass and productivity. This experiment highlights the different impacts major changes in fish species abundance of a specific trophic level can have on habitat structure.

Vanni et al. (1997) conducted another biomanipulation project in Michigan's Tuesday Lake. Following the piscivore addition by Carpenter et al. (1997) to Tuesday Lake, all of the introduced bass were removed in order to return Tuesday Lake's food web to pre-manipulation conditions. As a result of this, fish assemblages in Tuesday Lake at the beginning of the Vanni et al. (1997) study were essentially the same as before the Carpenter et al. (1987) study. Vanni et al.

(1997) wanted to quantify the effects of zooplanktivorous fish on nitrogen and phosphorus dynamics in order to understand top-down impacts of fish on phytoplankton nutrients. Four different enclosures were constructed to observe the effects of low, medium, and high zooplanktivorous fish abundance on zooplankton populations. One enclosure was kept as a control and no zooplanktivorous fish were added to it. The biomass of two large species of herbivorous zooplankton, *Daphnia* and *Holopedium*, were more abundant in the "no fish" enclosures than in the enclosures with fish. No significant difference was detected between fish enclosures with high, medium, and low zooplanktivorous fish populations. Vanni et al. (1997) observed that the zooplanktivorous fish had significant effects on the nitrogen and phosphorus dynamics in the water column; fish abundance was positively correlated with total nitrogen and total phosphorus. Total phosphorus increased more in relation to total nitrogen, which resulted in the ratio of total nitrogen to total phosphorus (TN:TP) decreasing significantly. The concentrations of particulate carbon, nitrogen, and phosphorus were significantly higher in the presence of fish and Vanni et al. (1997) noted that fish were a net source of phosphorus to the water column. Overall, this study emphasizes the role zooplanktivorous fish play in their habitat, suggesting implications for reducing or amplifying their populations especially in terms of controlling algal populations and limiting the occurrence of blooms.

In Wisconsin, Lathrop et al. (2002) conducted a biomanipulation project by continually stocking Lake Mendota with walleye fingerlings, walleye fry, and northern pike fingerlings between the years 1987 and 1999 in order to reduce phytoplankton populations. Harvest restrictions were established to protect walleye and northern pike populations. As a result of the additions, walleye and northern pike biomass increased and consumption of prey (cisco and Yellow Perch) biomass also increased. Prior to the biomanipulation, cisco and Yellow Perch were the dominant zooplanktivores in Lake Mendota, but as the study progressed, zooplanktivory declined. As a whole, the Lake Mendota biomanipulation project was successful, marked by high densities of *Daphnia* zooplankton as well as high northern pike and walleye biomass. The success of this project highlights the importance of careful husbandry of a biomanipulation project as opposed to simply adding or removing species and leaving the system alone; it is important to protect added populations and ensure that the fish being introduced are not immediately being taken out by fishermen. It is also important to continue assessing the populations and restocking when necessary.

Halliwell and Evers (2008) conducted a biomanipulation project in East Pond in the Belgrade Lakes watershed of Maine. Halliwell and Evers (2008) used a top-down approach with the hopes of minimizing zooplanktivorous fish species, allowing zooplankton populations to increase, and consequently increasing herbivory on algal populations. In total, 40,570 fish were captured and removed from East Pond. Adult White Perch dominated the biomass removed in both number of individuals and weight. As of November 2011, the results of the biomass removal are still unclear because there are still algal blooms in East Pond. Understanding the fish species occurrences and assemblages, in addition to the water and sediment chemistry in East Pond and the Serpentine may suggest reasons as to why the East Pond biomanipulation project has not been as successful as it was expected to be in terms of limiting algal blooms in the pond.

Economic and Ecological Services

Fish provide many important benefits for the economy and the ecosystem in the Belgrade Lakes community. In terms of societal value, fish provide economic benefit through recreational fishing (Holmlund and Hammer 1999). Fishing is a major tourist attraction to the Belgrade Lakes and the presence of game fish, such as bass and trout, make these lakes popular destinations for recreational fisherman. The total net economic value of Maine's Great Ponds is estimated at about $6.7 billion annually (Maine DEP 2005).

Additionally, fish provide many ecosystem services. For example, having a diverse assemblage of fish species is vital to maintaining diversity and resilience of an ecosystem. Resilience is an especially important characteristic of an ecosystem in order to maintain its structure and function in the face of ecological and anthropogenic stressors. Without a diverse fish community, the Serpentine could become more susceptible to pollution and algal blooms, which would negatively impact tourism and water quality (Holmlund and Hammer 1999).

Fish also play an important role in aquatic and terrestrial food web linkages, in that their existence does not merely impact their aquatic habitat, but also terrestrial habitats and processes. Holmlund and Hammer (1999) divide ecosystem services provided by fish into two categories: fundamental and demand-driven. They define fundamental services as services that are critical for ecosystem function. Demand-driven services, on the other hand, are those services that are not necessarily essential to the ecosystems, but are more often tied to human values and demands, such as recreation.

The primary ecosystem services that fish species provide are regulation of food web dynamics, nutrient cycling, regulation of sediment processes, and linking of ecosystems (Holmlund and Hammer 1999). Fish can regulate trophic structure through predator-prey relationships and the exertion of strong top-down control of primary productivity (Holmlund and Hammer 1999). Piscivores, fish that feed on other fish, prey on zooplanktivorous fish. Zooplankton, in turn, feed on algae, meaning that changes in the abundance of species in a given trophic level can impact population dynamics and community composition throughout an entire habitat (Holmlund and Hammer 1999). Furthermore, fish also contribute to essential nutrient cycling processes in lakes and streams by taking up and releasing nutrients such as phosphorus and nitrogen through consumption, excretion, and decomposition (Vanni 2002). Some fish have been shown to contribute to bioturbation, displacement and mixing of sediment particles. Through this process, bottom-dwelling fish resuspend silt, detritus, and other organic matter from the bottom and also contribute to the structuring of bottom conditions in lakes and streams (Holmlund and Hammer 1999). Bioturbation can impact biota present in a habitat if it causes the water to be turbid or if the lake or stream bottoms cannot support certain species.

Fish species link aquatic and terrestrial ecosystems through the consumption of terrestrial invertebrates that fall into the water, as well as by acting as prey for terrestrial organisms, such as birds and mammals (Baxter et al. 2005). Some of the demand-driven ecosystem services provided by fish species include signaling of ecosystem stress, cultural services, and recreational value (Holmlund and Hammer 1999). Therefore, by predicting which fish species are in the Serpentine, it will be possible to better understand the role fish may play in the habitat and the potential services they may be providing.

Limiting Factors

Dissolved oxygen (DO) pH and temperature are limiting factors that require consideration when describing suitable habitat for fish populations. Fish depend on DO as their only supply of oxygen to their blood, so optimum levels have great effects on fish distribution. Fish can survive at DO concentrations as low as 5 ppm, but as DO concentrations decrease, studies have found that feeding diminishes and eventually stops, reducing growth (U.S. Environmental Protection Agency 1986). Fish embryos and larval stages are more susceptible to the effects of limited DO concentrations because their ability to extract oxygen is not fully developed and they have limited mobility to move to more oxygen rich waters (U.S.

Environmental Protection Agency 1986). Higher DO concentrations have been found to support more diverse fish populations (U.S. Environmental Protection Agency 1986).

As with DO, pH can cause a range of effects to aquatic biota. For example, a pH range of 5-9 is not directly lethal, although fluctuations of pH within this range can increase the toxicity of several pollutants to fish (U.S. Environmental Protection Agency 1986). A pH outside of an optimal range may have physiological or reproductive effects. Mount (1973) found that a suboptimal pH on fathead minnows, *Pimephales promelas*, resulted in lower egg production and overall, eggs had lower hatchability. It was found that 97 percent of the locations with thriving fish populations had a pH between 6.7 and 8.6, which is likely the most optimal range (Mount 1973).

The temperature gradients in a freshwater system determine the distribution of fish populations because they are ecothermic. Suboptimal water temperature has been shown to effect respiration, metabolism, migration, and reproduction, causing fish to move to areas with more optimal temperatures when possible (U.S. Environmental Protection Agency 1986). DO, pH, and temperature can become lethal outside of a given fish species' optimal range (U.S. Environmental Protection Agency 1986).

Methods

In order to assess the species composition of fish populations in the Serpentine system, angling groups fished three days between 1:30 and 4:30 PM in September and October 2011, with varying effort. A total of 13 soak-hours were completed with 2.5 hours at site AD and 10.5 hours at site SC. Weather conditions limited the ability to fish at sites other than SC. Additionally, on one day there were 4 anglers instead of the usual three, contributing to a longer soak time at site SC. Angling was completed using worms as the primary bait and bass lures as secondary bait. Variable bobber length was used to increase comprehensiveness of fish survey as feeding depth preference is variable among species. The number of each species of fish caught was recorded and used to calculate catch per unit effort (CPUE) for each fish species. CPUE is defined as number caught per species divided by total soak time at site, (# caught)/(soak time). Measurements of length were also recorded.

Stomach contents of three Yellow Perch were collected in order to analyze their diet. Fish were placed in water containing MS222 anesthetic until they became passive. Water was then

pumped into the fish's stomach using plastic tubing. This was followed by a light massage of the fish's stomach, instigating regurgitation of stomach contents. Contents were collected through a funnel and solids were preserved in 70% ethanol. Yellow Perch stomach contents were identified to at least the Genus taxa.

A fisherman survey was also conducted. Three local fishermen were interviewed about what species they generally catch in the Serpentine and where the fish can be found. Each of these fishermen have worked on or lived on the Serpentine for years and are familiar with fish diversity in the area.

Twelve fish species were chosen based on their presence in East Pond and their ability to both access the Serpentine and potentially live in the habitat (Maine Department of Inland Fisheries and Wildlife 1940/2000). In addition, available scientific literature was surveyed in order to discern guidelines of presence or non-presence of a given fish species in the Serpentine. Optimal temperature, DO, and pH levels were found along with optimal breeding habitat, overall habitat suitability, and feeding ecology. These initial findings were compared to water chemistry data collected in this study of the Serpentine (CEAT 2012).

Results

Fish Profiles

Black Crappie (Pomoxis nigromaculatus)

Black Crappie, *Pomoxis nigromaculatus*, is native to freshwater lakes and rivers and present throughout most of the middle United States. Their native range stops at the Appalachian Mountains, but they have been introduced to the Belgrade Lakes region (Edwards et al. 1982). Adult diet consists of fish and planktonic insects and they feed, for the most part, over deep, open water. As with most fish, fry and juveniles feed on smaller prey including planktonic insects and microcrustaceans (Edwards et al. 1982).

Crappie thrive in clear water with abundant, dense vegetation. High turbidity has been found to negatively affect growth rates. Like Largemouth Bass, Black Crappie prefer current velocities less than 10 cm/sec and so prefer calmer rivers with many pools (Edwards et al. 1982). Standard DO and pH requirements for freshwater fish are assumed optimal for Black Crappie: this means a concentration of DO above 5 mg/L and a pH range of 6.5 to 8.5 (Table 5.1). The

summer temperature range for studied crappie is 23° C to 32° C with an assumed optimum for growth in the upper range (Edwards et al. 1982; Table 5.1).

During spawning from March to July, the most favorable temperature range is 17.8° C to 20° C. Males move into backwaters or littoral areas of lakes to construct bowl shaped nests. Such nests are usually made in beds of vegetation, mud, sand or gravel substrate (Edwards et al. 1982).

Brown Trout (Salmo trutta):

Brown Trout, *Salmo trutta*, is a non-native species introduced from Europe in the 1890s; they remain an important fishery in Maine and are restocked annually (Division of Fisheries and Hatcheries (US 2001). Brown trout can usually be found in mesotrophic lakes, those with an intermediate level of productivity, and lakes with suitable stream inlets for spawning (Division of Fisheries and Hatcheries (US). 2001). They also prefer relatively coarse substrata and adults have an affinity for cover; this cover can be found in the form of shade provided by overhanging tree canopies on the water's edge, vegetation in the water column, or boulders and rocks on the substrate (Armstrong et al. 2003). Brown trout also impact various stages of the aquatic food chain; in the juvenile life stage, brown trout are insectivores, but as they mature they become piscivores (McHugh et al. 2008).

Brown trout require a relatively high supply of dissolved oxygen. Low concentrations of oxygen can result in reduced growth, premature hatching, and reduced size at hatching (Armstrong et al. 2003). For these reasons brown trout require oxygen concentrations greater than or equal to 12.0 mg/L, when water temperatures are above 10° C (Raleigh et al. 1986; Table 5.1). Temperature also has a very large influence on spawning of brown trout and egg and fry survival. In general, survival and growth of brown trout occurs between temperatures of 12° C to 19° C (Raleigh et al. 1986; Table 5.1). Additionally, Raleigh et al. (1986) noted that brown trout are found in lakes and streams with a pH between 5 and 9.5, with optimal growth occurring at pH levels between 6.8 and 7.8 (Table 5.1).

Brown trout typically spawn in streams in the fall (Maine IFW 2001). Brown trout also prefer gravelly substrate for spawning and brown trout fry will continue to live for two to three years in their parent stream. When fingerlings reach maturity they migrate to a pond or lake where they consume other aquatic organisms such as fish and frogs (Maine IFW 2001).

Bullhead/Hornpout (*Ameiurus nebulosus*):

Bullhead or hornpout, *Ameiurus nebulosus*, is native to freshwater ecosystems in the state of Maine. A survey of bullhead habitat shows an affinity for vegetated shallow water in a variety of substrates, including sand, rock, mud, and silt (Stuber 1982). Bullheads also show an ability to survive in a wide range of water quality from clear to turbid water (Stuber 1982). Furthermore, bullheads have been observed to be nocturnal (Stuber 1982). Bullheads are classified as opportunistic bottom-feeders, consuming benthic invertebrates, insect larvae and fry of other fish species as well as their own species (Scott and Crossman 1973).

With regard to specific habitat requirements, U.S. Fish and Wildlife Service (1982) has recorded suitable bullhead habitat as freshwater with dissolved oxygen levels greater than or equal to 7.0 mg/L; however, the Global Invasive Species Database reports that bullhead can survive in waters with lower oxygen concentrations (Table 5.1). Bullhead can live in a wide variety of habitat types, including a fairly large pH range between 5.8 and 9.6, as long as there is a sufficient amount of vegetation (Stuber 1982; Table 5.1). Furthermore, bullhead can survive in lakes and streams with temperatures ranging from 18° C and 29° C (Stuber 1982**;** Table 5.1).

Bullheads do not migrate to spawn (West et al. 2006). Bullheads spawn between early spring and early summer (Blumer 1985). They also tend to nest beneath logs or other large objects in highly vegetated areas (Stuber 1982).

Chain Pickerel (Esox niger):

The Chain Pickerel, *Esox niger*, a native fish species to the state of Maine, is a piscivore. Chain Pickerel prefer slow moving streams and lakes with a high abundance of aquatic and emergent vegetation (Underhill 1949); they also show an affinity toward ponds with "brown water [and] muck bottom" and a maximum depth of approximately 20 feet (Underhill 1949).

Chain Pickerel prefer deeper, cooler waters during the warm summer months, but move to shallow weedy areas during fall, winter, and spring, when overall water temperatures are cooler (Armbruster 1959). The range of water temperature required to support Chain Pickerel populations has been observed to between 2° C and 22° C (Armbruster 1959; Table 5.1). On average, Chain Pickerel are able to survive in freshwater bodies with a pH range of 6.5 to 8.5 (NJ FGW; Table 5.1).

Underhill (1949) observed Chain Pickerel in Central New York, where they usually spawned during the month of April in swampy, marshy, or flooded areas. If pickerel fry are

undisturbed, they will attach to submerged debris or aquatic vegetation (Underhill 1949). As juveniles mature, they begin to hide among grass and submerged vegetation in order to capture any suitable food that ventures within their immediate sight (Underhill 1949). Therefore, highly vegetated waters are critical for Chain Pickerel spawning habitat.

Golden Shiner (Notemigonus crysoleucas)

Golden Shiner, *Notemigonus crysoleucas*, is included in the fish family Cyprinidae, commonly known as minnows. The golden shiner is native to the Belgrade Lakes region. Spawning begins in the spring when temperatures reach 20 to 27^{o} C (Lane et al. 1996). They are found at shallow depths from 0 to 2 meters with a high affinity for lakes rather than streams during spawning. The golden shiner utilizes aquatic and emergent vegetation as cover as well as organic debris and filamentous algae. The preferred spawning substrate is sand or silt, although eggs adhere to aquatic vegetation (Lane et al. 1996).

Largemouth Bass (Micropterus salmoides)

Largemouth Bass, *Micropterus salmoides*, are a non-native introduction to Maine and the Belgrade Lakes region, but have native populations in the eastern United States (Stuber et al. 1982). They are primarily piscivorous, but can also eat other organisms like crayfish depending on food availability. Juveniles eat insects and microcrustaceans. Feeding is bimodal and peaks in the early morning and late evening (Stuber et al. 1982).

Optimal Largemouth Bass habitat has lots of cover (40-60%), which is used for protection and a place for hunting prey. Largemouth Bass also require very low turbidity and prefer a low current velocity. High levels of turbidity may interfere with reproduction and growth (Stuber et al. 1982). Largemouth Bass require high DO concentrations, with optimal DO concentrations greater than or equal to 8.0 mg/L (Table 5.1). Their optimal pH range is 6.5-8.5, which is normal for most fish (Table 5.1). For growth of adult bass, optimal temperatures range from 24-30^{o} C while 15^{o} C is the lower limit where growth occurs and 36° C is the upper limit (Stuber et al. 1982; Table 5.1).

Largemouth Bass spawning begins in the spring with a temperature range of 13-26^{o} C. Gravel substrates are preferred for spawning, although vegetation, roots, sand and mud are also suitable. Areas with water velocities less than 10 cm/sec and an unchanging water level are ideal (Stuber et al. 1982).

Pumpkinseed Sunfish (Lepomis gibbosus)

Pumpkinseed Sunfish, *Lepomis gibbosus*, are native to eastern North America, including the Belgrade Lakes region, but have since been introduced further west of the Mississippi Valley (Holtan 1998). Sunfish prey on insects, mollusks, snails, other crustaceans and small fish. They feed throughout the day, but most heavily in the afternoon. They are prey for Yellow Perch as well as largemouth and Smallmouth Bass and other predatory fish (Holtan 1998).

Pumpkinseed Sunfish stay close to shore and are rarely found in open water. They use aquatic vegetation and submerged brush as cover (Holtan 1998). Standard DO and pH requirements for freshwater fish are assumed optimal for Pumpkinseed Sunfish. This means a concentration of DO above 5 mg/L and a pH range of 6.5 to 8.5 is optimal (Table 5.1). It is a warm water fish and optimal habitat temperature ranges between 24° C to 32° C (Table 5.1). Young are known to school, while adults rarely do (Holtan 1998).

When water temperatures reach 13° C to 17° C during the spring, males start creating nests for spawning. These are shallow depressions in sand or gravel substrate. The males protect nests until females move into the shallows and spawning begins. Afterward, eggs adhere to the substrate and males continue to protect the nest. Hatching then occurs and the young stay near the shallow breeding ground for around one year (Holtan 1998).

Rainbow Smelt (*Osmerus mordax*):

Rainbow smelt, *Osmerus mordax*, is a native fish species in Maine’s freshwater bodies. They tend to prefer stable riverbanks with adequate vegetative shading (Chase and Childs 2001). Rainbow smelt spend the day in deeper channels and the night in shallow waters (Chase and Childs 2001). In terms of feeding ecology, rainbow smelt are generalists and consume both plankton and zooplankton in the water column (Rooney and Paterson 2009).

Chase and Childs (2001) recorded an occurrence of rainbow smelt in waters with a minimum dissolved oxygen concentration of 10.0 mg/L (Table 5.1). A 2010 study on rainbow smelt in New York’s Lake George Watershed reported mean pH measurements between 6.6 and 7.6 in lakes and streams supporting rainbow trout communities (Table 5.1). The same study also noted that mean water temperatures supporting rainbow trout communities fell within the range of 5.6° C to 12.5º C (Lake George Waterkeeper 2010; Table 5.1).

Spawning begins in March, when the water temperatures reach 4.4° C, and lasts until May (NatureServe 2006). Rainbow smelt spawn in streams or on the gravel substrate of lakes; they deposit their eggs on sand, gravel, small boulders, and aquatic vegetation (NatureServe 2006).

Smallmouth Bass (Micropterus dolomieui)

Smallmouth Bass, *Micropterus dolomieui*, are non-native to the Belgrade Lakes region. Their native range extends from the Great Lakes to northern Georgia and from Eastern Oklahoma to the Appalachian mountain range (Edwards et al. 1983). Adults feed on fish and crayfish, while fry feed on microcrustaceans and juveniles prey on crayfish, fish and insects. Availability and abundance of prey influence diet (Edwards et al. 1983).

Smallmouth Bass prefer a gravel or rubble substrate in clear water. Unlike Largemouth Bass, Smallmouth Bass can tolerate periodic increases in turbidity. They usually seek cover from light in all life stages. Smallmouth Bass use deep water and submerged cover, such as rocks and vegetation to receive shade (Edwards et al. 1983). The optimal DO concentration is greater than 6 mg/L and growth decreases if DO is decreased to 4 ppm (Table 5.1). Optimum pH range is 7.9 to 8.1, but Smallmouth Bass have been observed in freshwater habitat with a pH range of 5.7 to 9 (Table 5.1). It is important to note, however, that behavior changed at levels below 6. Preferred temperature ranges between 21^{o} C and 27^{o} C in the summer, but they can acclimate to different ranges (Table 5.1). As temperatures drop during winter, bass become less active and they seek shelter. If there are warm springs available, Smallmouth Bass will congregate around them in winter (Edwards et al. 1983).

Spawning begins in the spring. Rocky lake shoals, river shallows or tributaries are preferred with clean stone, rock or gravel substrate. Nest building starts when temperatures get to 12.8-21.0^{o} C with most activity starting at 15^{o} C (Edwards et al. 1983).

White Perch (Morone americana)

White Perch, *Morone americana*, is often found in saltwater-estuaries; however, they are euryhaline and are native to freshwater systems in the Northeast (Stanley et al. 1983). White Perch prefer gravel, rock, mud, compact silt and coarse sand substrates and often live near submerged debris (Stanley et al. 1983). Substrates dominated by decaying organic matter, such as stagnant wetlands, are less preferred by this fish species. As White Perch do not depend on cover provided by debris, adults tend to inhabit areas with little to no cover or shade due to woody debris or canopy trees (Stanley et al. 1983). White Perch are predatory generalists. In the

fry life stage, White Perch have been known to consume zooplankton. Juveniles and adults tend to consume mollusks, insects, crustaceans, worms, small minnows, small fish and fish eggs (Stanley et al. 1983). White Perch can have a major impact on other fish species, especially Walleye and White Bass, due to the consumption of other fish eggs (Stanley et al. 1983).

White Perch require dissolved oxygen levels above 5.0 mg/L for all life stages; however, levels above or equal to 6 mg/L are preferable for adults (Stanley et al. 1983; Table 5.1). Studies have shown that young White Perch exhibit up to 40% mortality when living in waters with DO levels less than 5.0 mg/L (Stanley et al. 1983). Adult White Perch tolerate a pH range of 6.0 to 9.0 (Stanley et al. 1983; Table 5.1). White Perch are able to live in a wide range of water temperatures: 2.0° C to 32.5° C (Stanley et al. 1983; Table 5.1).

White Perch enter feeder streams or shallow waters, usually with lower salinity levels, such as estuaries, rivers, lakes, and marshes to spawn (Stanley et al. 1983). Increasing water temperatures from March through early June triggers males, followed by females, to migrate to spawning areas (Stanley et al. 1983). They prefer sand and gravel substrates for spawning.

White Sucker (Catostomus commersonii)

The White Sucker, *Catostomus commersonii*, is an invasive species to northeast freshwater systems (Twomey et al. 1984). These fish prefer lakes or rivers that contain slow moving pools with gradual to moderate gradient (Twomey et al. 1984). Water flow rate is a critical component of habitat suitability with an optimal range of 10 to 19 cm/sec. Water bodies with no inlets have been found to be unsuitable for any White Sucker habitation (Twomey et al. 1984). Shade and cover provided by canopy trees, woody debris, boulders, or pool depth is essential for juvenile and adult living as well as spawning for White Suckers (Twomey et al. 1984). Fry begin feeding on surface dwelling zooplankton and mature into consuming benthic organisms such as larvae and clams. Adults generally feed on gastropods, insects, and amphipods (Twomey et al. 1984).

White Suckers are able to survive in waters with dissolved oxygen levels as low as 2.4 mg/L, which is much lower than many fish species native to the Northeast (Table 5.1). However, they avoid areas with DO this low (Twomey et al. 1984). They tolerate a pH range of 5.0 to 9.0 (Twomey et al. 1984; Table 5.1). White Suckers have a high temperature tolerance but optimal temperature for a population tested in Colorado was between 19° C and 21° C (Twomey et al. 1984; Table 5.1).

A clean bottom with coarse sand or gravel is necessary for White Sucker spawning (Twomey et al. 1984). White Sucker begin spawning in the late spring to early summer when water temperatures reach about 10° C and continues to spawn until water temperatures reach 18° C (Twomey et al. 1984). White Suckers utilize rivers with swift moving water, less than 30 cm deep, for egg deposition. Water velocity and sediment type, especially large gravel with little silt, have been shown to have the greatest influence on preferred White Sucker spawning site selection (Twomey et al. 1984).

Yellow Perch (Perca flavescens)

Yellow Perch, *Perca flavescens*, is a native freshwater species in the northeast (Krieger et al. 1983). These fish develop and live in the littoral zone of lake or river systems. They prefer clear, slow moving water with good cover in the form of aquatic vegetation greater than 20% (Krieger et al. 1983). Yellow Perch are generalists that impact several trophic levels in aquatic systems by feeding on copepods, amphipods, ostracods, insects, fish, and crayfish. Yellow Perch diet at any point is dependent on the relative density of prey, indicating that Yellow Perch do not have feeding preferences. Fry survival, however, is dependent on zooplankton abundance because they are zooplankton specialists (Krieger et al. 1983). Turbidity also plays a role in Yellow Perch diet as they rely on sight to hunt for prey. High turbidity can decrease the ability of Yellow Perch to capture certain prey species (Krieger et al. 1983)

Yellow Perch survive in waters with dissolved oxygen levels equal to or above 5.0 mg/L with levels below 1.5 mg/L being lethal (Krieger et al. 1983; Table 5.1). They tolerate a pH range of 3.9-9.5 (Krieger et al. 1983; Table 5.1). Yellow Perch prefer a more narrow temperature range than White Perch ranging between 17.6° C and 25.0° C (Krieger et al. 1983; Table 5.1).

Yellow Perch migrate to slow moving rivers and shallow areas of lakes to spawn between April and June (Krieger et al. 1983). Females must be subjected to an extended winter period with temperatures below 10° C in order to produce eggs the next spring (Krieger et al. 1983). Eggs are laid near or on submerged vegetation, which provide support for eggs as well as protection against predation. Yellow Perch have a specific temperature requirement for spawning with a range of 7.8° C to 12.2° C (Krieger et al. 1983).

Table 5.1. Summarized data for limiting factors affecting fish population distributions in the serpentine for 12 fish species known to reside in East Pond.

Species	DO	pH	Temp (°C)
Black Crappie	>5.0 mg/L	6.5-8.5	23-32°C
Brown Trout	≥12.0 mg/L	5-9.5	12-19°C
Bullhead	≥7.0 mg/L	5.8-9.6	18-29°C
Chain Pickerel	n/a	6.5-8.5	2-22°C
Golden Shiner	n/a	n/a	20-27
Largemouth Bass	>8.0 mg/L	6.5-8.5	15-36°C
Pumpkinseed Sunfish	>5.0 mg/L	6.5-8.5	24-32°C
Rainbow Smelt	10.0 mg/L	6.6-7.6	5.6-12.5ºC
Smallmouth Bass	>6.0 mg/L	5.7-9	21-27°C
White Perch	>5.0 mg/L	6.0-9.0	2.0-32.5°C
White Sucker	>2.4 mg/L	5.0-9.0	19-21°C
Yellow Perch	>5.0 mg/L	3.9-9.5	17.6-25°C

Note: Data summarized from: Armbruster 1959; NJ FGW; Stuber 1982; Stuber et al. 1982; Edwards et al. 1983; Krieger et al. 1983; Twomey et al. 1984; Raleigh et al.1986; Holtan 1998; Lane et al. 1996; Chase and Childs 2001; Armstrong et al. 2003; Lake George Waterkeeper 2010.

Catch per Unit Effort

A total of 12 fish were caught during the 13 hours of soak time completed while angling. Two Yellow Perch were caught at site AD during 2.5 soak-hours. Catch per unit effort (CPUE) calculated for Yellow Perch at this site is 0.8 fish/hr. Nine Yellow Perch were caught at site SC during 10.5 soak-hrs giving a similar CPUE, 0.857 fish/hr. One Chain Pickerel was caught during fishing at site SC giving a CPUE of 0.095 fish/hr. The mean of Yellow Perch caught was 21.48 cm.

The stomach contents of three Yellow Perch were collected and identified. From these three fish, eight categories of prey were found. These include dragonfly larva, Amphipoda, bivalves, leech, Trichoptera, damselfly larva, and Isopoda. One Yellow Perch consumed 2 dragonfly larvae, 1 Amphipoda, and 13 bivalves. The second Yellow Perch consumed 8 Amphipoda and 1 leech. Finally, the last Yellow Perch consumed 2 dragonfly larvae, 1 Trichoptera, 1 damselfly larva, and 1 Isopoda.

Interviews with local anglers

In lieu of an electro-shock fishing boat to conduct a survey of the fish species present in the Serpentine, interviews with local anglers provided first-hand accounts of fish caught in this

system. Angler 1 (A1) has fished on the Serpentine his whole life, approximately 40 years. Angler 2 (A2) and Angler 3 (A3) both have over 3 years of experience fishing on and around the Serpentine.

A1 indicated that he fished from the straightaway just before the major bend in the Serpentine (sampling point SC) to the dam into North pond (sampling point AD). Fishing was done with lures and more recently with flies. The waterway between East Pond and SC was generally characterized as having less fish than the rest of the Serpentine and A1 indicated that the area past the straightaway toward East Pond was generally poorer fishing. A1 caught mostly Yellow Perch from the dam (AD) to the first bend (around S3), but Yellow Perch was also caught in all other fishing areas (Table 5.2). Yellow Perch seem to dominate this area near the dam and may be keeping other fish out. Smallmouth Bass were caught in the area between the SC and the dam, but were only found along the edges, where more cover is present (Table 5.2). Largemouth Bass were caught more often in coves, near the banks of the Serpentine between SC and AD (Table 6.2); these areas generally had a fair amount of vegetation cover. Chain Pickerel were caught past the bend (SC), into the straightaway, towards sampling point S2 (Table 5.2). A1 has also caught White Perch and Black Crappie, in unspecified regions of the Serpentine (Table 5.2).

A2 had not fished in the Serpentine waterway site (S2), but fishes in and around the head of the Serpentine (sampling point S1). This angler has used lures, but switched to fly fishing this past year. A2 indicated a catch very similar to A1, with the exception of catching Pumpkinseed Sunfish in this area (Table 5.2). A2 thought that the best fishing was at the north end of East Pond, near the head of the Serpentine, where he has caught fairly large Largemouth Bass and Black Crappies (Table 5.2).

A3 preferred fishing in the boat channel and found the other areas harder to fish due to greater amounts of vegetation. Unlike A1 and A2, A3 did not indicate catching any Chain Pickerel (Table 5.2). A3 also stated that they had caught a Brook Trout in the spring (Table 5.2). Brook Trout and brown trout are stocked in East Pond in the spring and so are usually more rare than the major fisheries of perch, bass and crappie (Table 5.2).

Table 5.2. Identified fish species caught by interviewed anglers.

Fish species	Angler 1	Angler 2	Angler 3
Largemouth Bass	▯	▯	▯
Smallmouth Bass	▯	▯	▯
Yellow Perch	▯	▯	▯
White Perch	▯	▯	▯
Black Crappie	▯	▯	▯
Chain Pickerel	▯	▯	-
Pumpkinseed Sunfish	-	▯	-
Brook Trout	-	-	▯

Notes: Anglers 1 and 3 fished in the serpentine, while Angler 2 fished in and around the head of the serpentine in the northern region of East Pond. Brook and Brown trout are stocked and so are rare. Smaller species like minnows are typically too small to be caught with angling equipment.

Discussion

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most influential limiting factors for fish distribution. Mean DO for East Pond is sufficient to support the brown trout as it exceeds 12.0 mg/L (Table 5.1). However, DO concentrations decrease moving along the Serpentine, toward North Pond. At site S3, DO concentrations are below the brown trout and rainbow smelt optimal concentrations and at the bottom threshold of Largemouth Bass's optimal DO concentrations (Table 5.1). At points I1 and I2, DO concentrations are lower than 5 mg/L. These two inputs flow into site SC, which has a mean DO concentration less than the optimal concentrations for any of the fish species assessed for potential presence in the Serpentine, except for White Sucker (Table 5.1). It is expected that fish would avoid these upper tributaries and site SC, moving to other areas with higher oxygen levels. These sites (I1, I2, SC) do not show lethally low DO concentrations, which would be around 1-3 mg/L, but they would have negative effects on growth and activity.

pH

A pH outside a species' optimal range may not be directly lethal, but could have negative physiological effects or cause problems with reproduction, including problematic egg production (U.S. Environmental Protection Agency 1986). The mean pH at the sampling sites (EP, S1, S2, SC, S3, I1, I2, AD) was relatively consistent at around a pH of 6 (Appendix 5.A). This is within the optimal range for yellow and White Perch, Pumpkinseed Sunfish, White Sucker, and

bullhead (Table 5.1). Although, the pH does not fall within the other fish species' optimal range, none of the differences are large enough to completely rule out the presence of these fish in the Serpentine. Most can survive in a pH of 5.0, but there may be physiological effects such as decreased growth and decreased fecundity.

Temperature

Temperature changes are used as an indicator by fish to trigger actions like migrations and spawning; extreme temperatures can be lethal. As ectothermic organisms, fish regulate their temperature by movement. During the summer heat, fish need to find cover or water depth to cool down. During the winter, fish need to find protection under cover or warm springs to keep warm (U.S. Environmental Protection Agency 1986). Recorded temperatures at sample sites along the Serpentine fall close to all the fish species' optimal temperatures (Table 5.1). The Serpentine offers ample cover during the summer heat under lily pad beds, within aquatic vegetation, and from overhanging vegetation. Although much of the Serpentine is relatively shallow, there are deeper areas in the ox-bows and close to site AD that could provide depth for over-wintering fish. Lastly, Angler 1 commented that ice fishing does occur on the Serpentine near the dam, although there are soft spots along certain areas of the Serpentine where the ice is weakened by groundwater springs. Fish can utilize these springs as a buffer for cold winter water temperatures.

Fish Assemblages

Based on these findings, it is hypothesized that the Serpentine is a suitable, effective habitat for 9 of the 12 species analyzed. Most of the fish found in East Pond could be found in the Serpentine, except for brown trout and rainbow smelt, based on their highly specific habitat requirements, such as DO and substrate (Table 5.1). It is unclear whether golden shiner would utilize the Serpentine, due to a lack of information about their habitat requirements. The interviewed anglers would not have caught this fish species either, since they are not preferred sports fish. Therefore, the Serpentine is suitable habitat for most of Maine's freshwater fish and may potentially support populations of Chain Pickerel, bullhead, Largemouth Bass, Smallmouth Bass, Black Crappie, Pumpkinseed Sunfish, golden shiner, White Perch, and Yellow Perch (Table 5.1). These fish species occupy top and mid-trophic levels (piscivores and zooplanktivores), meaning that fluctuations in population abundance of individual fish species can influence community structure in the Serpentine through trophic cascades. Additionally, the

chemistry of the Serpentine (e.g., dissolved oxygen, pH, and temperature) suggests it is a habitat that can support a relatively diverse population of fish species. High species diversity, in turn, can have a strong, positive influence on ecosystem health (Holmlund and Hammer 1999).

Our interviews with anglers gave us further proof of which fish populate the Serpentine. Largemouth Bass, Smallmouth Bass, Yellow Perch, White Perch, Black Crappie, Chain Pickerel and Brook Trout were caught in the Serpentine. Angler 1 stated that Yellow Perch could always be caught very easily near the dam, indicating a large density of Yellow Perch. Since they also seem to diminish in density moving toward East Pond, this could be a sustained population unique to the Serpentine and not Yellow Perch moving in and out of a population in East Pond. Yellow Perch seem to dominate the area near the dam, so they are likely competitively excluding other fish species there. Bass species seemed to prefer areas of cover, so coves of lily pads and vegetation near the shore provides suitable habitat for bass. Angler 1 stated that winter ice fishing is also present on the Serpentine, in limited amounts, indicating that the Serpentine has the capacity to over-winter fish. Thin areas found in the ice with groundwater springs underneath were also noted and these springs could provide warmer water for fish to thrive in during the winter months.

Both bass species, both perch species, Black Crappie, Chain Pickerel and Pumpkinseed Sunfish were caught in the northern regions of East Pond near the head of the Serpentine (Table 5.2). In general, the northern region of East Pond near the head of the Serpentine was identified as having larger densities of fish compared to the rest of East Pond, which could be due to the shallower water depth and Serpentine refuge.

Stomach Content

The extent of variation in stomach contents observed in Yellow Perch support their generalist nature. Eight different types of organisms were found in three Yellow Perch with little overlap between individuals. Yellow Perch are known to eat prey at rates equivalent to the encounter rate of that prey. This indicates that Yellow Perch may have a strong top-down trophic impact on many species and in many areas of the overall Serpentine trophic web. Yellow Perch also had the highest CPUE indicating that they are the most abundant fish species at the fished sites. These results indicate that Yellow Perch may be the fish having the highest impact on the Serpentine’s biological systems.

Ecological Implications

Understanding the potential trophic interactions that may be occurring in the Serpentine makes it possible to better hypothesize the role of the Serpentine in the 2008 East Pond biomanipulation project and may help shed light on why the project has not had significant impacts on the occurrence and frequency of algal blooms in East Pond. Even though there is a high potential for piscivore presence in the Serpentine, the abundance and biomass of piscivores in the Serpentine may not actually be very high. If this is true, piscivores may not have a strong top-down control on zooplanktivore populations, allowing zooplantivore populations of East Pond to retreat into the Serpentine and use it as a refuge. Therefore, even though the biomanipulation project removed extremely high amounts of zooplanktivore biomass from East Pond (Halliwell and Evers 2008), ignoring the Serpentine as a potential refuge from East Pond may offer a clue as to why the project has not been effective. By simultaneously conducting the project in the Serpentine, White Perch populations that may take advantage of suitable habitat in the Serpentine may also be targeted and removed.

Limitations and Recommendations

Several procedural limitations made this survey difficult to complete. As a result, alternate methods of gathering data of fish presence should be considered for future studies in the Serpentine. Angling was completed with minimal temporal variation and variation in bait. This could cause potential targeting of fish species for several reasons. Using lures specific to a certain fish will leave out most other species and using worms as bait may decrease the likelihood of catching smaller fish species. Time of day that fishing is conducted can lead to catching solely diurnal, nocturnal, or day feeding fish, excluding the others. A more thorough survey would utilize a variety of baits, bobber depths, and fishing times to more evenly distribute probability of catching each fish species located within the Serpentine.

Other methods of fish catching should be considered, including seine netting and shock boat fishing. Shoreline seine netting is very difficult in the Serpentine due to the depth of organic substrate and high density of aquatic vegetation. Seine catching may be completed in the center of the Serpentine channel using floating ends. Shock boat fishing should also be considered as an alternate method. In this method, electricity is utilized to stun fish within a certain area for easy, non-species specific surveying; this method has a potentially high catch rate and would allow for

larger sample sizes to be collected. Conducting a shock-boat survey would allow a non-biased survey of all fish species present in the Serpentine, which angling is unable to provide.

Obtaining more data through these proposed methods would open up a variety of new analysis options. Most importantly, future researchers could overlay known habitat and water chemistry values for the Serpentine with locations of fish species. This will show what areas fish are able to live in and why. One potential hypothesis for use of the Serpentine by fish is for a low velocity spawning habitat. Surveys completed in differing seasons may be able to support or reject this idea. The relationship of the inlets, site I1 and I2, with fish populations and migration through the Serpentine is another question that may be investigated using future data. Obtaining a more robust data set of fish in the Serpentine will allow for an overall better understanding of trophic interactions in the wetland.

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6. ALGAE

Introduction

Algae populations are important not only as biotic organisms, but also as indicators of water properties and quality. Some species act as bioindicators and can be used to determine what inputs the water has received (Bellinger and Sigee 2010). Good indicator species have the following characteristics: a narrow ecological range, rapid response to environmental change, well defined taxonomy, reliable identification, and wide geographic distribution (Bellinger and Sigee 2010). Freshwater algal bioindicators provide both long-term and short-term information about the physical and chemical properties of their environment.

Few algal population samples have been taken in such complex river-fen-marsh systems. Several studies, however, have been completed in bogs dominated by Sphagnum moss. Hooper (1981) measured the diversity and abundance of algal populations in high and low sites in a Sphagnum mat in a bog in Michigan and discovered that Sphagnum moss in the low plots had significantly more algal epiphytes, as well as a more diverse algal assemblage. The most abundant algae, *Cylindrocystis brebisonni*, belonged to the Phylum Chlorphyta and because it was found in both high and low plots, it was assumed to be a generalist. Interestingly, the low plots, which had higher levels of diversity, had lower nutrient levels. This led Hooper (1981) to hypothesize that low nutrient levels are a result of greater algal abundance, not the cause; however, other factors, such as moss nutrient uptake, cation exchange capacity and inputs into the system, likely also play a role.

Rakowska and Sitkowska (2010) studied the role of nutrient inputs and their effects on algal assemblages in a peat-bog reserve in Poland. The purpose of their study was to find out how the eutrophication of a bog affected algal diversity and abundance. The majority of algae sampled were from the Phyla Bacillariophyceae and Chlorophyta. A total of 148 diatom taxa, algae in Phyla Bacillariophyceae, and fifty-nine taxa of Chlorophyta were observed. These totals included twenty-nine algae species, which had never before been observed in such an ecosystem. The dominant taxa from Bacillariophyceae all preferred oligotrophic to mesotrophic waters. Bacillariophyceae algae such as *Achnanthes* sp. and *Fragilaria* sp. were found in multiple sites, indicating that they can tolerate a broad range of conditions. The diversity of green algae, Chlorophyta taxa, was highest in the summer and early fall, and found to be highly dependent on water temperature. They concluded that the inflowing nutrients, particularly nitrogen and

phosphorus, stimulated algal development, especially diatom development, because diatoms tolerate higher nutrient levels. At the same time, however, the bog water is becoming less acidic, which makes it less habitable for diatom species that live in ecosystems with lower pH. Although the Serpentine system is not a closed bog, it is important to realize the effects the Sphagnum moss may have on algal populations.

Algal Phyla Background

Algae are broad group of organisms from several phyla, including prokaryotes and eukaryotes. Algae from the following phyla were identified in the East Pond, Serpentine and/or North Pond (Reviewed from Bellinger and Sigee 2010).

Bacillariophyta

Algae in the Phylum Bacillariophyceae, also called diatoms, are the most diverse group of algae found in freshwater systems. Usually a light yellow-brown color, diatoms can be planktonic, benthic, epiphytic and epizoic organisms. They are most often found in mesotrophic systems with mid-level total phosphorus levels. In certain times of the year, diatoms are major contributors to primary production. In spring and early summer, algal blooms in temperate lakes may be formed primarily of diatoms, especially *Asterionella* and *Tabellaria*, because they can out-compete other algae by tolerating low temperatures and low light conditions as well as turbulent water. Species such as *Fragilaria* and *Asterionella* may form fall algal blooms. Additionally, diatoms are major components of biofilms. Their distinct habitat preferences mean that diatoms are useful bioindicators for the present conditions within a freshwater system. For example, some benthic diatoms can be used to assess the water quality of rivers while others are helpful in determining historical ecological conditions in lakes through sediment analysis.

Chlorophyta

Green algae, or algae in the Phylum Chlorophyta, are commonly found in mesotrophic and eutrophic environments, but are not the dominant taxon when total phosphorus levels are high. Green algae are major producers of biomass in aquatic systems, especially in early summer between the clear-water phase and midsummer mixed algal bloom, when they become dominant or co-dominant. Although they do not normally form large algal blooms, green algae can overtake blue-green algae when nutrient levels become very high. In freshwater systems, they have either planktonic forms or attached forms, depending on if the water is standing or flowing. Certain species of green algae have particular habitat preferences, and for this reason can be

reliable indicators of alkaline habitats, hard waters, chronic low-light conditions, high acidity, and high levels of external dissolved organic carbon. A specific example is filamentous green algae, which are found in environments affected by cultural eutrophication, acidification and metal contamination.

Chrysophyta

Chrysophytes, also called golden algae, live in environments with lower levels of total phosphorus. They are ecologically important as primary producers in environments with adverse conditions such as low nutrients and high acidity. In addition, they have a versatile method of nutrition, obtaining carbon from organic sources either by surface absorption or phagocytosis of particulate organic matter. When golden algae reach high population levels, they can be nuisance algae. Chrysophytes, although not readily used as bioindicators, have the potential to be useful in monitoring environmental changes. They are useful in studying paleoecology, because they have cell-wall material made of non-degradable silica. Also, if golden algae are measured over time, their ratio compared to those of other algae species can indicate environmental change. For example, sediments from Sunfish Lake, Canada, showed that the ratio of golden algae to diatoms decreased with increased lake eutrophication.

Cryptophyta

Cryptomonads generally compose a small portion of the total algae assemblage with an estimated total of twelve genres, which encompass about 100 species each of freshwater and marine cryptomonads. They are relatively abundant in oligotrophic and mesotropic temperate, high latitudinal, standing waters. Preferring cold water and even growing under ice, cryptomonads are most abundant in lakes in early spring. Cryptomonads are also found on the surface of lakes during the clear-water phase of the seasonal cycles, which is the time between the diatom spring bloom and the beginning of the mixed summer bloom when zooplankton prey heavily on algae. Increased predation reduces competition and allows rapidly growing r-selected organisms like cryptomonads to flourish. Another unique aspect of cryptomonads is that they can use ammonium and organic sources as a supply of carbon and nitrogen in heterotrophic nutrition. Although cryptomonads prefer oligotrophic and mesotrophic lakes, they can be found in eutrophic environments, negating any role as bioindicators.

Cyanophyta

Perhaps the most notorious algae are blue-green algae from the phylum Cyanophyta, which frequent freshwater environments and dominate eutrophic systems. The following characteristics enable them to form large algal blooms: optimal growth at high summer temperatures, tolerance of low light conditions, ability to grow in water with a low nitrogen to phosphorus ratio (because they fix nitrogen efficiently), resistance to zooplankton grazing, tolerance of high pH and low CO_2 concentrations, and a symbiotic association with aerobic bacteria, which supply the cyanobacteria with inorganic nutrients. Because blue-green algae form algal blooms, they indicate high nutrient levels in the environment and are an important part of aquatic food webs. Other species of unicellular blue-green algae grow in oligotrophic to mesotrophic waters.

Dinophyta

Of all algae in the Dinophyta phylum, only about 10%, or 220 species of dinoflagellates, are found in freshwater systems. They have a higher relative abundance in mesotrophic systems, are K-strategists and dominate environments with high populations of competing organisms. Dinoflagellates, like other algae, make seasonal appearances: there is often a midsummer to autumn bloom, when the phosphorus level in surface waters is low, causing the dinoflagellates to migrate to a position lower in the lake where phosphorus levels are higher. They also have an overwintering phase, when they sink to the bottom and survive on sediments as resistant cysts. Two genera, *Ceratium* and *Peridinum*, are widely dispersed, but are indicators of high calcium-ion concentrations and low levels of inorganic nutrients. Both species are phototrophic, obtaining nutrients in an inorganic form. Other species are heterotrophic and particularly adapted to conditions where photosynthesis is limited.

Rhodophyta

Only 3% of the 5,000 worldwide Rhodophyta, red algae, species occur in freshwater environments, usually in streams and lakes. The species, which live in freshwater, are generally large enough to be seen with the naked eye and are not always red in color. Freshwater red algae have a morphology that enables them to resist swiftly flowing water. Attached red algae make up an important part of the lake periphyton, assemblage of organisms that live on the surface of rooted aquatic plants, as part of the epiphytic (supported by another plant) flora.

Xanthophyta

Algae from the Phylum Xanthophyta, or yellow-green algae, do live up to their nickname, because they have a distinctive pigmentation, which makes them appear yellow or fresh green. Although the Xanthophyta phylum contains relatively few species, yellow-green algae have a wide range of morphology and can be single celled or colonial algae. They are non-motile, which often restricts them to living in small bodies of water and damp soils. Because they are not prevalent in the environment, yellow-green algae are not generally used as bioindicators. However, they can provide information on ambient conditions when caught, because different species are found in different environments, such as acid bogs, calcareous waters, humic waters, organically rich conditions, inorganic nutrient-enriched waters, and brackish environments.

Our Study

Large algal blooms have been reported in East Pond since 1987. These blooms have been occurring more frequently in the past decade, however, with an algal bloom nearly every year since 2002 (CEAT 2000, MDEP 2011). Algal blooms are common in eutrophic lakes, because they contain many nutrients, but such large-scale blooms are hazardous for aquatic life as well as being damaging to the tourist industry. The algal blooms in East Pond presumably occur because of the high concentration of phosphorus in the sediments. Most of the sediment phosphorus comes from organic material, such as decaying algal cells, which are at levels high enough to sustain algal blooms indefinitely. Based on the history of algal blooms in East Pond, we hypothesized that both East Pond and the Serpentine would have abundant algae from the Cyanophyta phylum, because these algae in particular have an affinity for eutrophic conditions with high phosphorus levels.

Methods

Our five sampling sites correspond to the water chemistry sampling study sites EP, I2, S3, BD, and NP. On October 6, 2011, one algal sample from each site was collected using plankton tow nets with 3 m towlines. Each sample jar contained the contents cumulative of three replicated tows. Two different tow nets were used; one net had 80 μm mesh netting and the other had 155 μm mesh. The samples were preserved in ethanol and refrigerated. The refrigerator had glass doors, so light was able to reach the samples. The contents of each sample were identified using a microscope at 40x and 100x magnifications. Five slides were prepared from each sample

location, and each specimen was identified to genus to measure presence or absence. Due to the limitations of our sampling procedure, we could not reliably count the number of each genus in the samples, and therefore could not make statements about abundance or diversity at the sampling sites.

Results

In total, 29 different algal genera were observed, from 5 slides per each study site (Table 5.1). The most frequent genera observed were *Aphanocapsa* (8 slides, 4/5 sites), *Asterionella* (5 slides, 2/5 sites) *Fragilaria* (5 slides, 4/5 sites), *Mougeotia* (5 slides, 4/5 sites), *Botryococcus* (4 slides, 3/5 sites), and *Tabellaria* (4 slides, 2/4 sites). Site EP had the greatest number of genera observed (20 in five slides), and site SC the least (1 in 5 slides). The phytoplankton observed represented eight phyla: Bacillariophyta, Chlorophyta, Cryptophyta, Crysophyta, Cyanophyta, Dinophyta, Rhodophyta, and Xanthophyta. Bacillariophyta, Chlorophyta, and Cyanophyta represented the greatest number of genera overall and at sites EP, I2, BD, and NP (Figures 6.1-5, 6.4-5). The five slides from site SC only contained one specimen, a Cyrptophyte (Figure 6.5).

The number of genera observed in the lakes (sites 1 and 10) was compared to the stream (sites S3, I2, and BD) by a 2-sample t-test to see whether the lakes experienced more of a bloom than the Serpentine stream. Lake sites appeared to have more genera per phylum represented, but this trend was not significant ($t_{0.05}$=2.4438, df=3, p=0.0922). We had predicted that Cyanophyta would be the most represented phylum, indicating high system TP. However, 3 phyla were the most common: Chlorophyta, Bacillariophyta, and Cyanophyta. Chlorophyta was the most represented, with 11 different genera identified on 20 slides. Bacillariopyta was second most common, with 7 genera represented on 22 slides. Cyanophyta had 6 phyla represented on 14 slides.

Table 6.1. A list of all the algal genera observed and their corresponding phyla, with a count of the number of slides with each genus present.

Genus	Count	Phylum	Notes
Acanthoceras	1	Bacillariophyta	Slightly alkaline, nutrient-rich lakes
Anabaena	1	Cyanophyta	Common in ponds, ditches, can form blooms
Aphanocapsa	8	Cyanophyta	Usually grow in periphyton, benthos and metaphyton of stagnant and streaming freshwater biotopes, clear water
Aphanochaete	8	Chlorophyta	Nutrient-rich waters; can grow on submerged plant structures or larger filamentous green algae
Asterionella	5	Bacillariophyta	Abundant in lakes in autumn and spring
Aulacoseira	2	Bacillariophyta	Usually found in eutrophic lakes
Botryococcus	4	Chlorophyta	Found in clear epilimnia, tolerate low nutrients, may be sensitive to CO2 deficiency and high turbidity
Ceratium	1	Dinophyta	Found in many aquatic habitats
Cladophora	1	Chlorophyta	Often found in hard or slightly hard water that contains sewage
Cryptomonas	1	Cryptophyta	Found in small, enriched lakes and tolerant of low light
Draparnaldia	1	Chlorophyta	Found in phosphorus-poor waters
Fragilaria	5	Bacillariophyta	Found in meso- and eutrophic water, form blooms
Gloeocapsa	1	Cyanophyta	Colonies that grow on rocks can be seen unaided
Hildenbrandia	1	Rhodophyta	Pink rock-encrusting algae; found in streams with hard water
Mallomonas	1	Crysophyta	Found in small, oligotrophic, base-poor lakes, tolerate nutrients
Melosira	3	Bacillariophyta	*M. varians*, species observed, found in shallow, small eutrophic water bodies
Microcystis	2	Cyanophyta	Produce toxins in water
Microspora	1	Chlorophyta	More common in cooler months
Microthammnion	1	Chlorophyta	Found in acidic, organic-rich water with higher manganese or iron concentrations
Mougeotia	5	Chlorophyta	Found in deep, well-mixed epilimnia, tolerates light deficiency but sensitive to nutrient deficiencies
Oscillatoria	1	Cyanophyta	Several species produce toxins
Pandorina	2	Chlorophyta	Move by rolling through water; can smell badly
Peridinum	1	Dinophyta	Cause water to taste and smell badly
Staurastrum	1	Chlorophyta	Can be found in oligo- to meso- to eutrophic lakes
Stichococcus	1	Chlorophyta	Found in freshwater, can grow on damp ground
Stigeoclonium	2	Chlorophyta	Indicate enriched waters; tolerate heavy-metal pollution
Synedra	2	Bacillariophyta	Common in lakes and slow-moving rivers
Tabellaria	4	Bacillariophyta	Common in oligo- and mesotrophic waters; found in mesotrophic epilimnia, tolerate nutrient deficiency, sensitive to stratification and rise in pH
Tolypothrix	1	Cyanobacteria	Often found in calcareous lakes
Xanthidium	1	Xanthophyta	Found in mesotrophic waters; some found in acidic peat bog water
Total:	62		

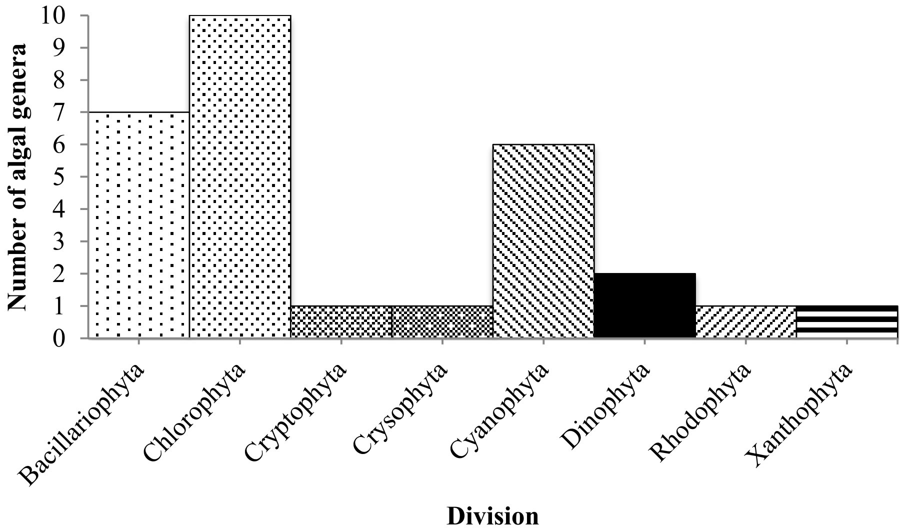

Figure 6.1. The number of algal genera per division (phylum) represented in the slides for all 5 sampling sites combined.

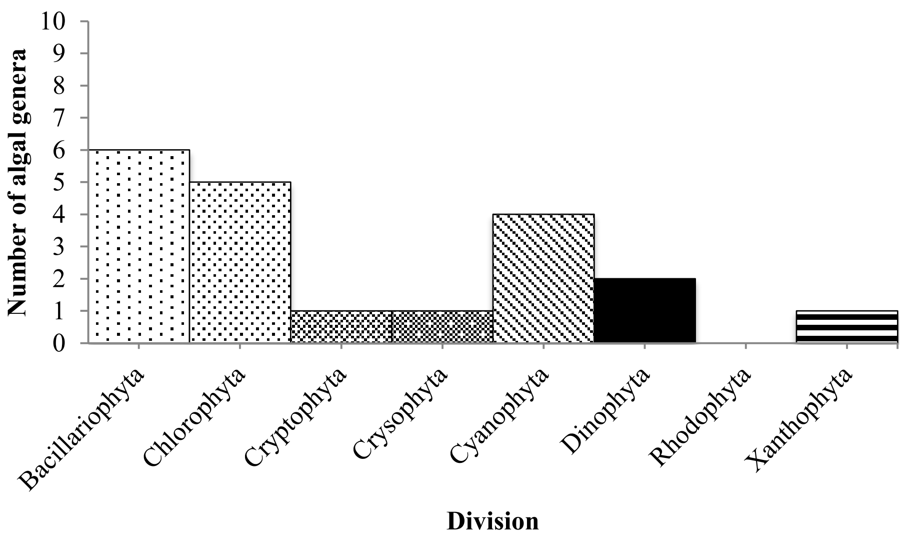

Figure 6.2. The number of algal genera per division (phylum) represented in the slides for sampling site EP. Site EP is neat the center of East Pond.

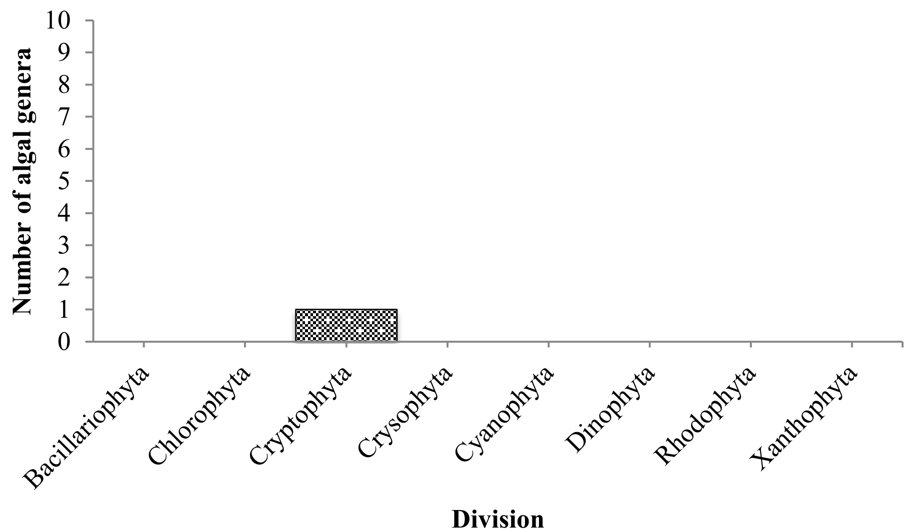

Figure 6.3. The number of algal genera per division (phylum) represented in the slides for sapling site SC. Site SC is in the wooded area of the Serpentine after the peat fen.

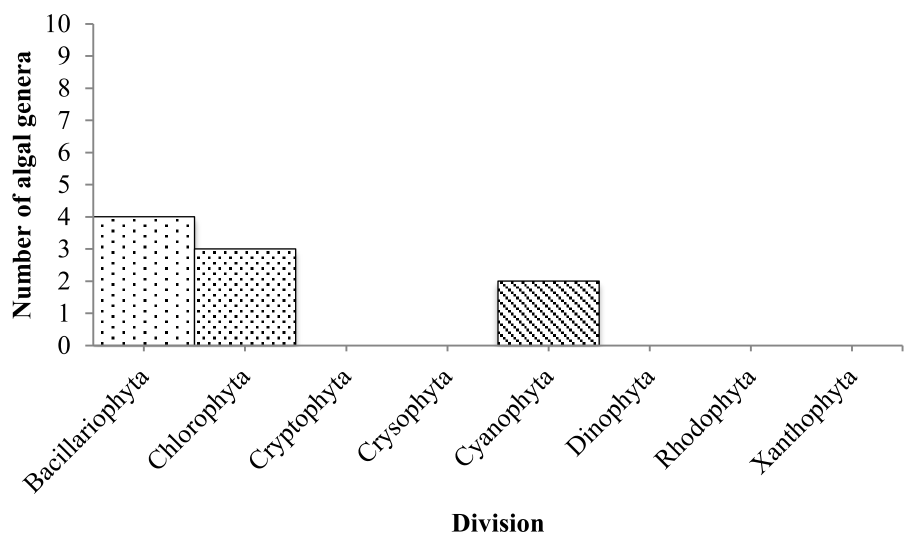

Figure 6.4. The number of algal genera per division (phylum) represented in the slides for sampling site I2. Site I2 is in a tributary stream that flows into the Serpentine.

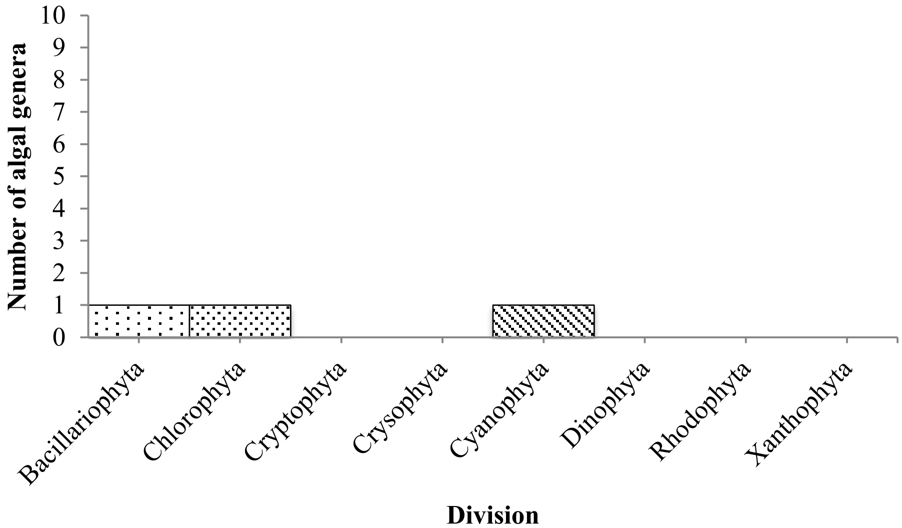

Figure 6.5. The number of algal genera per division (phylum) represented in the slides for sampling site BD. Site BD is in the Serpentine streambed next to North Pond, after the dam and bridge.

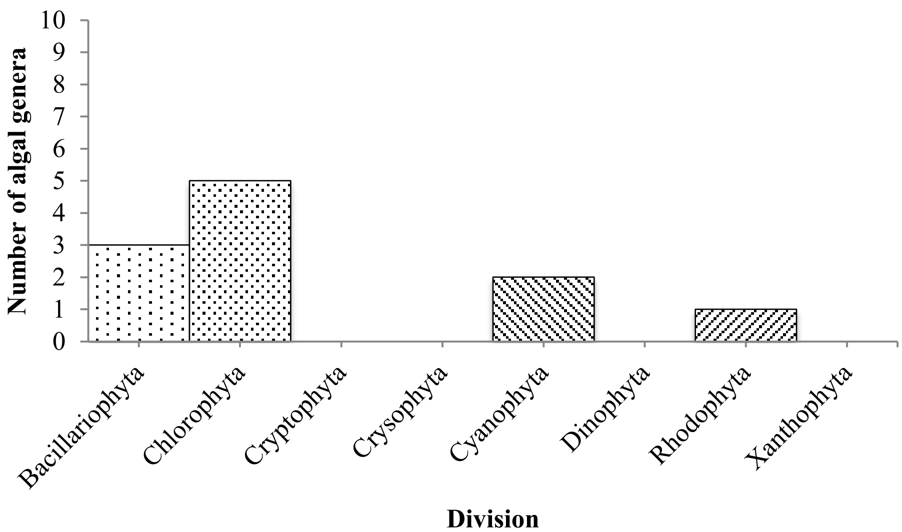

Figure 6.6. The number of algal genera per division (phylum) represented in the slides for sampling site NP. Site NP is close to the center of the North Pond.

Discussion

System Summary

The habitat requirements for each algal phylum, and sometimes for each algal genus, are different, and many can be used as bioindicators to signal water quality. Chlorophyta was the most abundant algal phylum in the Serpentine, East Pond, and North Pond system. Chlorophytes, or green algae, grow well in mesotrophic and eutrophic environments, where nutrient levels are medium to high. However, they do not dominate when TP levels are very high (Bellinger and Sigee 2010). Because Chlorophyta was the most abundant phylum in the system and found in all sites except for site S3, it suggests that phosphorus levels in the water column may be raised, but are most likely not high enough for the system to be classified as severely eutrophic.

Bacillariophyta was the second most represented phylum overall. Also called diatoms, bacillariophytes are found in conjunction with mid-level TP and autumnal algal blooms. This is consistent with observations we made while sampling on a cool day after a very warm fall (October 6, 2011).

Our initial prediction stated that Cyanophyta, or blue-green algae, would dominate the system, since East Pond is known to be eutrophic and bloom frequently. Cyanophytes were very common, but not the most common taxa in our samples. They grow best in warmer water, and can tolerate low light, low dissolved CO_2, and high pH. They indicate enriched, high nutrient conditions. The presence of Cyanophytes suggests that nutrient levels are fairly high, but not high enough for that phylum to dominate. Time of year may play a role; blue-green algae may have dominated the ecosystem in the summer but are now giving way to other types of algae as conditions such as temperature and nutrient-input shift away from cyanophyte preferences.

Specimens from Cryptophyta, Crysophyta, Dinophyta, Rhodophyta, and Xanthophyta were also observed. Cryptophytes prefer cold water, and can be found in almost any ecosystem, thereby negating any use as a bioindicator. Dinophytes (dinoflagellates) are common in mesotrophic systems, like Chlorophytes and Bacillariophytes. Crysophytes prefer low nutrients and low pH, and therefore would grow in areas like the Serpentine peat fen. Xanthophytes and Rhodophytes both grow attached to substrates, and most species and genera have specific habitat requirements. The Rhodophyta genus we found grows on rocks in cold, fast moving streams, and requires hard water. It was found in a sample from North Pond, and may have been washed in

through a tributary. Figure X summarizes habitat requirements and characteristics of individual genera.

East Pond

Site EP, at the center of East Pond, displayed the greatest number of genera per phylum and the greatest number of phyla represented. The sampling day was cool and windy, creating turbulent water and possibly fall turnover. The phyla with the most genera present were Chlorophyta, Bacillariophyta, and Cyanophyta, in order of abundance. Dinophyta, Cryptophyta, Crysophyta, and Xanthoyphyta were also present. The great abundance of these organisms and the fact that the most abundant organisms favored mid to moderately high total phosphorus indicates that East Pond probably only has moderate TP concentrations, despite its frequent algal blooms.

Serpentine Stream

Site S3 is located in the Serpentine, in the wooded area after the fen. Only one phylum was present there, a Cryptophyte. Cold water is the only major habitat requirement for Cryptophytes, so they are not reliable bioindicators of nutrient levels in this part of the Serpentine. The densely forested banks of this part of the stream may shade and cool the water and limit the energy available for algal blooms. More genera were recorded at site BD. It is located in the Serpentine streambed, below the dam and bridge but above the outlet to the North Pond. We observed three genera, one Chlorophyte, one Bacillariophyte, and one Cyanophyte.

Tributary Stream

Site I2, located in a Serpentine tributary stream, contained Bacillariophyta, Chlorophyta, and Cyanophyta, in order of abundance. This follows the trend of the overall system. The water is likely mesotrophic, with moderate inputs, and experiencing an autumnal algal bloom.

North Pond

Site NP, located in the center of North Pond, also contained algae from Phyla Chlorophyta, Bacillariophyta, and Cyanophyta, but more genera per phylum were seen. Chlorophyta was the most abundant. This is consistent with the results from the other elements of the system (East Pond, the Serpentine, and the tributary), and implies that the water in North Pond is probably mesotrophic, with slightly elevated TP. There are fewer genera and phyla represented in North Pond that East Pond, perhaps signifying lower nutrients levels or increased competition. We also observed one specimen from the Phylum Rhodophyta. This particular

genus, *Hildenbrandia*, is common in cold, hard, swiftly moving streams. It is unlikely that *Hildenbrandia* grew in North Pond, as the water is neither swiftly moving nor hard. However, the organisms may have washed in from a tributary.

Synthesis

When the nitrogen to phosphorus (N:P) ratio is greater than 16:1, phosphorus is limited (Belliger and Sigee 2010); when the ratio is less than 16:1, nitrogen is limited. High total phosphorus (TP) usually means that N:P is less than 16. Cyanobacteria dominate systems with N:P less than 16 (abundant phosphorus and limited nitrogen) because they fix nitrogen most efficiently. They also prefer warm water. Chlorophyta and Bacillariophyta occur when N:P is less than or equal to 16, (meso- and eutrophic conditions). They occur but do not dominate when TP is very high. When all three phyla occur in relatively similar abundance, this can indicate mesotrophic systems.

At sites S3, I2, and NP, N:P was less than or equal to 16, and nitrogen was the limiting nutrient. However, Cyanobacteria did not dominate. S1 was nitrogen limited (N:P less than 16). Cryptophyta was the only phylum represented. Cryptophytes can live in any nutrient conditions, but require cold water. The water might have been too cold for the other phytoplankton phyla. At the other sites where N:P was less than or equal to 16, Cyanobacteria may not have been dominant as a result of the cold water temperatures (EP was 15.84˚ C, S3 12.0˚ C, and BD 12.5˚ C) Although the TP was high, the water in the mid-fall is cold, making it a suboptimal habitat for Cyanobacteria, who prefer water between 20 and 30˚ C (Konopka and Brock 1978). Sampling earlier in the season when the water is warmer might allow us to estimate nutrient levels more accurately.

Conclusions

As algal phyla and genera have specific habitat requirements, they make very useful bioindicators of water quality and nutrient levels. This is particularly relevant in light of East Pond’s recurring algal bloom problems. East Pond had the greatest number algal genera observed, and these genera represented the most phyla. North Pond, which does not bloom as frequently, had the second highest abundance of phyla and genera. On the day we sampled, East Pond had a slightly lower concentration of phosphorus than North Pond. Mid-levels of phosphorus contribute to the greatest algal diversity because no species can gain a great advantage and outcompete the others. The ponds might have had a slightly greater number of

genera than the stream sites (but not significantly greater) because the cool, windy weather initiated fall mixing. Mixing brings nutrients from the sediment to the surface, where algae can use them for growth. The wind was especially strong in the lakes, where it had a lot of distance to gain momentum (fetch). The calm, sheltered stream water may have experienced fewer turnovers.

By comparing the algal abundance to measured levels of TP and nitrogen, we can understand the prevailing nutrient cycles in the system. The most represented Phyla (Chlorophyta, Bacillariophyta, and Cyanophyta) may indicate that the system has mid-levels of phosphorus, since Cyanophyta, which prefers high TP, does not dominate the population. Cyanophyta also prefers warm water. If the water was too cold, they could not dominate a system with high TP. We sampled on a cool day in October, so the water may have already reached that temperature threshold. Unfortunately, it is difficult to know exactly what effects the recent weather events had on the algal assemblage, because it can take anywhere from a few hours to two days for an algal population to adjust to new conditions and begin using increased nutrients or light to reproduce (Reynolds 2006).

Sources of Error

There were several sources of error in the algal sampling process. Due to time constraints, algal populations were only sampled on one day, and only five sites were sampled. Due to seasonally differing water chemistry, some phyla may have been more dominant at other times of the year, but were not found in great diversity or abundance at the time of sampling. For example, Cyanophyta prefers warmer water, so the higher water temperatures during the summer are more favorable for their growth, and they may have been the most abundant phylum at that time (Bellinger and Sigee 2010).

Another issue was the method of observation. The method of capturing and preserving algae was not what the general literature suggested; plankton tows, each with different sized mesh, were used and the samples were stored in ethanol. A more appropriate method is to take water samples in jars and later centrifuge them, preserving the specimens in Lugol's solution. The samples should then be stored in the dark. The use of ethanol and the light conditions inside the glass-fronted refrigerator resulted in the breakdown of cellular structure and the dissipation of pigmentation, further inhibiting classification of the algae. Additionally, as there was little time to research algal identification, the algae were difficult to identify due to limited prior

knowledge. Finally, the unusual weather patterns in the fall, such as the hurricane, may have affected algal populations, resulting in different algal species than would normally be found in this system.

Recommendations/Suggestions for Further Study

In light of the limitations of our study, we make the following recommendations for future algal monitoring in the Serpentine system: (1) in-depth research about the best methods for sampling, storing and identifying algae; (2) several sampling days in order to study seasonal changes in algae; (3) a several year project monitoring bioindicator species, which can provide useful long-term data about environment and possible changes in the system; and (4) a better understanding of seasonal impacts on algal populations. These steps would lead to a more comprehensive study of the algal populations in the Serpentine system, and may be better able to explain the differences between East and North Ponds, and why East Pond has frequent algal blooms while North Pond does not.

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7. PLANTS

Introduction

The plants that grow adjacent to a stream or lake have a significant and complex impact on the ecosystem and water quality. For example, nitrogen-fixing plants can increase nitrogen available is ecosystems, which can increase overall productivity, as nitrogen is often a limiting nutrient. Additionally, different types of vegetation perform better in different circumstances, and therefore may act as indicators of environmental conditions. For example, the tamarack (*Larix laricina*) is a tree commonly found in wetland areas. Because of its tolerance of high soil moisture, high acidity, and low soil temperature, the presence of the tamarack can be used to indicate that these factors may characterize the environment (Fowells 1965). Not only are the aquatic flora and fauna of the Serpentine important for understanding its ecology as it relates to East and North Ponds, but the nearby vegetation plays a major role in the biotic and abiotic processes. A wide variety of plants inhabit the shoreline adjacent to the Serpentine. These include, but are not limited to, mosses, grasses, shrubs, small trees, and mature trees.

Buffer Zones

The riparian zone is the area adjacent to a stream that acts as a buffer, based on the specific vegetation type, width, and flow pattern. Riparian zones are essential to stream and lake ecosystems because they filter out nutrients from surface and groundwater and prevent sediment erosion. Riparian buffers reduce nitrogen concentrations in the water through plant uptake, microbial immobilization and denitrification, soil storage, and groundwater mixing (Ducnuigeen et al. 1997). Mayer et al. (2005) found that nitrogen removal effectiveness varied by buffer vegetation type. The roots of trees, for example, reduce soil erosion by stabilizing stream banks, and thus eliminate the subsequent nutrient addition from these sources (Ducnuigeen et al. 1997).

Due to varying rates of nutrient uptake by different plants, a classification of the riparian zone along the Serpentine may provide insight into the water quality and nutrient concentrations. Vegetative uptake is defined as the absorption of nutrients principally by the roots. Researchers have shown that buffer zones can retain up to 89% of the nitrogen and 80% of the phosphorus from adjacent agricultural land (Ducnuigeen et al. 1997). Wetlands are highly variable in their effectiveness at removing nutrients from ground and surface water. Research has cited anywhere from 12% to 80% removal of surface water nitrogen. However, wetlands are very effective in removing nitrate in groundwater; in some cases greater than 95% of nitrate can be removed

within 1 m of the surface (Mayer et al. 2006). Blankenberg et al. (2008) found that organic filters perform better than mineral filters at retaining nitrogen, highlighting the value of wetlands downstream from agricultural land. The riparian zone along the Serpentine ranges from wetland to forest, suggesting a broad range of effects on nutrients.

Plant communities in freshwater ecosystems interact with the fauna and can act as an indicator of fish community composition and health. A study of 115 Great Lakes coastal marshes concluded that aquatic macrophyte communities were more indicative of fish communities associated with the coastal marshes than water quality parameters were (Cvetkovic et al. 2010). Aquatic plants are critical for fish because they provide food, a refuge for small fish from predators, a barrier from wave and wind disturbances, as well as shade and cooler temperatures.

The wetland of the Serpentine is most likely in a transitional phase between a fen and a bog, also called a poor fen, because the vegetation is Sphagnum dominated, yet it receives groundwater and surface water inputs from the Serpentine and East Pond. Peatlands can be characterized by any number of combinations of mosses, sedges, shrubs, and other acidophilic plants. The plants have many special adaptations to the low-nutrient conditions. Species richness and plant community composition are closely related to nutrient availability. According to a study by Bedford and Godwin (2003), most wetlands were nitrogen limiting; however, some fens with high inputs of aluminum or calcium rich waters can be phosphorus limiting.

Mosses of the genus *Sphagnum* are the most important peat-building plants in bogs and fens; they grow shoots actively in the surface layers (about 1-10 cm annually) and the lower layers die off and convert to peat (Mitsch et al. 2009). Species that often grow in association with *Sphagnum* are cotton grass (*Eriphorum vaginatum*), sedges (*Carex* spp.), leatherleaf (*Chamaedaphne calyculata*), cranberry and blueberry (*Vaccinium* spp.), and Labrador tea (*Ledum palustre*). In the United States, fens tend to consist of a diverse community of plants that include bryophytes, sedges, dicotyledonous herbs, and grasses. Tree growth is often stunted at 1 meter when growing in a fen. Common species include Scots pine (*Pinus sylvestris*), crowberry (*Empetrum* spp.), spruce (*Picea* spp.), and tamarack (*Larix* spp.).

The main objective of this study was to determine which wetland plant species characterize the Serpentine and how those species influence the water and sediment nutrients and vice versa. The second objective was to look for spatial gradients both horizontally and vertically

to see how the composition of species changes moving away from open water and also moving along the Serpentine.

The Serpentine Wetland

Due to the Sphagnum mat, the wetland along the Serpentine was initially classified as a bog and it was predicted that the peat mat would act as a sink for nutrients. The final hypothesis was that the external inputs (groundwater and human factors), combined with internal nutrient cycling, would influence the rest of the Serpentine, from SC to AD.

Methods

Wetland Study

A stratified sampling approach was used to allow comparison of one end of the Serpentine to the other, and to enable examination of the fen on a scale of proximity to the open water of the Serpentine. Fifteen 100 meter transects were placed in the fen starting from the beginning of the emergent zone of the Serpentine and continuing perpendicular to the water's edge into the fen. These transects were placed based on GPS points chosen using satellite imagery of the Serpentine. The GPS points were selected along somewhat even intervals along the Serpentine adjacent to the fen, so that the entire area of the fen could be characterized by the survey (Figure 7.1). Quadrats sized 0.5 m x 1 m were placed at 0, 5, 10, 15, 20, 25, 50, 75, and 100-meters on the upstream side of each transect, and percent cover for each species was recorded using species key (Appendix 7.A).

Percent cover is notoriously subject to observer bias, especially when many observers are involved in the study. In fact, one study found that estimates of cover of wetland vegetation in 25 cm x 25 cm plots could vary 10-fold among observers (Clymo 1980). Therefore, to minimize observational bias, percent cover was reclassified using the Daubenmire system, re-numbering each observed percent cover into the midpoint of a set of classes (Daubenmire 1959). These classes are: 0-5, 6-25, 26-50, 51-75, 76-95, 96-100 percent cover. Therefore each percent cover was converted to 2.5, 15.0, 37.5, 62.5, 82.5, or 97.5 percent. Using the midpoints to interpret data assumes that actual values tend to be symmetrically dispersed about these points. Thus, this methodology allows us to dismiss some of the error of observer bias (Daubenmire 1959).

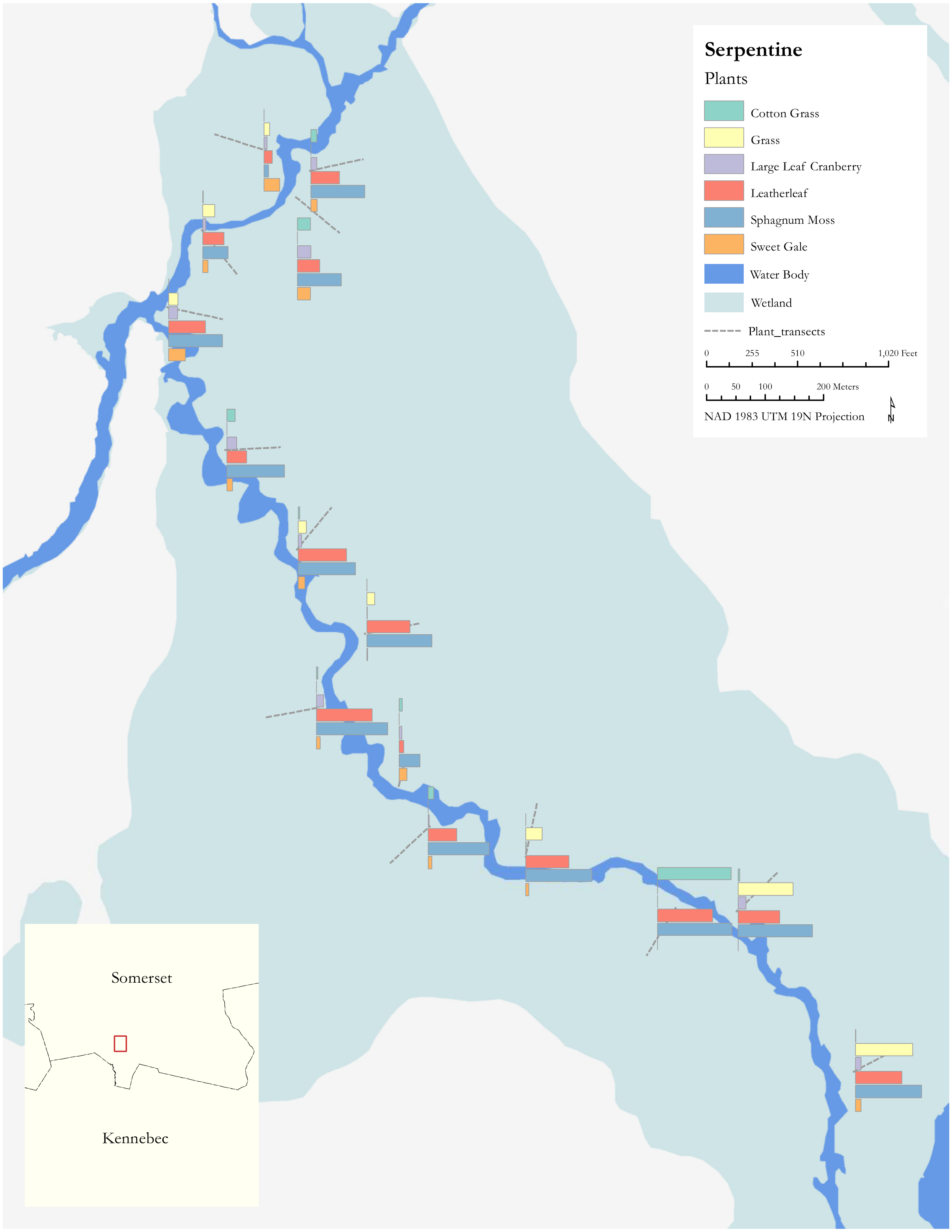

Figure 7.1. The percent abundance over the entire transect of the top six most abundant plant species. Abundances were averaged from observations at 0,5,10,15,20,25,50,75 and 100 meters extending from the water's edge along each transect. Transect vectors are displayed.

Voucher specimens were collected for any unknown species, and identification was done through use of Crow and Hellquist "Aquatic and Wetland Plants" manual of aquatic plants (2000). Remaining unknown species were either given a number following the common family name (if known), or referred to as "unknown" followed by a number.

Plant Importance Index

To analyze the importance of each species in the fen adjacent to the Serpentine, we wanted to create a system to measure plant dominance incorporating both abundance and frequency. In any one transect, a plant might be found infrequently but in massive quantities when present, or a plant may be present in nearly every quadrat, but with very low abundance. To calculate the dominance of each plant in the ecosystem, we compiled percent cover and frequency to create a Plant Importance Index (PII) (Figure 7.2). To represent plant importance, each variable was normalized on a consistent scale. Percent cover for each species was summed among all transects put together, and then divided by the grand total of all species' percent cover totals. This normalized percent cover represents the ratio of a species percent cover to all plant cover observed.

Species	Normalized Cover		Normalized Frequency		Plant Importance Index
A	0.7752	x	1	=	0.7752
B	0.0310	x	1	=	0.0310
C	0.1938	x	.25	=	0.0485

Figure 7.2. Example demonstrating the necessity to include both abundance and frequency when calculating plant importance. Species B, with high frequency but low abundance, has a similar importance value to Species C, which has a high abundance but low frequency. Species A has both a high frequency and a high abundance, and therefore has a much higher importance value.

Frequency data were also normalized by dividing the number of quadrats a species was observed in by the total number of quadrats used (n=135.) The ratios of cover and frequency for each species were then multiplied to combine the two measures of plant importance. This output was then normalized by dividing each species' value by the total of all species' values and multiplying by 100, yielding the PII. Therefore, the sum of the PII value from each species is exactly 100. The PII is not a standard index, and it was created for the purpose of this project in an effort to more accurately measure plant dominance.

$$\frac{\text{sp.percent cover}}{\text{total percent cover}} = \text{normalized percent cover}$$

$$\frac{\text{sp.frequency}}{\text{total \# of quadrats}} = \text{normalized frequency}$$

$$\text{Normalized percent cover} \times \text{normalized frequency} = \text{initial PII}$$

$$\frac{\text{initial PII}}{\text{total initial PII (all species)}} = \text{Normalized PII}$$

Shannon-Weiner Index

To measure species diversity between transects, the Shannon-Weiner index was calculated for each transect to compare species richness and evenness between various parts of the Serpentine. Rank abundance was also calculated and then graphed for each transect to yield a visual display of plant diversity along the Serpentine.

Observational Study

In order to compare the fen to the other wooded areas adjacent to the Serpentine, an observational study was conducted to identify what trees and shrubs characterized the remainder of the Serpentine. Tree and shrub species were recorded from site AD to site SC, and the area was categorized based on forest cover type.

Results

In our stratified quadrat study, we found a total of 49 species present in the fen. Three unknown species were identified, two of which were identified to the rush family, *Juncaceae*, and the third remaining as unknown. Additionally, we identified grass as one family, *Poaceae*, without distinguishing between grass species. (Appendix 7.B)

It is clear that Sphagnum moss is the most dominant species of the fen, with a PII of 52.8. Leatherleaf also ranks high in dominance with a PII of 32.3. Aside from these two species however, the next highest-ranking plant is the unknown grass species, with a PII of only 4.2. Sweetgale, Cotton Grass, Large Leaf Cranberry, and Small Leaf Cranberry all follow grass fairly closely with PII values of 2.8, 2.2, 1.7, and 1.2 respectively (Table 7.1). Aside from these 7 species, every other species has a PII value below 1.0. Out of the remaining 42 species, 8 species were found ranging from 0.5 to 0.01, and 34 species had PII values below 0.01 (Appendix 7.C).

Table 7.1. Plant Importance Index for top seven dominant species

Species	normalized cover	relative frequency	normalized plant importance index
Sphagnum Moss	0.36	0.81	52.8
Leatherleaf	0.22	0.79	32.2
Grass	0.07	0.29	4.1
Sweetgale	0.04	0.37	2.8
Cotton Grass	0.05	0.24	2.2
Large Leaf Cranberry	0.03	0.29	1.7
Small Leaf Cranberry	0.03	0.24	1.2

Rank abundance curves were created for each transect. By plotting mean species cover by abundance rank (1 being species with the highest mean cover, 2 being species with second highest mean coverage…etc.), distributions of abundant species can be seen for each transect. Almost every transect showed similar patterns of a few abundant species and many species with low abundance and frequency (Figure 7.3). In thirteen of the fifteen transects Sphagnum moss and leather leaf were both the highest ranked according to the rank abundance curves (Appendix 7.D).

Shannon–Wiener (S-W) indexes were calculated for species diversity within each transect. Transects with higher S-W index values have higher diversity than those with lower S-W index values. The transect with the highest S-W index value was transect four with a value of 1.84. Values ranged from 1.14 to 1.84 (Table 7.2). The S-W values for each transect were plotted by location and visually assessed to find trends. From the top of the Serpentine closest to the stream inputs towards East Pond, the Shannon-Wiener index decreases relatively steadily. S-W index was compared with species count to help compare evenness (Figure 7.4).

Our observational study of the Serpentine described an increased abundance of woody plants, large trees and shrubs from SC to NP. The forest type is a well-developed northern mixed hardwood (containing red oak, red maple, sugar maple, speckled alder, birch, and aspen) with

patches of white pine and eastern hemlock. From SC to EP is wetland cover and fen/bog habitat denoted in the quadrat and transect sampling.

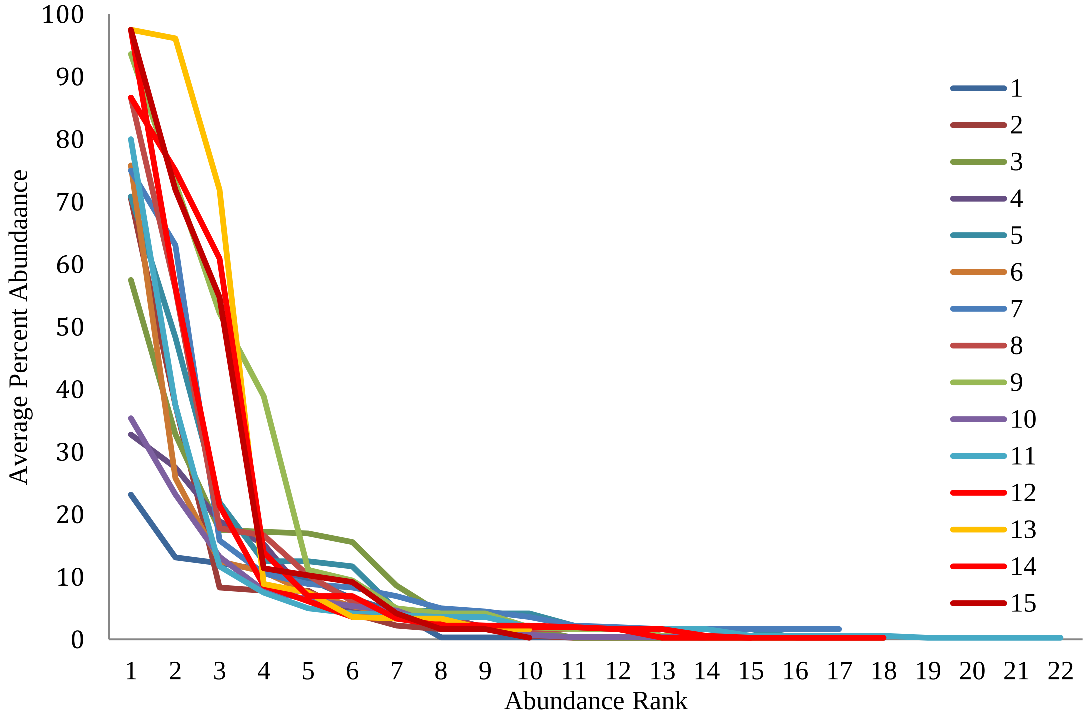

Figure 7.3. Rank-Abundance for each transect where average percent abundance relates to average percent cover.

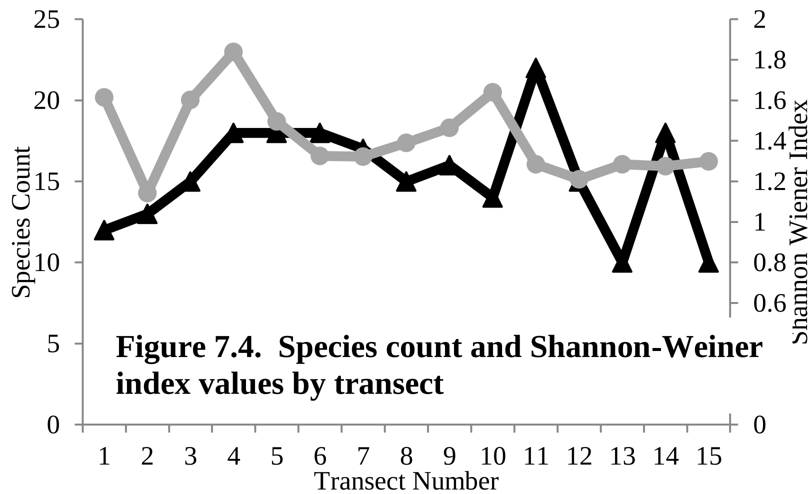

Figure 7.4. Species Count and Shannon Weiner Index by transect number.

Discussion

Plant Importance Index

Overall, the Plant Importance Index (PII) results show that the two most important species are Sphagnum and Leatherleaf. The third to eighth most important species have a lower dominance than Sphagnum and Leatherleaf. These five species tended to have relatively high frequency, but lower percent cover. For example, Sweetgale had a normalized frequency at nearly half the normalized frequency of Leatherleaf: 0.370 to 0.785, respectively. However, Leatherleaf's normalized percent cover (0.23) was over five times that of Sweetgale (0.04). Although the lower PII value species are not dominant in the ecosystem due to their low percent cover, they are still widely dispersed across the fen, and therefore are necessary species to mention when defining this ecosystem.

The majority of observed plant species in the fen represented little to no biomass. In fact, the sum of all Plant Importance Indexes of the 42 least dominant species is 2.7, still lower than the PII value for Sweetgale. The extremely low PII values demonstrate low dominance the majority of the fen's species occupy. This distribution, with a large number of rare species and few very common species, is a common distribution pattern found in many United States fens. Bedford and Godwin (2003) note that in the United States, fens are very floristically diverse, even when compared to other wetland types, with a large number of rare and uncommon bryophytes and vascular plant species. Although the PII values for these plants may be low, they still pose a significant importance to the ecosystem in the form of biodiversity. The plant diversity found in fens is a huge part of what makes them such an important ecosystem to protect.

Plant Species Diversity

The Shannon-Weiner index results show clear peaks in plant species diversity in transects 4 and 10. With the exception of transect 2 and transect 10, diversity seems to increase moving along the Serpentine from EP to SC. This corresponds positively with patterns observed in concentration of surface water nutrients, which were also observed to rise moving from EP towards SC. These data cannot be statistically correlated since chemistry and plant diversity data were collected at different sample sites and there are fewer sample sites in the water chemistry study; however, the trend is still observable. Additionally, there is an observable increase in

species richness moving from the stream inputs to the Serpentine, from transects 1 to 4 (Figure 7.4). This could indicate that the streams act as a source of nutrient inputs, since high nutrients tend to decrease biodiversity. This is because only very competitive species tend to outcompete others with abundant nutrient resources (Huston 1979). Agricultural land located near the stream input is likely the cause of this nutrient loading, since runoff from agricultural land often carries nutrients from fertilizer and manure into stream and freshwater ecosystems causing a decrease in biodiversity (Robertson and Saad 2011).

Rank Abundance

The rank abundance curves for each transect make it possible to compare trends along the length of the Serpentine. As with PII, rank abundance results show that there are only a few species that are highly abundant and many species that have very low abundance. This is consistent along the Serpentine with exceptions of transects 1, 4, and 10. Transect 1 is closer to non-wetland landmass than the other transects, and thus is quite different compositionally. Lower Sphagnum abundance and lower percent plant cover overall, as well as different coverage ranks for species indicate that it is a different ecosystem than the rest of the transects (Appendix 7.D). Transect 4 has a similar species ranking to the majority of transects, but has lower abundances of Sphagnum, making its rank abundance curve different. This could be the result of a discrepancy in our methods, such as incorrect cover observations of Sphagnum. Lastly, transect 10 lacked data points from the last three quadrats since a pool of open water towards the end of the transect prevented further species observation. The difference in number of data points made transect 10 incomparable to the others, yet is still included to compare.

Sphagnum Moss and Leatherleaf

Species differ slightly from transect to transect, but Sphagnum and leatherleaf were two dominant species, in each transect except for transect 1. These two species are the main components of a bog ecosystem (Gotelli 2008). Sphagnum moss forms large mats and provides an organic peat soil in which other plants grow. The mats build up as living Sphagnum moss leaches compounds that inhibit decomposition (Aerts et al. 1999). In true bogs, this reduced rate of decomposition is exacerbated by the acidic conditions characteristic of bogs, as described. In the case of the Serpentine, the decomposition rates may be a bit higher than those of a true bog, as there are more inputs and less acidic conditions. The second most prevalent species, leatherleaf, provides a lot of structure to the bog, as it is the most abundant woody species found

in the fen. Leatherleaf grows out of the mat and was found all over the Serpentine fen. Leatherleaf has a waxy cuticle, enabling it to live in wet conditions and is adapted to low nutrient and acidic conditions.

Forested Riparian Zone

The second component of the Serpentine plant study was an observational comparison of the two sides of the Serpentine. Observers took note of the shoreline plants as well as canopy cover. While no quantifiable data were collected, qualitative observations indicated drastic differences in the riparian zone vegetation as one moves from East Pond to North Pond along the Serpentine. The Serpentine can be divided into two distinct sections in terms of riparian buffer vegetation. From EP to SC, the vegetation is a fen peatland. The downstream area from SC to AD can be characterized as a well-developed northern mixed hardwoods forest. The distinct difference in vegetation type is most likely due to the landform and over land water flow direction of the two areas. As shown by the flow direction map produced by GIS (Appendix 2.A), the forested area shows clear surface water flow into the stream from both the west and east. The wetland area, however, has a lot of variation in the surface water flow direction. Because water is not flowing off of the land into the stream, but rather flowing in both directions, water is absorbed and stored by the peat, and remains available to the plants.

Overall, the forested riparian is expected to have high nutrient uptake from the water. Deciduous trees have greater nutrient demands than conifers due to the fact that deciduous trees have to compensate for the nutrient losses caused by annual leaf loss (Ducnuigeen et al. 1997). The trees along the forested section of the Serpentine are a mix of deciduous and coniferous trees, with slightly greater abundance of deciduous trees. Studies have shown that red and white oak, red maple, and quaking aspen accumulate substantial amounts of nitrogen up to a threshold point (Ducnuigeen et al. 1997). Once their nitrogen requirements are met, growth and absorption of nitrogen level off. However, during autumn, it is important to consider the impact of falling leaves and debris from the trees that may be an input of nutrients to the system. As decomposition occurs, stream flora and fauna may use nutrients such as phosphorus and nitrogen. Leaching of leaf litter can also lead to higher DOC levels, which affects water quality (Wallace et al. 2008). It is difficult to quantify, or even isolate the effects of the forest buffer on the ecosystem. However, it is important to note the difference between the forested area and wetland area when analyzing the biotic and abiotic factors that make up the ecosystem.

Conclusions and Recommendations

This study of the riparian zone along the Serpentine and a closer study of the fen wetland provide the basis for understanding the impacts that the vegetation has on the abiotic and biotic components of the Serpentine. It is recommended that more comprehensive and ongoing studies continue in the wetland area. The species composition and growth may vary throughout the year, which is why it is recommended to begin a yearlong (excluding winter) multi-year study that accounts for seasonal changes. The same transects that were used in this study should be sampled again to make statistical comparison possible for evaluating the wetland. At a minimum, a four-year study will provide insight into trends and changes in the wetland plant composition, and will allow for predictions of the future of the wetland and the Serpentine. The current methods of this study can be expanded upon in order to gain a more complete understanding of the fen. These include, but are not limited to: peat/sediment cores in the wetland, monitoring surface water flow through the fen, water sampling in the fen, and sampling of the submersed plants. It is important that we get a better understanding of what happens throughout all dimensions of the fen. We know the composition of the surface, and how water interacts at the edge, but we need to know more about what is happening within the other levels. Cores will help us learn more about the organic sediment and water content. Additionally, sampling of submersed plants will enable us to know more about the deeper water areas.

Synthesis

Some connections were made between surface water chemistry and plant species diversity observed along the Serpentine. Total phosphorus (TP) levels increased from downstream to upstream, while species diversity also trended upward along the same gradient. However, it is likely that other factors such as agricultural runoff, land use impacts, and other human inputs, would play a larger role on water chemistry than plants. It is unlikely that surface water would make a significant impact on species richness in the fen, despite its impact on wetland versus forest. The influence of the fen on the Serpentine water chemistry is relatively low but there remains the possibility that some other unmeasured factor might be impacting both plants and water chemistry.

In the substrate of the Serpentine, high amounts of total C and low measures of P were observed from EP to SC. From SC to AD, the inverse was true, with high P and low total C. This indicates higher rates of decomposition in the predominantly wooded area, due to the labile

properties of the leaves. Rates of decomposition are lower in the area of the Serpentine adjacent to the fen, due to the native lignin of the Sphagnum, and also enzymes that slow decomposition. The low total P and high total C in the substrate near the fen also relates to the increased organic fraction commonly observed in fen and bog ecosystems.

Ultimately, this means that the fen is acting as a carbon and nutrient sink for East Pond, and is most likely not a nutrient source for either lake. It is well documented that wetlands in general store enormous amounts of carbon; in fact, on a global scale, the carbon stored in peatlands and other organic-rich wetland soils far exceeds the carbon stored in forests and agricultural soils, despite covering less than 2% of the earth's surface. (Dean and Gorham 1998). This proves important when addressing global climate change, since draining these peatlands, or using the peat for fuel can add significant amounts of greenhouse gases into the atmosphere. In this sense, the fen provides an important ecological service to the Belgrade lakes area, and continued research of the fen, as well as its protection, should be a priority.

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IMPLICATIONS AND CONCLUSIONS

Spatial Analysis

Our bathymetric data do support a uniform depth along the Serpentine, indicating a possible differential of water storage potential along the length of the Serpentine. A temperature gradient exists along the Serpentine, at least during the early fall when we were sampling, facilitating a differentiation in aquatic habitats for flora and fauna. Similar levels of forest cover were observed both within the 100-foot buffer and the watershed of both East Pond and North Pond. Similar levels of shoreline development also suggest that residential camps less likely to be the primary contributor to the eutrophic status differential between North and East Pond. However, East Pond has a larger percentage of its total watershed area occupied by residential land use. Further studies that include specific upland site inspections could support the hypothesis of long distance nutrient transport.

The erosion potential model is strongly correlated with land use types. Furthermore, if a high risk land use type is close to a flow path or water body, it holds the greatest erosion potential, stressing increased awareness of land use conversion and activities that decrease soil stability like grazing and land clearing. The Serpentine is not only situated between two major water bodies, but it is also nearby areas of highest erosion potential and impact.

Therefore, property owners should be aware of the risk their property poses to lake water quality, especially around East Pond due to its relatively smaller watershed. Current land use patterns should be improved to match current standards under Maine's Mandatory Shoreland Zoning Act (MSZA) regulations and future development must be monitored with attention to areas of higher erosion potential. Of particular importance is to minimize activities that disturb or increase overland flow paths. Our best recommendations to decrease nutrient loading and to improve soil stability is to improve and maintain vegetative buffers adjacent to water bodies, outlined in the Lake Smart Program established by the Maine Department of Environmental Protection.

Water Chemistry

North Pond appears more strongly influenced by water column chemical processes occurring in the input streams than by those occurring in East Pond and the sites upstream of the

confluence; this is indicated by trends in phosphorus, aluminum, iron, manganese, calcium, and magnesium concentrations across sampling sites. For each of these elements, concentrations are relatively low in East Pond, S1, and S2, high in the input streams and SC, and then gradually decrease between S3 and North Pond. These patterns indicate that the primary water inputs, and therefore nutrient inputs, are from the feeder streams and not East Pond.

Phosphorus, an element that can have significant implications for an ecosystem due its status as both a limiting nutrient and a contributor to eutrophication, appears to be entering the ecosystem via I2, one of the input streams. Land use data has indicated that this stream receives inputs from agricultural land, which is important due to the use of phosphorus in fertilizers. It is also important to note that it appears as though phosphorus enters the stream in high concentrations following rain events as runoff.

Iron binds phosphorus in freshwater aquatic ecosystems during oxic conditions, helping to prevent algal blooms. The data from this study show a negative correlation between dissolved oxygen concentrations and iron concentrations. This indicates that when dissolved oxygen is high, iron is still complexed with phosphorus in the sediment, and when it is low it releases phosphorus into the water column. This has important implications for the Serpentine, as more algal blooms and increased eutrophication are likely to occur during anoxic conditions when phosphorus is not a complexed form in the sediment.

Magnesium and calcium concentrations are both indicators of the source of water in aquatic systems. As calcium concentrations were lower than the 10 ppm threshold for long flow path groundwater sources, the majority of water present in the Serpentine comes from precipitation or short flow path groundwater inputs.

Arsenic does not appear to be a problem in the Serpentine ecosystem. All of the concentrations were below the EPA limit for drinking water of 10 ppb.

Sediment

The difference in occurrence and severity of algal blooms between East Pond and North Pond may be explained by the physical differences that influence biogeochemistry. North Pond is shallower with increased wind fetch, allowing it to remain mixed throughout the summer. East Pond is about a meter deeper, leading to stratification and anoxic conditions in the bottom sediments. Both East Pond and North Pond have Al:Fe ratios below 3; however, the Al:Fe ratio

becomes null for North Pond since it remains aerobic. East Pond will have a release of nutrients as a result of the anoxic conditions.

S1 and S2 (on the fen side) do not release many nutrients from the sediments. This is confirmed through high TOC concentrations, high DO, and the presence of sphagnum moss. Additionally, the water team measured high amounts of aluminum and iron flowing into the Serpentine from the I1 and I2. This not reflected in the sediments for iron. However, there are slightly higher aluminum concentrations in the soil. This indicates that the nutrients entering the Serpentine and eventually flowing into North Pond are traveling mainly in the water and not settling out in the sediments. A trend of low phosphorus associated with organic matter, low DO, and low TOC is seen in I1, I2, SC, and the a lesser extent in S3 and Ad. This is likely the result of higher amounts of inorganic sediment and higher rates of decomposition at these sites. Lastly, this area of the Serpentine has lower concentrations of DO, indicating that it may go anoxic at times. However, the releasable P at sites I1, I2, SC, S3 and AD is low. Thus, even in anoxic conditions, there will not be a big nutrient release. Most of the phosphorus is tied up in organic matter and will be released slowly as the organic matter decomposes.

Calcium and magnesium do not play a large role in the nutrient cycling. However, they do introduce interesting questions about ground water inputs in this area. Additionally, the flow of water from East Pond to North Pond should be studied more extensively in the future as it appears as though only a small portion of East Pond is draining into the Serpentine.

Fish

Based on scholarly literature and dissolved oxygen, pH, and temperature data from the Serpentine, it was determined that the Serpentine is suitable habitat for most fish and may potentially support populations for 9 of the 12 species analyzed including: Chain Pickerel, bullhead, Largemouth Bass, Smallmouth Bass, Black Crappie, Pumpkinseed Sunfish, White Sucker, White Perch, and Yellow Perch. Brown trout and rainbow smelt most likely do not use the Serpentine because of their highly specific habitat requirements. It is unclear whether golden shiner would utilize the Serpentine, due to a lack of information about their habitat requirements. It will eventually be very important to try and derive a more accurate picture of the actual fish assemblages of the Serpentine in order to understand the diversity of species present and the role they are playing in shaping its community structure.

Understanding the potential trophic interactions that may be occurring in the Serpentine makes it possible to better predict the role of the Serpentine in the 2008 East Pond biomanipulation project and may shed light on why the project has had mixed results on the occurrence and frequency of algal blooms in East Pond. Even though there is a high potential for piscivorous fish in the Serpentine, the abundance and biomass of piscivores in the Serpentine may not actually be very high. If this is true, piscivores may not have a strong top-down control on zooplanktivore populations, allowing zooplantivore populations of East Pond to retreat into the Serpentine and use it as a shelter. Therefore, even though the biomanipulation project removed extremely high amounts of zooplanktivore biomass from East Pond, the ignoring of the Serpentine as a potential refuge from East Pond may offer a clue as to why the project has not clearly reduced algal blooms. By simultaneously conducting the project in the Serpentine, significant White Perch populations that may take advantage of suitable habitat in the Serpentine, may also be targeted and removed.

Algae

As many algal genera and phyla have specific habitat requirements, they make very useful bioindicators of water quality and nutrient levels. East Pond had the greatest number algal genera, and these genera represented the greatest number of phyla. North Pond had the second highest abundance of phyla and genera. On the day we sampled, East Pond had a slightly lower concentration of phosphorus than North Pond. Mid-levels of TP contribute to the greatest algal diversity because no species has a great advantage. The ponds might have had a slightly greater number of genera than the stream sites because nutrients could have been released through lake mixing, especially on our windy sampling day. The calm, sheltered stream water might have experienced less turnover.

By comparing the algal abundance to measured levels of TP and nitrogen, we can understand the prevailing nutrient cycles in the system. The most represented phyla (Chlorophyta, Bacillariophyta, and Cyanophyta) may indicate that the system has mid-levels of phosphorus, since Cyanophyta, which prefers high TP, does not dominate the population. Cyanophyta also prefers warm water. If the water was too cold, they could not dominate a system with high TP. We sampled on a cool day in October, so the water may have already reached that temperature threshold.

In light of the history of severe algal blooms in the system, and in East Pond particularly, further monitoring of the algal populations would provide a better understanding of the interactions between nutrient levels and biotic communities in the system. Algal samples should be taken regularly, throughout the ice-free portion of the year. The habitat requirements for the species found can then be correlated with abiotic factors, like water temperature, pH, and TP, to better understand what causes a bloom.

The biomanipulation of East Pond depends on the assumption that native fish eat the type of phytoplankton that causes blooms. Understanding which species blooms the most severely will affect biomanipulation strategies. If cyanobacteria prove to be the most abundant during blooms, biomanipulation may not be successful in reducing bloom severity, as zooplankton avoid eating them.

Plants

This study was able to evaluate the plants living around the Serpentine. The two sides of the Serpentine, from EP to SC and SC to AD, are quite different, with wetland consisting mainly of sphagnum moss and leatherleaf in the upstream portion, and forest consisting of mixed northern hardwoods on the downstream portion. The plant makeup can influence C levels in the water, yet the plants can also be influenced by nutrients and patterns of growth. It is important that these wetlands be studied more to find out specifics such as actual nutrient content of plants and water flow throughout.

The maintenance and protection of the Serpentine wetland is important to preserving the overall health of the system. The submergent and emergent plants provide habitat for fish and other aquatic fauna. The water level in the Serpentine is something that should be closely monitored, as it has a large impact on the wetland, and the fish species that it may support.

Broad Implications and Conclusions

The main objective of our research was to understand the effects of the Serpentine on East Pond and North Pond. The Serpentine is an interesting study site as it connects two lake ecosystems that have an important difference; East Pond experiences large algal blooms whereas North Pond does not. Large algal blooms such as those seen in East Pond have significant implications both economically and ecologically. These blooms are caused by excess nutrients, namely phosphorus.

In order to gain a holistic understanding of the Serpentine, we divided into research groups that focused on different components of the system (GIS, water chemistry, algae, fish, plants, sediments). As information was gathered it became clear that each research group would make an important contribution to the overall understanding of the system.

Sites S1 and S2 in the Serpentine are dominated by sphagnum moss which produces a compound called sphagnol, inhibiting decomposition. Low rates of decomposition were confirmed at these sites by high levels of total organic carbon in the sediment and low dissolved in the water. When decomposition does not occur bacteria at the bottom do not use oxygen, and therefore do not deplete it from the water column. Additionally, nutrients tied up in the dead organic matter will not be released. Another notable characteristic of sphagnum is that it takes up nutrients from the water column. This was confirmed by water chemistry data that showed lower concentrations of nutrients at sites S1 and S2. These data imply that any nutrients coming in from East Pond would be taken up by the sphagnum moss and therefore would not make it into North Pond.

Conversely, the input streams appear to have a much larger effect on the Serpentine than originally anticipated. High levels of phosphorus, iron, and aluminum were found in the water column at the input streams, especially after a rain event. This suggests that the nutrients are being washed into the input streams from erosion and is supported by GIS data showing high erosion potential near the input streams (most likely from agricultural sites near I2).

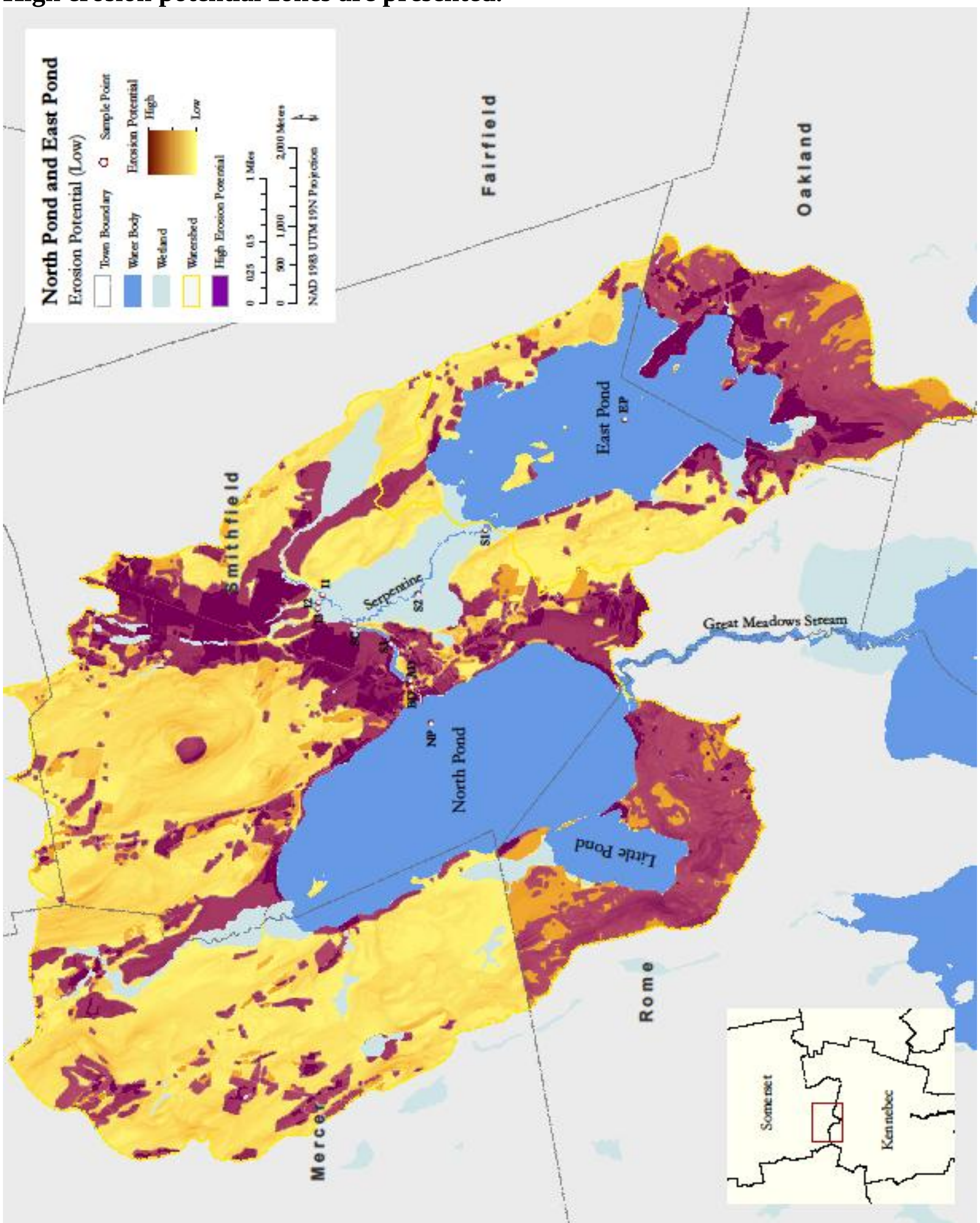
Despite large inputs of phosphorus, aluminum and iron at I2, nutrient concentrations decline as water moves from I2 towards the dam. There are several hypotheses that may explain this phenomenon: 1) Phosphorus is sequestered by algae (this seems unlikely due to the absence of large algal blooms in the Serpentine and that water is most likely moving too fast for biological uptake to occur), 2) Phosphorus binds with aluminum and iron, thus precipitating out into the sediment (the sediment data supports this hypothesis for aluminum and phosphorus, however the iron data does not match), 3) As the nutrient rich water from the input streams meet the relatively nutrient poor water from S1 and S2, the two waters mix ultimately resulting in water near the dam becoming diluted and lower in concentration. This hypothesis is the strongest because it explains the decrease in nutrients for all elements including calcium and magnesium. As may be expected the decrease in concentrations could also be the result of a combination of all three of these hypotheses.

Overall, the Serpentine appears to act as a nutrient sink rather than a nutrient source. The Serpentine seems to mitigate the effect of nutrients approaching North pond from both East Pond and the input streams. Thus, the Serpentine is a missing link. Conserving the Serpentine is important for maintaining the health of North Pond.

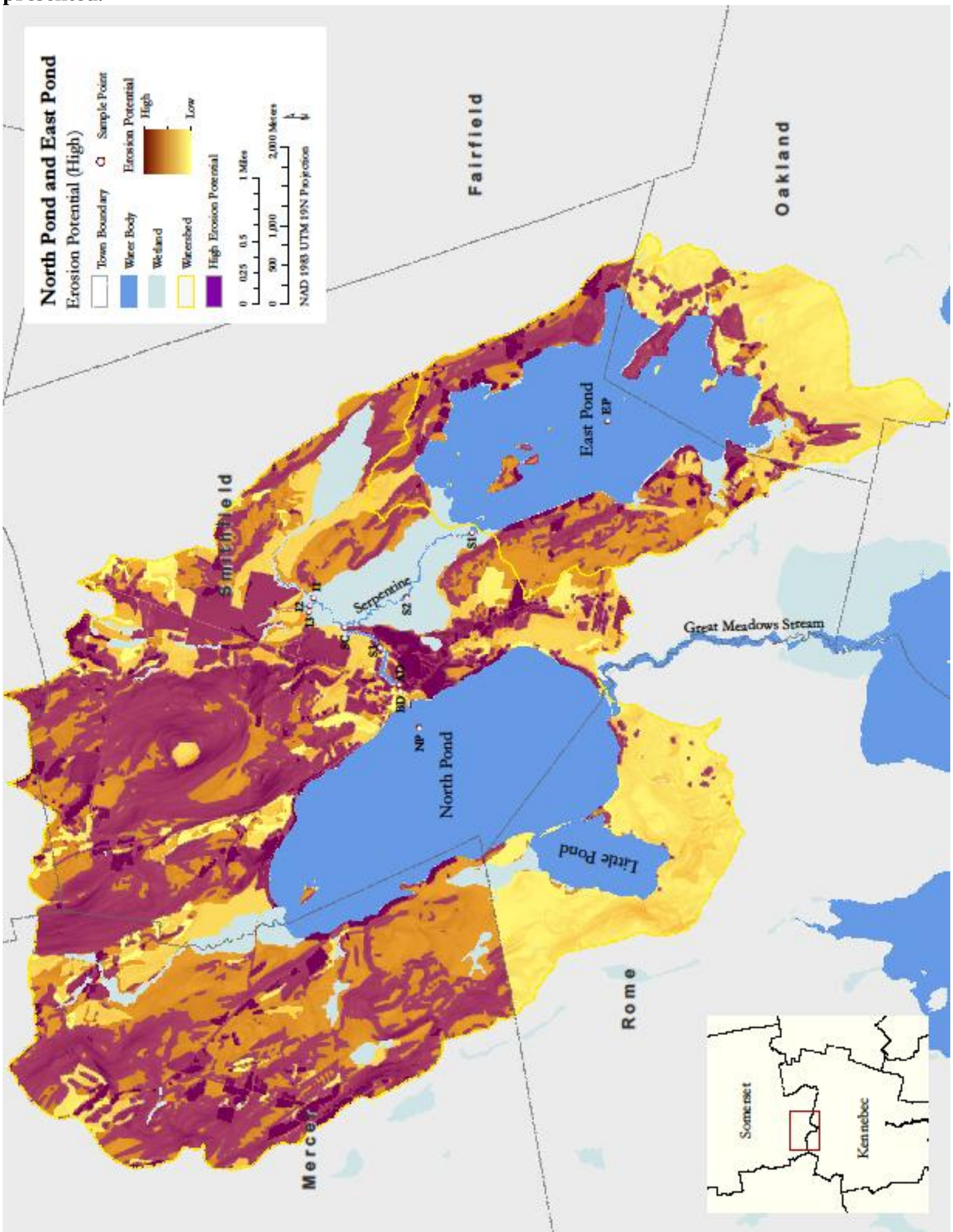
Out study provides a strong baseline for future studies highlights the importance of fully investigating stream inputs into lakes. Sampling solely at the mouth of an input stream does not necessarily explain the complexities and dynamics of a system. Further investigating inputs will help dictate the best places to focus management efforts.

APPENDICES:

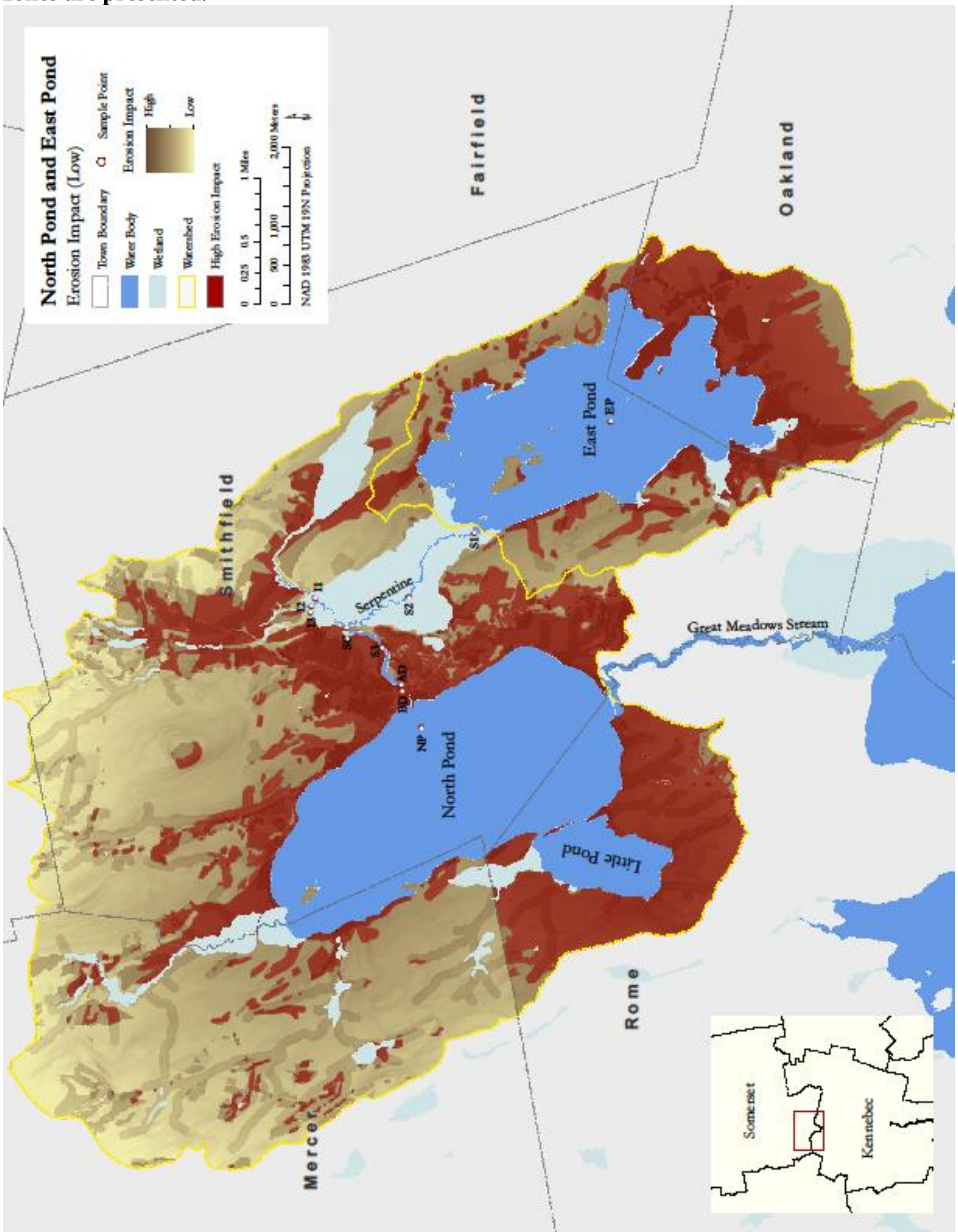
Appendix 2.A. Erosion potential model to the extent of the East Pond and North Pond watersheds. This model is a weighted function of slope, soil type, and land use types within the watershed using the low K factor (K factor = 0.02 for missing data) scenario. High erosion potential zones are presented.



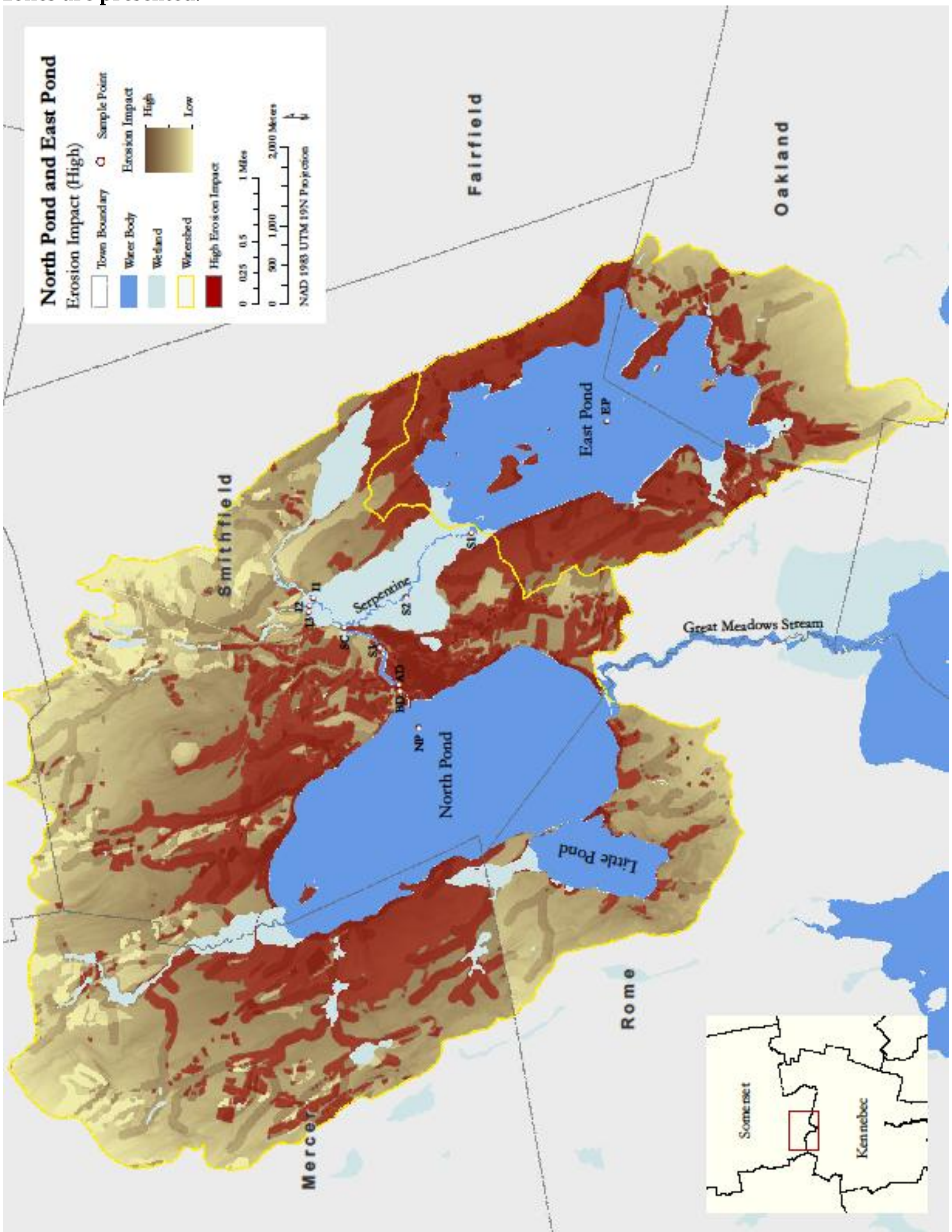
Appendix 2.B. Erosion potential model to the extent of the East Pond and North Pond watersheds. This model is a weighted function of slope, soil type, and land use types within the watershed using the high K factor (K factor = 0.49 for missing data) scenario. High erosion potential zones are presented.



Appendix 2.C. Erosion impact model of the East Pond, North Pond and Serpentine watersheds based on a weighted combination of the soil erosion potential model, lake proximity, and flow route proximity using the low K factor scenario (K factor = 0.02 for missing data) . High erosion impact zones are presented.



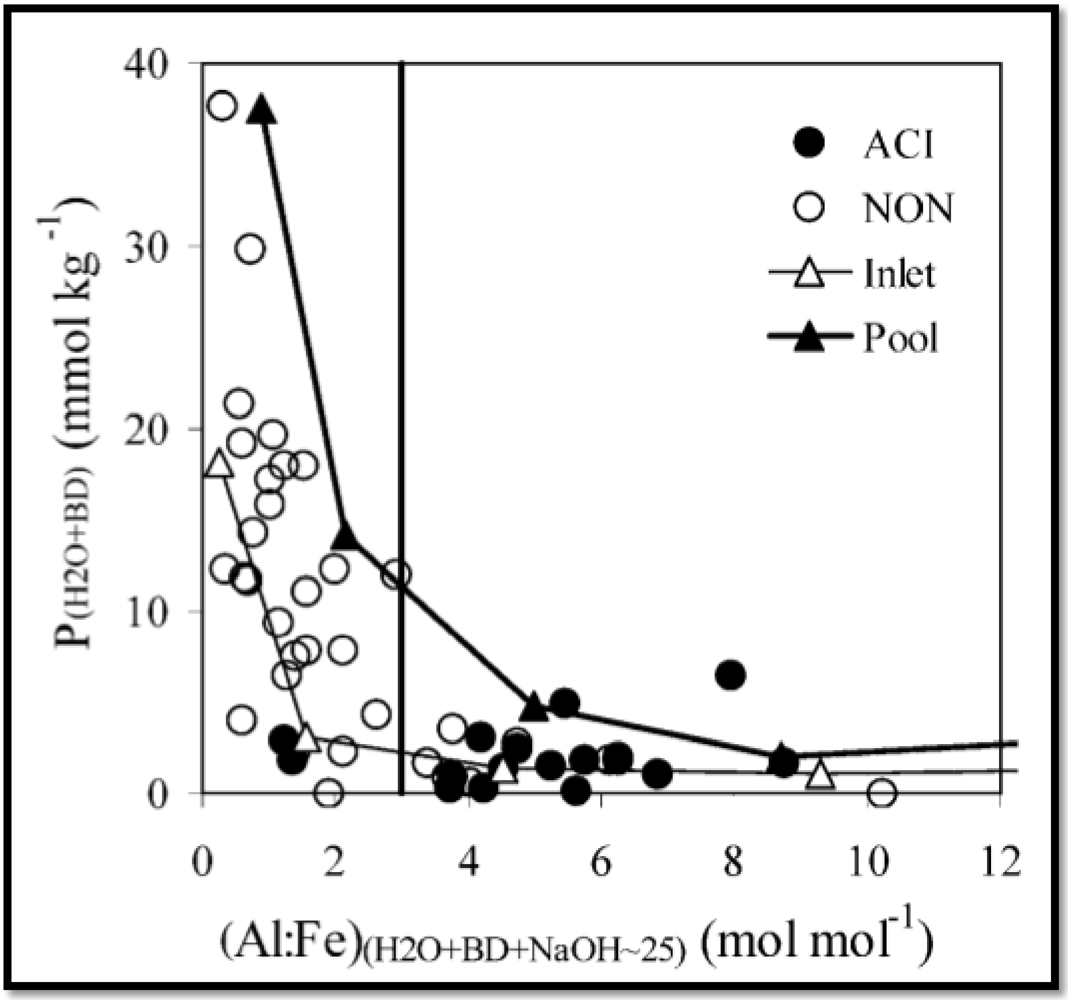
Appendix 2.D. Erosion impact model of the East Pond, North Pond and Serpentine watersheds based on a weighted combination of the soil erosion potential model, lake proximity, and flow route proximity using the high K factor scenario (K factor = 0.49 for missing data) . High erosion impact zones are presented.



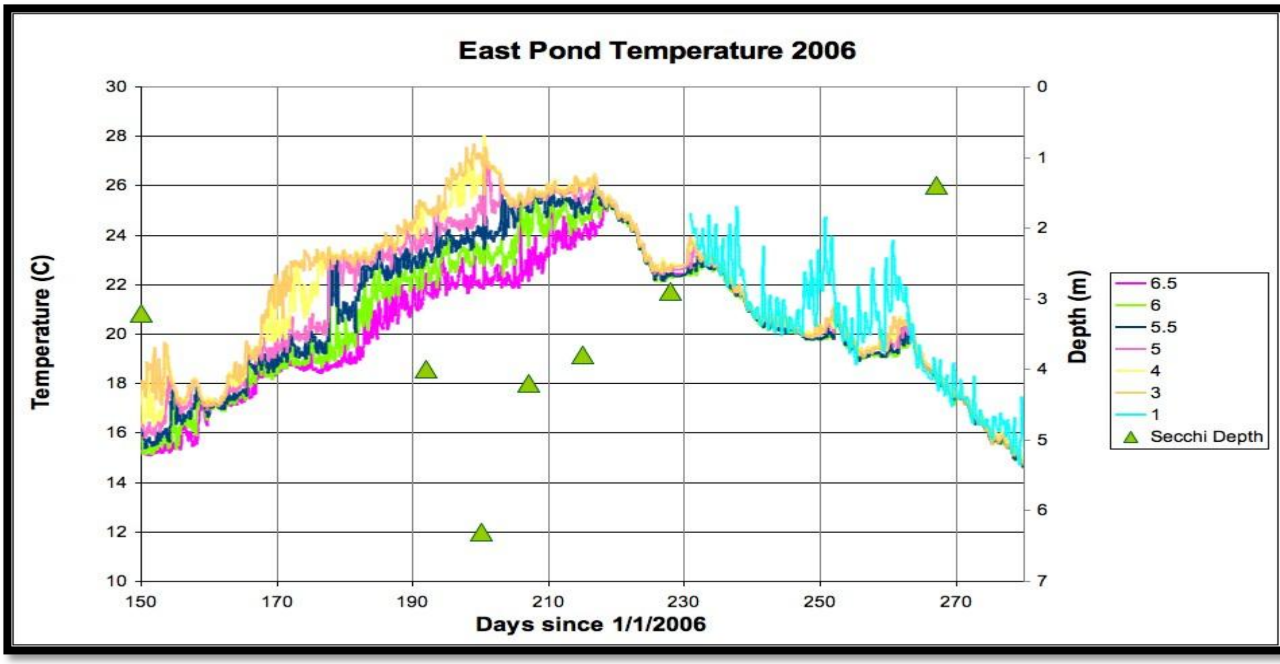
Date	Site	pH	DO (mg/L)	DOC (mg/L)	Temp (°C)	Al (ppb)	TP (ppb)	Mn (ppb)	Fe (ppb)	Ca (ppb)	Mg (ppb)	TN (mg/L)	Nitrate (mg/L)	As (ppb)
Sep 22	EP	5.60	9.30		18.86								0.0941	
Sep 22	S1	5.62	8.83	10.45	18.21	5.04	10.58	5.91	14.90	2408.39	556.56	0.2683	0.0077	7.52
Sep 22	S2	5.21	9.90	13.18	17.87	29.78	3.69	9.51	55.38	2395.18	596.05	0.2668	0.0140	7.74
Sep 22	SC	5.25	2.02	10.75	14.52	72.34	27.55	24.63	299.85	3454.09	855.32	0.1887	0.0186	6.81
Sep 22	S3	5.53	6.31	14.01	15.47	48.16	19.76	20.28	203.58	3218.95	803.02	0.4911	0.0128	9.17
Sep 22	AD	5.66	7.99	10.85	15.98	34.02	22.84	12.05	109.95	2828.48	698.17	0.2071	0.0667	8.29
Sep 22	BD	8.06	7.75	6.81	17.80	35.58		11.76	110.02				0.0652	8.98
Sep 22	NP	7.80	8.04		18.50	164.80		91.08	364.67				0.0494	7.83
Sep 22	I1									2708.03	693.28			
Sep 22	I2									2803.58	698.29			
Sep 29	EP	6.12	8.81		19.51									
Sep 29	S1	6.21	8.59		19.5									
Sep 29	S2	6.24	5.31		19.00									
Sep 29	SC	6.10	5.85		19.00									
Sep 29	S3	6.22	5.55		18.80									
Sep 29	AD	5.88	5.65		18.90									
Sep 29	BD		9.25	8.82	18.80	31.99	17.49	40.44	189.05	4014.99	1477.55	0.1262		8.61
Sep 29	NP		9.06	12.94	19.50	20.54	9.40	3.03	31.14	3422.95	974.25	0.3824		8.70
Sep 29	I1	5.94	8.54		16.80	74.89		28.62	529.72	2146.76	709.08			6.12
Sep 29	I2	6.10	2.31		17.50	135.57	41.76	122.62	999.63	2852.05	690.50			5.86
Oct 3	EP									2352.68				
Oct 3	S1	6.24		4.43	17.45	13.81	6.81	4.94	13.74	2431.84	563.74	0.0887	0.0105	7.99
Oct 3	S2	6.27			16.01	23.64	3.20	5.30	60.32	2273.51	558.31			7.66
Oct 3	SC	6.00		15.62	15.33	215.23	69.81	29.11	543.61	4143.83	1247.43	0.3601	0.1070	9.65
Oct 3	S3	6.05		12.24	15.48	97.06		20.35	385.84	3776.93	984.43	0.1090	0.0315	6.82
Oct 3	AD	6.04		8.57	15.83	58.20	17.49	13.27	190.08	2655.21	673.08		0.0275	8.40
Oct 3	BD									3113.20	974.24		0.0671	
Oct 3	NP									4019.96	2163.44		0.0102	
Oct 3	I1	6.40	2.26	19.89	14.90	302.01	29.64	106.51	1154.45			0.2005	0.0080	8.60
Oct 3	I2	6.14	6.55	13.65	15.20	543.23	320.21	13.18	598.22			0.3182	0.0178	8.42
Oct 6	EP	5.91	21.15	4.67	15.84		10.61		6.30	2520.25	519.30	0	0.0102	
Oct 6	S1													
Oct 6	S2													
Oct 6	SC													
Oct 6	S3	6.24	12.5	15.81	12.00	144.31	38.58	13.07	468.75	4125.14	1055.38	0.2578	0.0416	4.94
Oct 6	AD													
Oct 6	BD	6.35	7.26	15.79	12.50	190.57	44.02	15.78	522.52	2969.14	849.52	0.4665	0.0381	3.90
Oct 6	NP	6.42	9.52	4.64		13.51	12.68	2.92	42.64			0.0431	0.0058	4.62
Oct 6	I1	5.87	3.84			209.98	21.28	62.99	831.54	2129.02	648.33			5.42
Oct 6	I2									4085.35	1159.76			

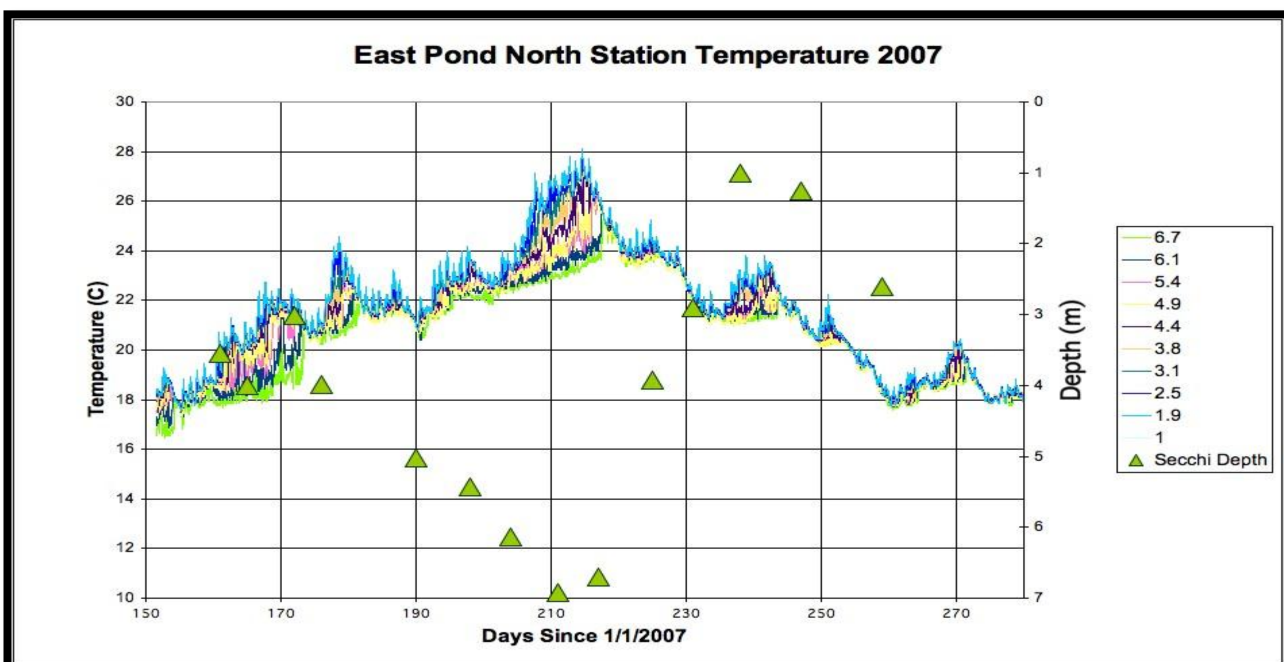
Appendix 3.A All measured water chemistry parameters organized by date and by site. Empty cells denote a lack of data for the variable.

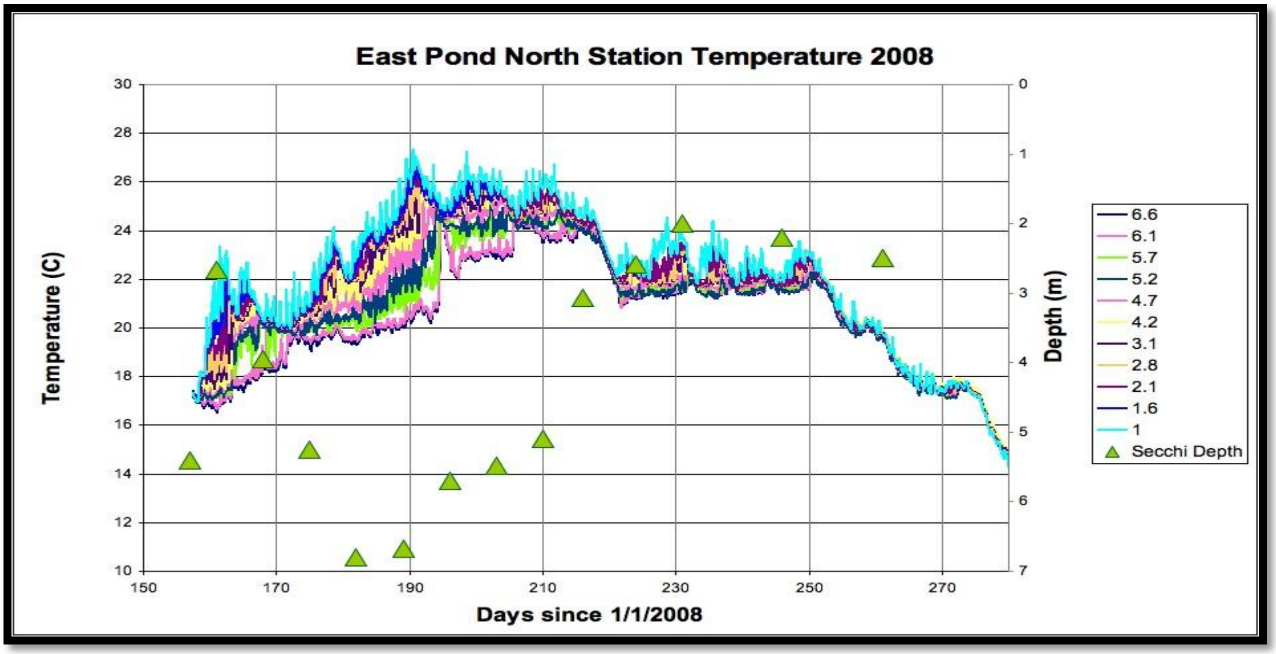
Appendix 4.A Al:Fe ratios found in acidified lakes (ACI), nonacidified lakes (NON), aluminum treated sediments (Inlet) and a deep hole in the Jordan Reservoir (Pool) (Kopacek et al. 2005).

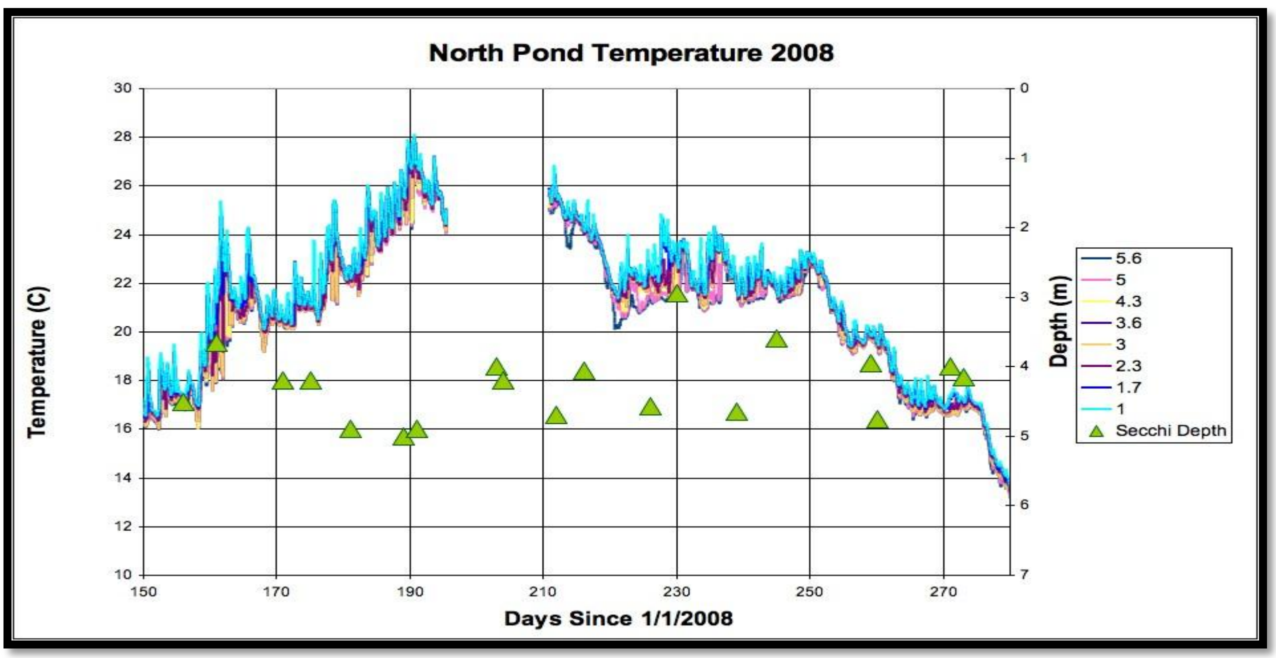


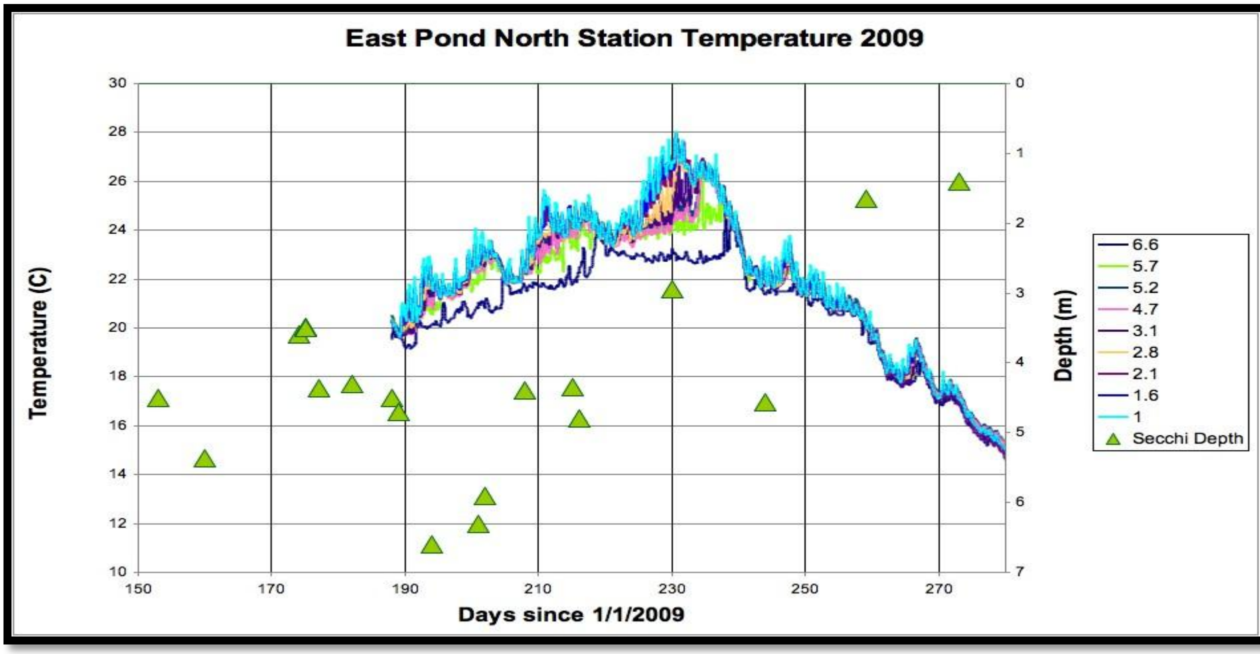
Appendix 4.B Temperature and secchi graphs for East Pond and North Pond starting with the year 2006 through 2010. There is no data for North Pond Temperature is graphed in degrees Celsius on the left y-axis and Secchi depth is graphed in meters on the right y-axis. The x-axis is day number since January 1st. For a couple points of reference, Day 150 is May 30th and Day 210 is July 29th. (King, unpublished data)

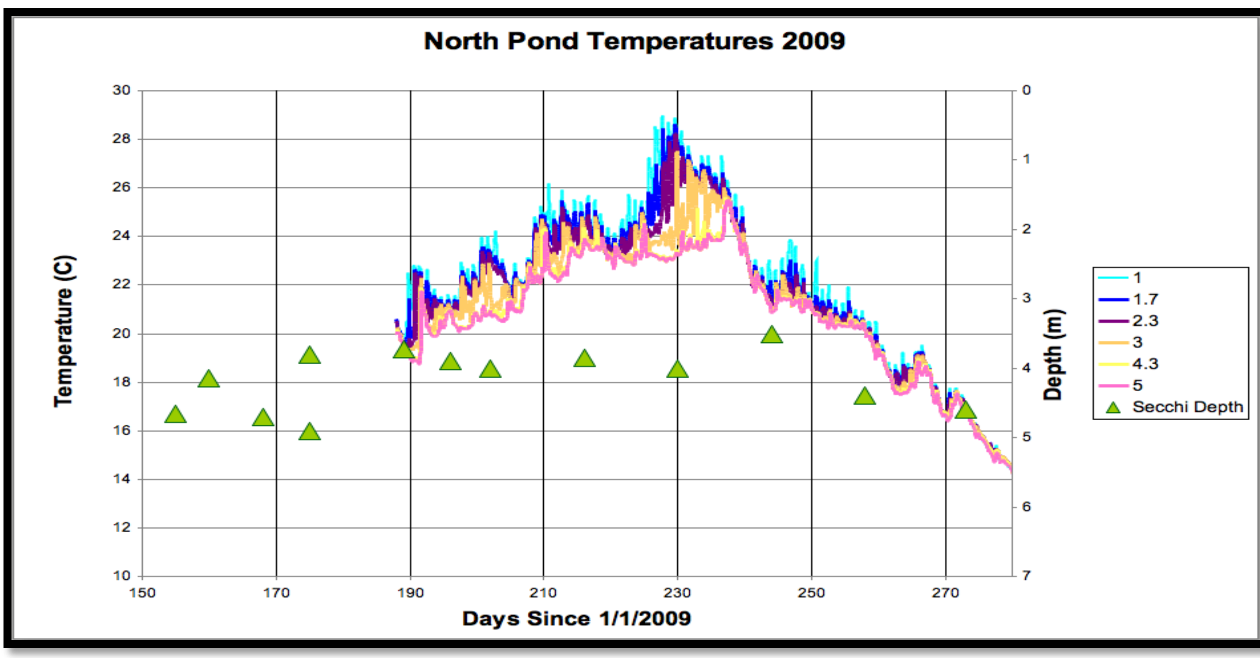


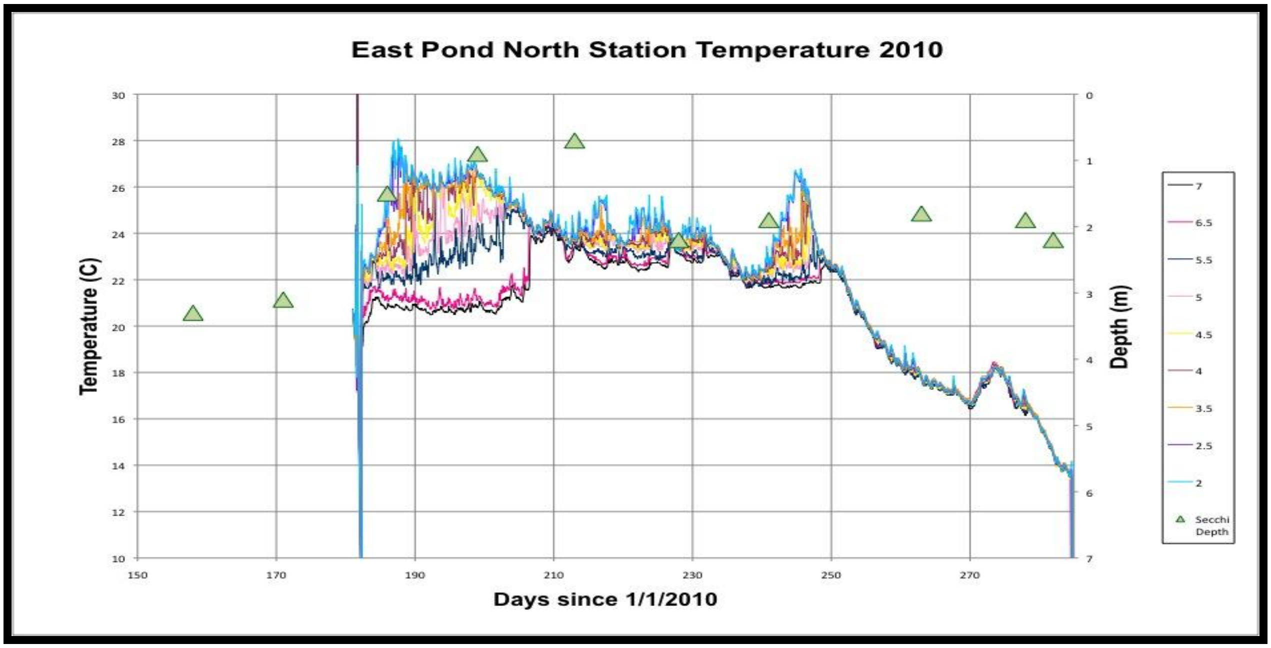


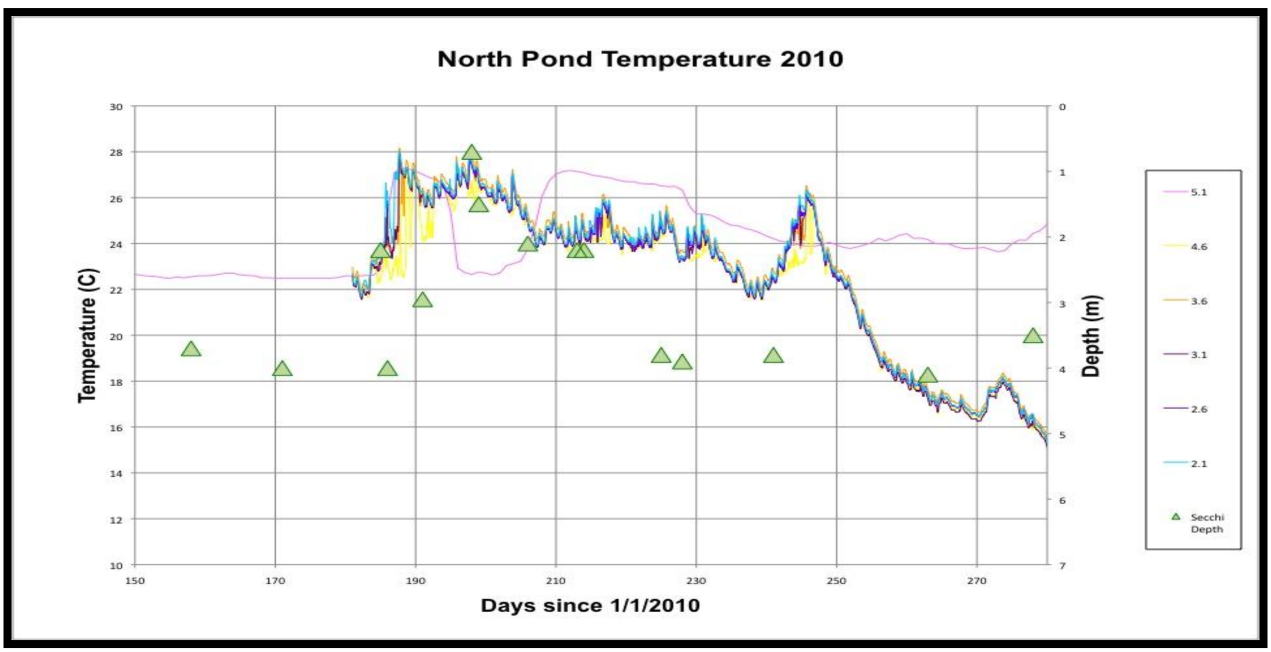

East Pond North Station Temperature 2008
Temperature (C)
Depth (m)
Days since 1/1/2008
6.6
6.1
5.7
5.2
4.7
4.2
3.1
2.8
2.1
1.6
1
Secchi Depth

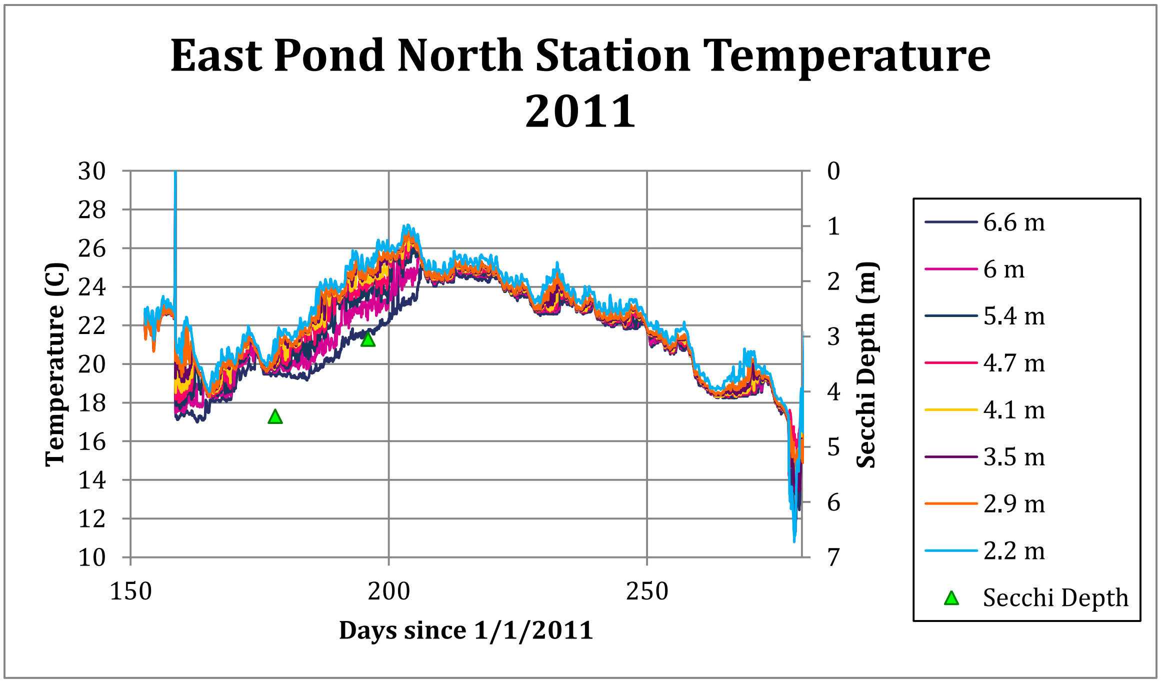

North Pond Temperature 2008
Temperature (C)
Depth (m)
Days Since 1/1/2008
5.6
5
4.3
3.6
3
2.3
1.7
1
Secchi Depth

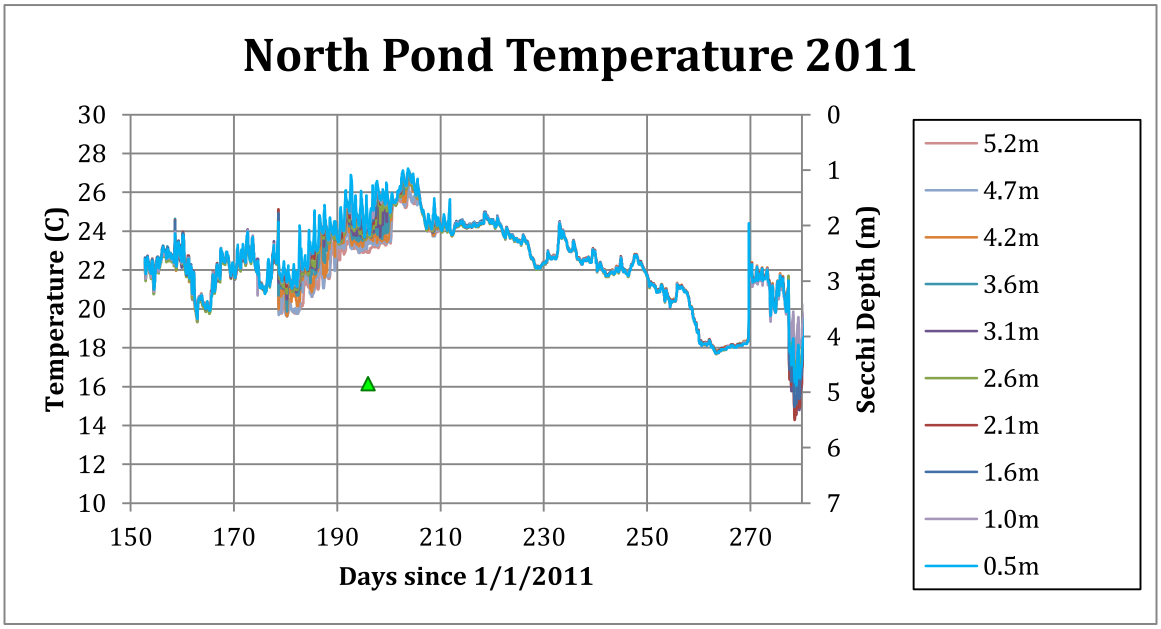

East Pond North Station Temperature 2009
Temperature (C)
Depth (m)
Days since 1/1/2009
6.6
5.7
5.2
4.7
3.1
2.8
2.1
1.6
1
Secchi Depth


North Pond Temperatures 2009
Temperature (C)
Depth (m)
Days Since 1/1/2009
1
1.7
2.3
3
4.3
5
Secchi Depth

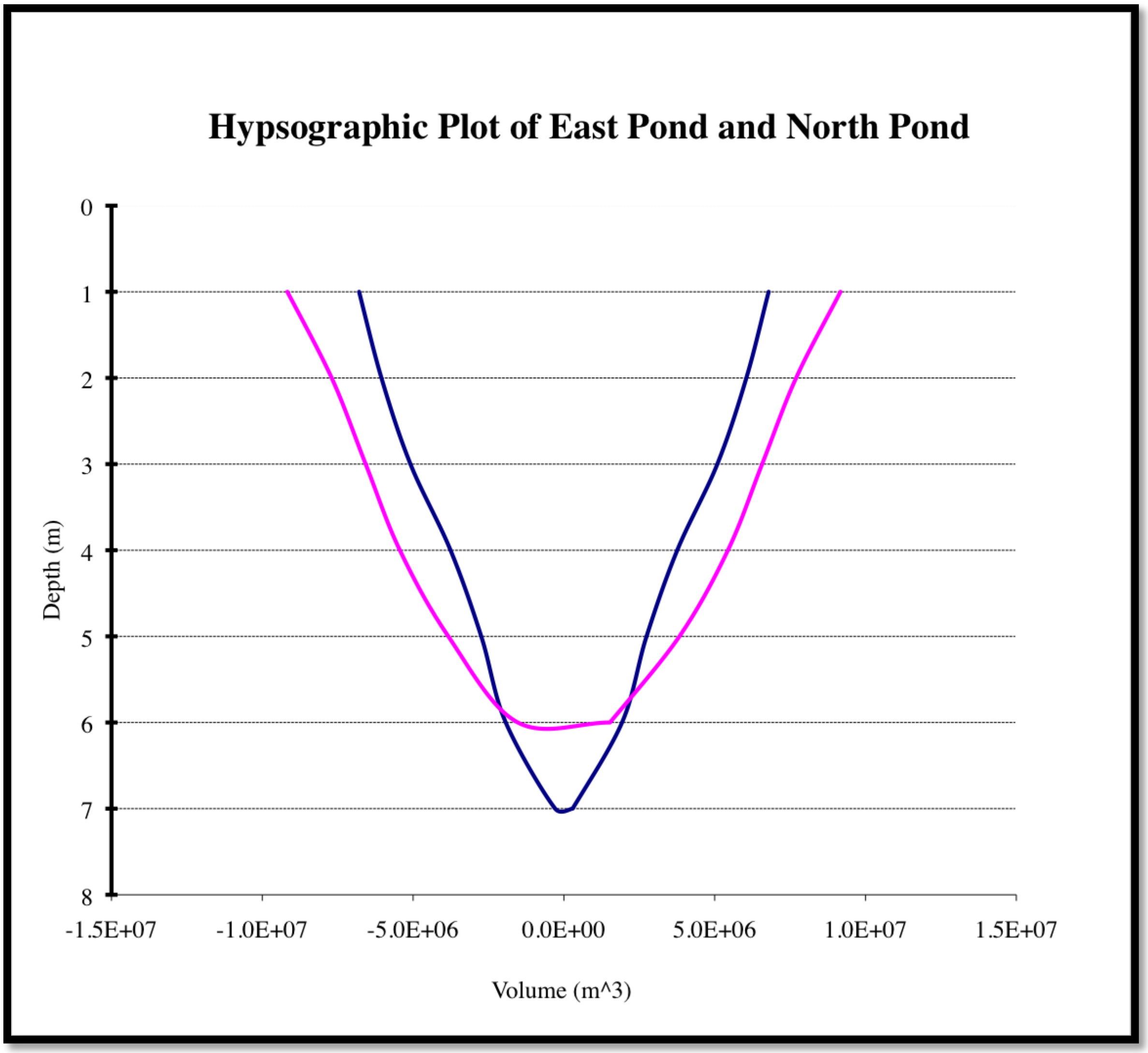

East Pond North Station Temperature 2010
Temperature (C)
Depth (m)
Days since 1/1/2010
7
6.5
5.5
5
4.5
4
3.5
2.5
2
Secchi Depth


North Pond Temperature 2010
Temperature (C)
Depth (m)
Days since 1/1/2010
5.1
4.6
3.6
3.1
2.6
2.1
Secchi Depth

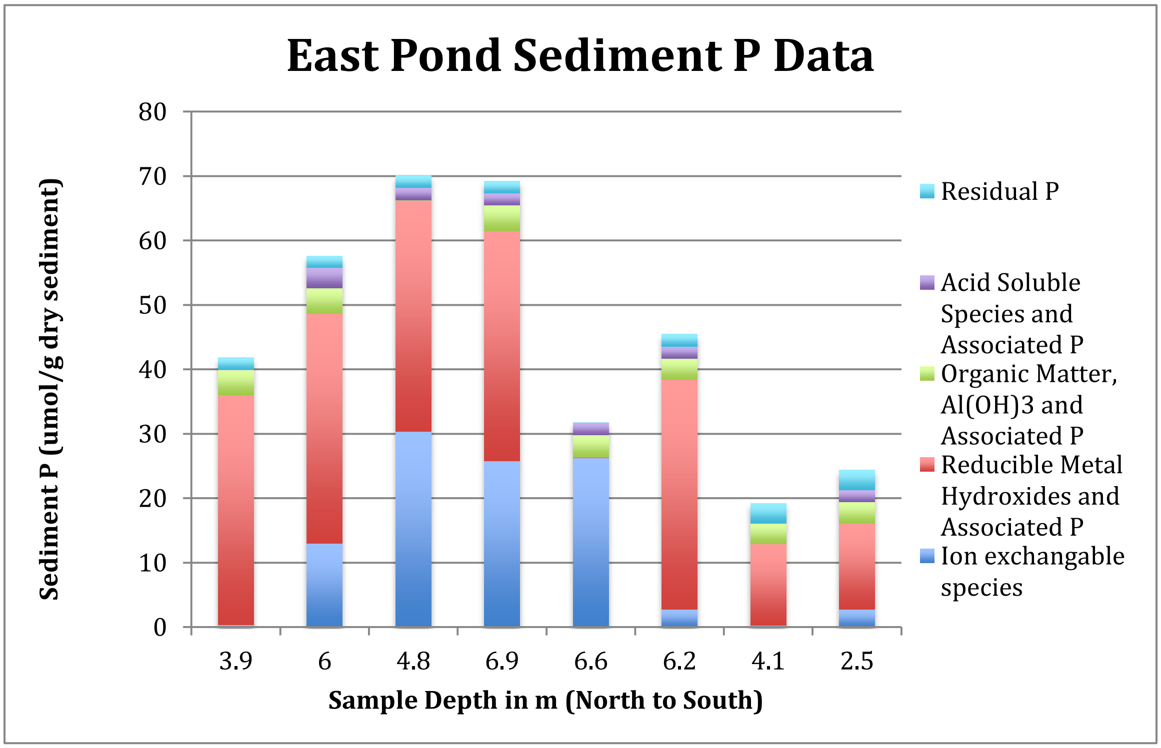

East Pond North Station Temperature 2011
Temperature (C)
30
28
26
24
22
20
18
16
14
12
10
Secchi Depth (m)
0
1
2
3
4
5
6
7
150
200
250
Days since 1/1/2011
6.6 m
6 m
5.4 m
4.7 m
4.1 m
3.5 m
2.9 m
2.2 m
Secchi Depth

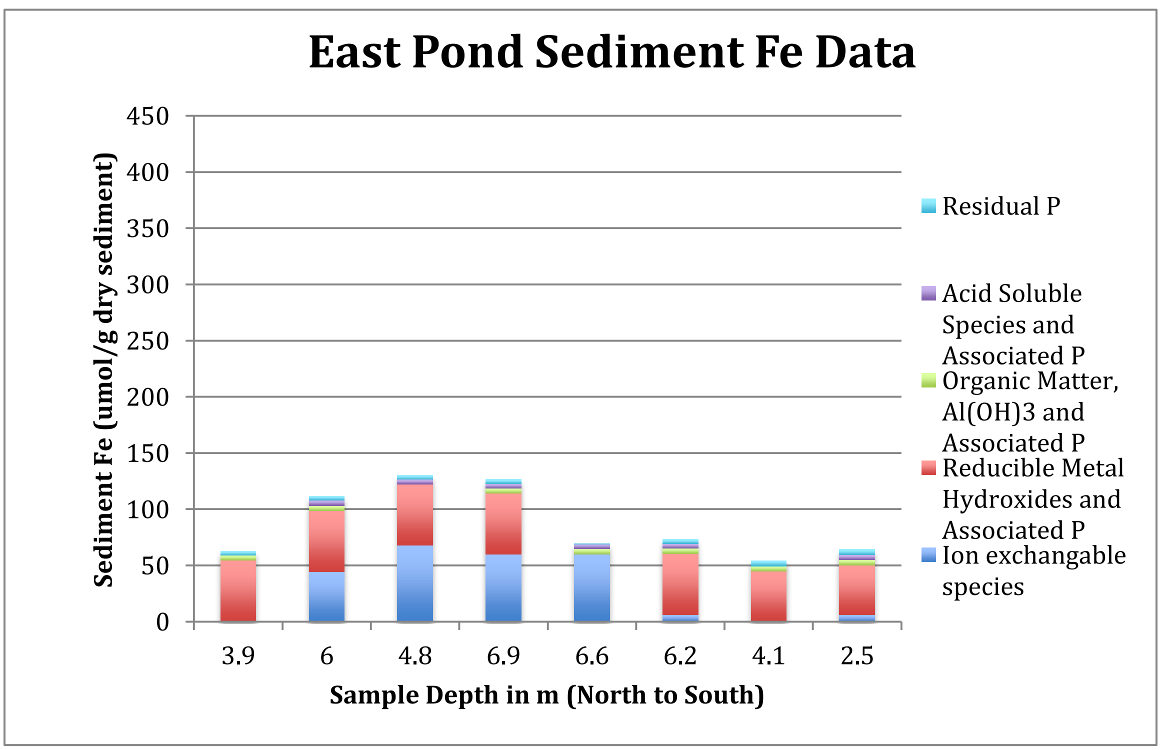

North Pond Temperature 2011
Temperature (C)
30
28
26
24
22
20
18
16
14
12
10
Secchi Depth (m)
0
1
2
3
4
5
6
7
150
170
190
210
230
250
270
Days since 1/1/2011
5.2m
4.7m
4.2m
3.6m
3.1m
2.6m
2.1m
1.6m
1.0m
0.5m

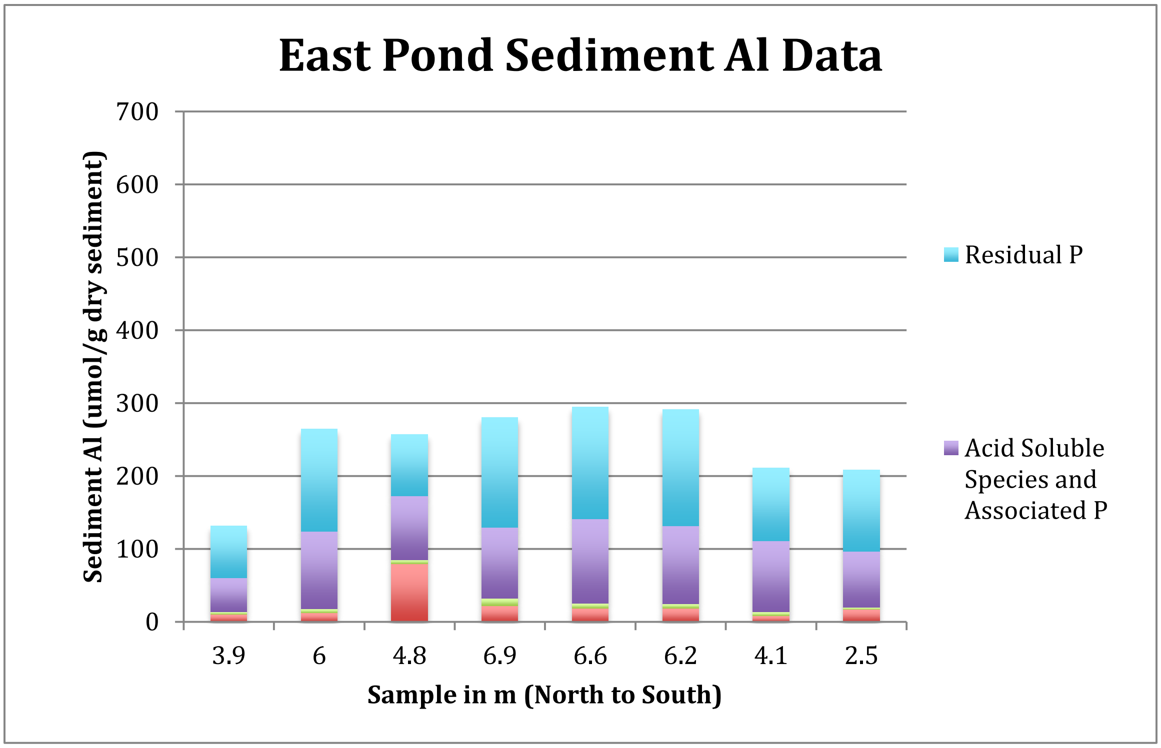
Appendix 4.C This graph shows the bathymetry of East Pond and North Pond. East Pond is depicted in blue and North Pond is depicted in pink. East Pond is about 1 meter deeper than North Pond (King, unpublished data).

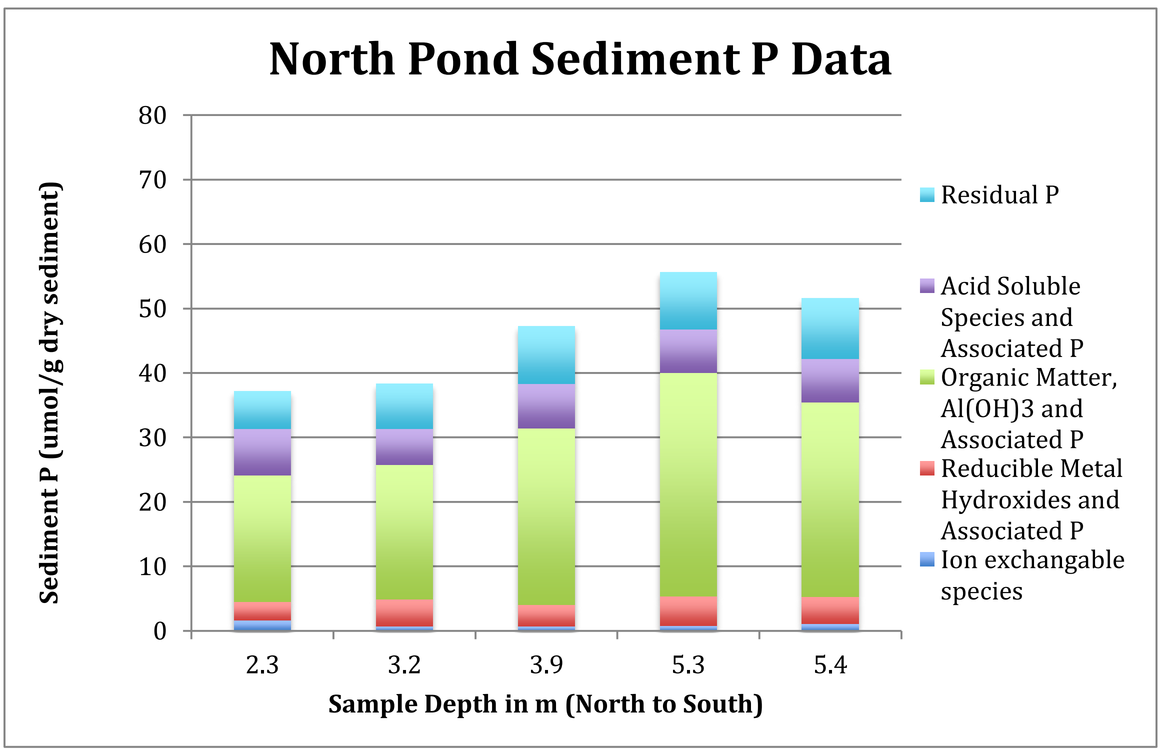


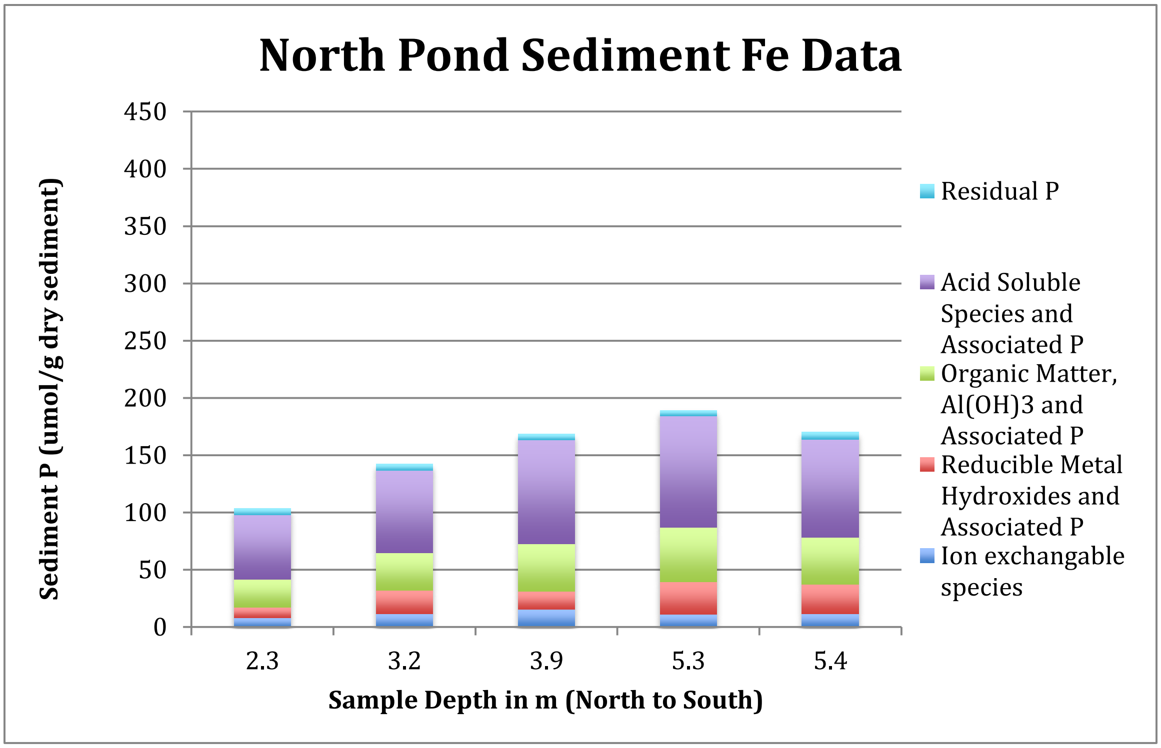
Appendix 4.D These graphs show the concentrations of phosphorus, iron, and aluminum for East Pond and North Pond. The sediments for East Pond were gathered in 2004 by Robin Nesbeda but the analysis was run in the summer of 2011. The sediments for North Pond were gathered and analyzed in the summer of 2011. Sediments were taken in a transect of the lake in order to display varying element concentrations over varying depths (King, unpublished data).

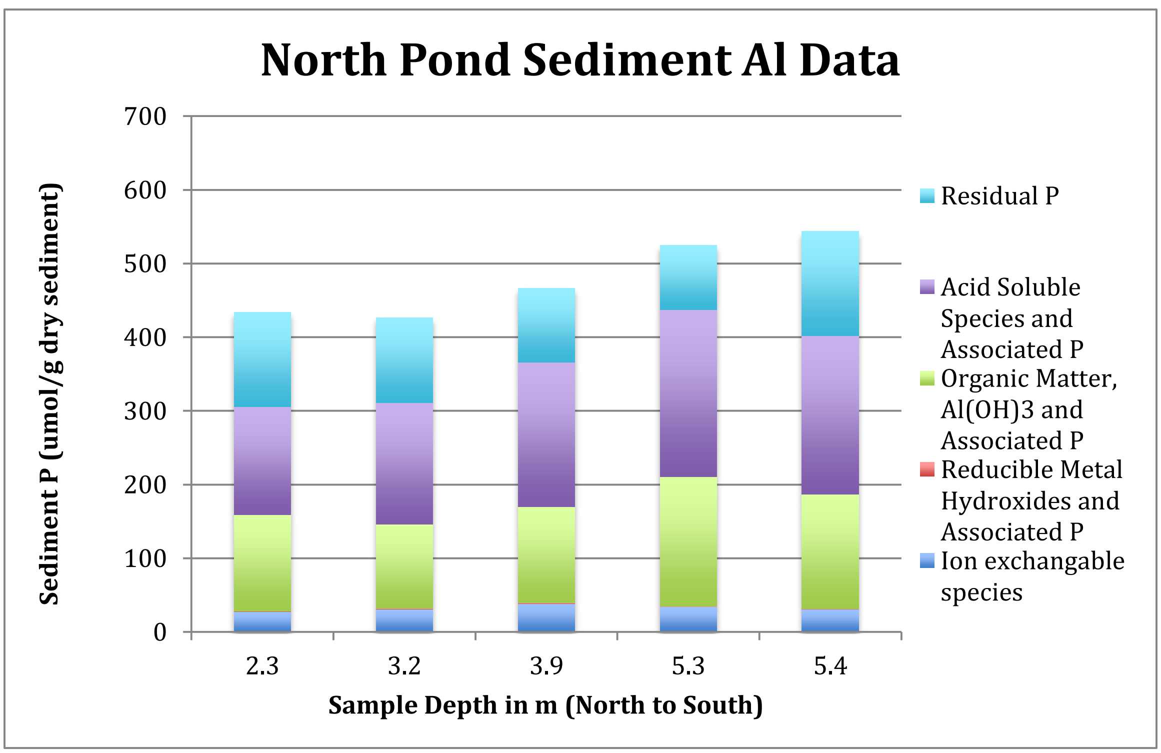




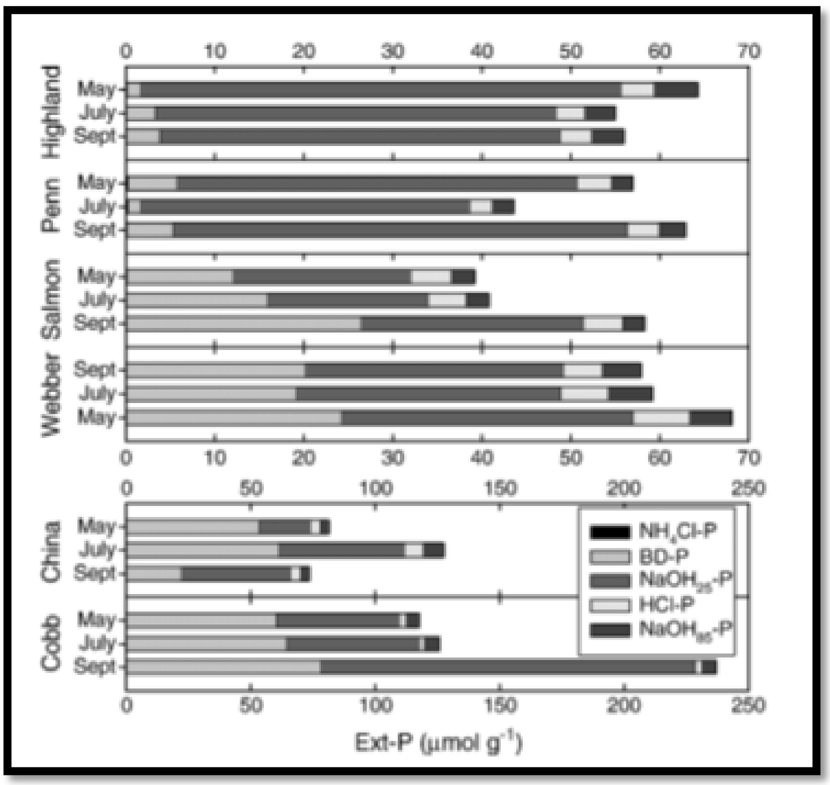

East Pond Sediment Al Data
700
600
500
400
300
200
100
0
Sediment Al (umol/g dry sediment)
3.9
6
4.8
6.9
6.6
6.2
4.1
2.5
Sample in m (North to South)
Residual P
Acid Soluble Species and Associated P

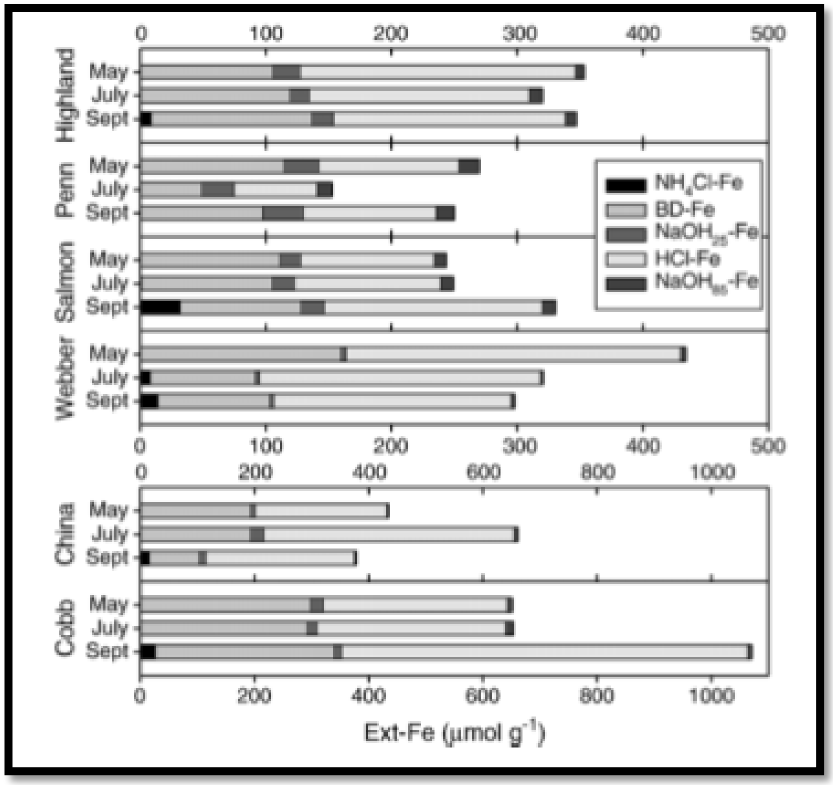

North Pond Sediment P Data
80
70
60
50
40
30
20
10
0
Sediment P (umol/g dry sediment)
2.3
3.2
3.9
5.3
5.4
Sample Depth in m (North to South)
Residual P
Acid Soluble Species and Associated P
Organic Matter, Al(OH)3 and Associated P
Reducible Metal Hydroxides and Associated P
Ion exchangable species


North Pond Sediment Fe Data
Sediment P (umol/g dry sediment)
450
400
350
300
250
200
150
100
50
0
2.3
3.2
3.9
5.3
5.4
Sample Depth in m (North to South)
Residual P
Acid Soluble Species and Associated P
Organic Matter, Al(OH)3 and Associated P
Reducible Metal Hydroxides and Associated P
Ion exchangable species

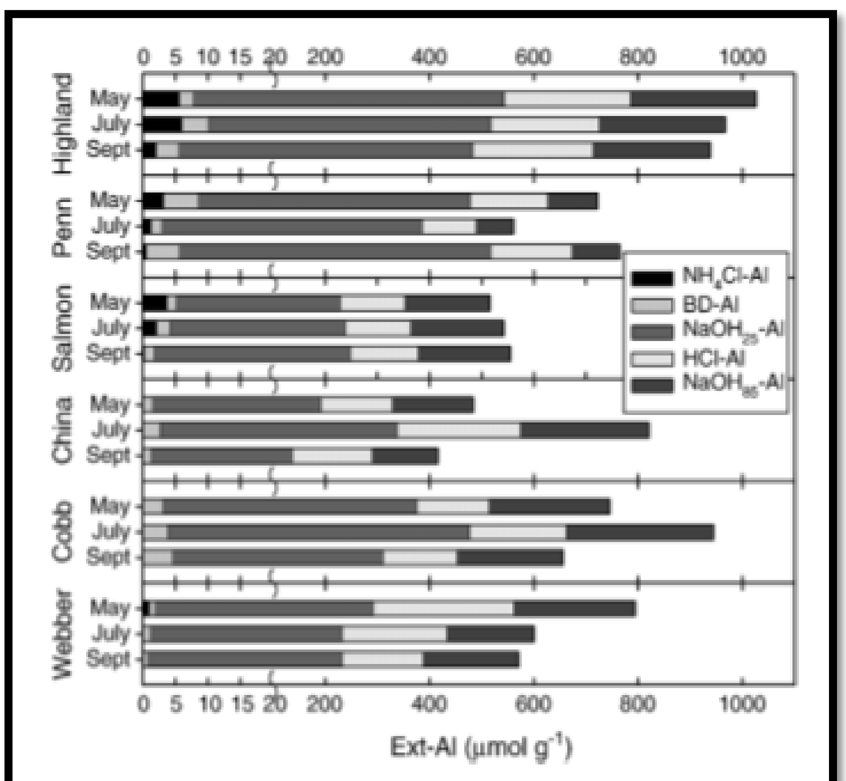

North Pond Sediment Al Data
Sediment P (umol/g dry sediment)
700
600
500
400
300
200
100
0
2.3
3.2
3.9
5.3
5.4
Sample Depth in m (North to South)
Residual P
Acid Soluble Species and Associated P
Organic Matter, Al(OH)3 and Associated P
Reducible Metal Hydroxides and Associated P
Ion exchangable species

Appendix 4.E These graphs depict concentrations of phosphorus, iron, and aluminum respectively for six Maine lakes. The data was gathered and analyzed by Lake et al. 2007 using the same extraction procedure we used. They collected sediment in three different months to show how sediment composition may change in the beginning, middle and end of the summer. (Lake et al. 2007)



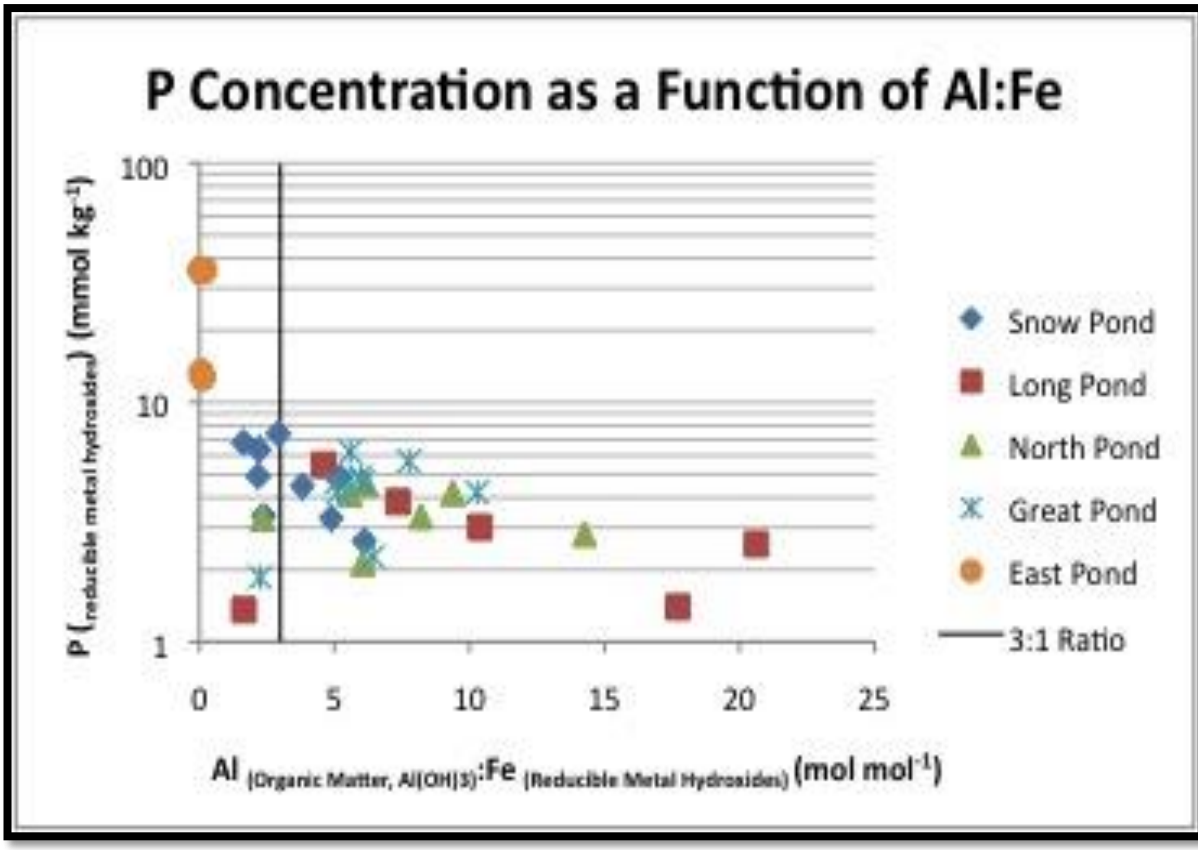


Highland
Penn
Salmon
Webber
China
Cobb
May
July
Sept
NH4Cl-Fe
BD-Fe
NaOH25-Fe
HCl-Fe
NaOH85-Fe
Ext-Fe (µmol g-1)



Highland
Penn
Salmon
China
Cobb
Webber
May
July
Sept
NH4Cl-Al
BD-Al
NaOH25-Al
HCl-Al
NaOH85-Al
Ext-Al (µmol g-1)

Appendix 4.F Al:Fe ratio for all the Belgrade lakes. It is graphed on a log scale (King, unpublished data).



Appendix 5.A Summarized water chemistry data (figures 3.2, 3.3, and 3.4) for mean dissolved oxygen (mg/L ± SD), mean pH (± SD) and mean temperature (°C ± SD) at eight sampling sights along the serpentine and in East Pond.

Category 1	EP	S_1	S_2	S_C	S_3	A_D	I_1	I_2
DO (mg/L± SD)	13.1±6.99	8.71±0.17	7.61±3.25	3.94±2.71	8.12±3.82	6.82±1.65	4.43±2.99	4.88±3.27
pH (± SD)	5.88±0.26	6.02±0.35	5.91±0.60	5.78±0.47	6.01±0.33	5.86±0.19	6.12±0.03	6.07±0.29
Temp. (°C ± SD)	18.1±1.96	18.4±1.09	17.6±1.51	16.3±2.39	15.4±2.78	16.9±1.73	17.9±0.64	15.9±8.59

Note: Water chemistry data was summarized from Appendix 3.B. Sampling points BD, NP, and I3 were excluded from this table because serpentine fish cannot access areas below the dam and I3 was not a major sampling point.

Appendix 7.A. Species guide for Marsh Sampling. Created by CEAT 2012.

Near Water

Utricularia spp. -Bladderwort
Pontederia cordata- pickerel weed
Scirpus acutus- great bulrush
Scirpus fluvfluviatilis- river bulrush
Vallisneria americana- tapegrass
Elodea canadensis- elodea
Potamogeton natans- floating brownleaf
Sagittaria spp. -Arrowhead
Typha spp. -Cattail
Lemna sp. -Duckweed
Brasenia schreberi -water shield
Nuphar advena -yellow pond lily
Juncus effusus- common rush, mat rush
Menyanthes trifoliata- Bog bean, buck bean
Dulichium arudinaceum- three-way sedge
Juncus militaris- Bayonet rush
Cladiuem mariscoides-Twig Rush

Bog

Chamaedaphne calyculata - leather leaf
Sphagnum spp- sphagnum moss
Eriophorum sp.- cotton grass
Sarracenia purpurea -pitcher plant
Vaccinium macrocarpon -large-leaf cranberry
Vaccinium oxycoccos -small-leaf cranberry
Drosera sp. - sundew
Myrica gale -sweet gale
Acorus calamus- sweet flag
Ledum groenlandicum- labrador tea
Kalmia angustifolia- sheep laurel
Andromeda glaucophylla-Bog Rosemary
Spiraea latifolia -Meadow Sweet
Hypericum virginicum-Marsh St. Johns wort
Polytrichum commune -Hair Cap moss
Kalmia polifolia -bog laurel, pale laurel

Larger

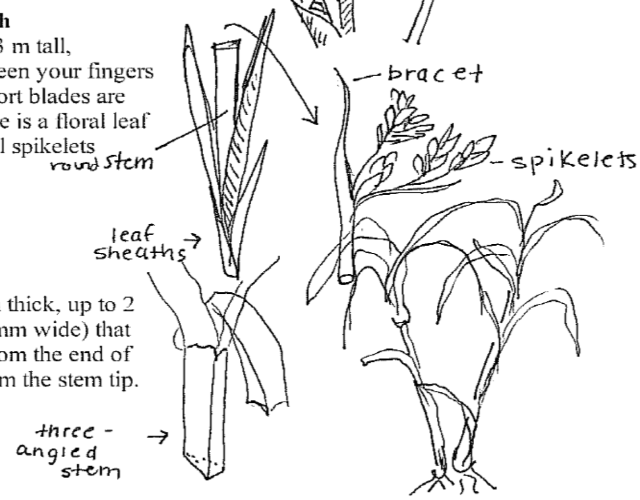
Ilex verticillata – winterberry
Osmunda cinnamomea- cinnamon fern
Woodwardia virginica- virginia chain fern
Larix laricina - tamarack, larch
Picea mariana - black spruce
Pinus strobus- white pine
Myrica gale- Sweet Gale
Alnus rugosa- Speckled Alder
Nemopanthus mucronatus - mountain holly

Near Water

***Utricularia* spp. -Bladderwort**
Description: has floating stems with branches that may fork 3-7 times and are finely divided. Bladders that trap prey are scattered on the branches. May be green tinted or dark brown to black.

***Pontederia cordata*- pickerel weed**
Description: glossy, heart-shaped leaves that emerge from long, round stalks. The leaf blade has many fine, parallel blades. Can be found in shallow water to water up to 2 meters deep.

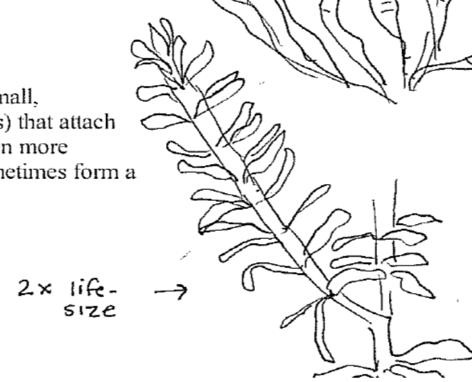
***Scirpus acutus*- great bulrush, hardstem bulrush**
Description: tall, cylindrical, olive-green stems (1-3 m tall, 0.5-1cm wide). Stems are firm when pressed between your fingers due to small chambers within. Leaf sheaths and short blades are sometimes present near the base of the stems. There is a floral leaf called a bract at the tip of the stem from which oval spikelets emerge in clusters.



***Scirpus fluvfluviatilis*- river bulrush**
Description: stems are sharply triangular (7-15 mm thick, up to 2 m tall) with prominent, three-ranked leaves (8-12 mm wide) that are M-shaped in cross-section. Spikelets emerge from the end of the stem, some on the stalks and others directly from the stem tip.

***Vallisneria americana*- tapegrass**
Description: ribbon-like leaves (up to 2 m long 3-10 mm wide) are mostly submerged, but the tips trail on the surface of the water. Leaves have a prominent central stripe and a cellophane-like consistency.

***Elodea canadensis*- elodea, common waterweed**
Description: slender stems (up to 1 m long) with small, lance-shaped leaves (6-17 mm long, 1-5 mm wides) that attach directly to the stem. Leaves in whorls of three, often more crowded toward the stem tip. Branching stems sometimes form a tangled mat in the water.



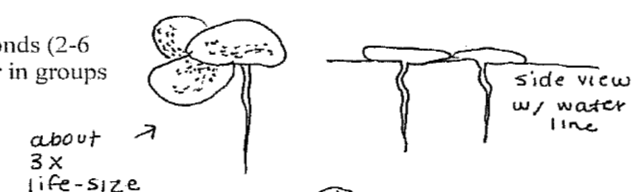
Near Water

***Potamogeton natans*- floating brownleaf**
Description: floating leaves (5-10 cm long, 2-4.5 cm wide) are heart-shaped at their base. The leaf blade is at a right angle to the stalk and lays flat on the water. Usually found in water less than 1.4 meters deep.

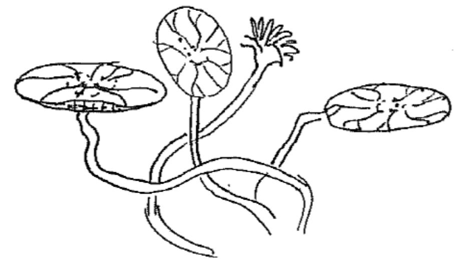
***Sagittaria* spp. -Arrowhead**
Description: The blades (5-40 cm long, 0.5-25 cm wide) range from a slender "A" shape to a broad wedge. Found in shallow water (up to 1 meter deep) and marsh areas.

***Typha latifolia*. -Broad-leaved cattail**
Description: pale green, sword-like leaves (10-23 mm wide, 1 m or more tall) that are sheathed around one another at the base. The tightly-packed flowers look like a hotdog on a stick. Found in marshes and lake shores. Can grow in moist soil to water up to a meter deep.

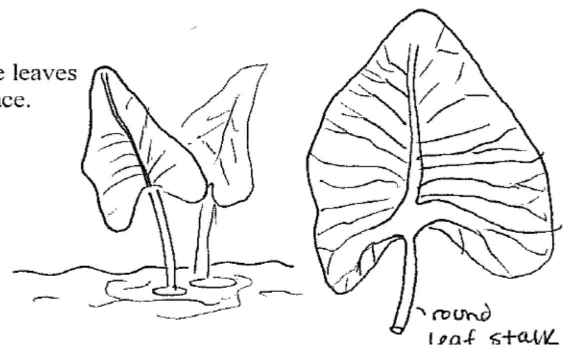
***Lemna* sp. -Duckweed**
Description: round to oval-shaped leaf bodies called fonds (2-6 mm long and 1.5-4 mm wide) that float individually or in groups on the surface. Free-floating



***Brasenia schreberi* -water shield**
Description: elastic stems and leaf stalks with floating leaves (4-12 cm long, 2-6 cm wide). Leaf stalks attach to the middle of the leaves. Leaves have a green upper surface and purple underside. Submersed portions are covered with a thick, gelatinous coating. Grows in water ranging from shallow depths to about 2 meters.



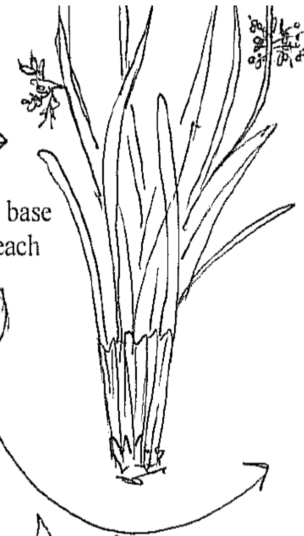
***Nuphar advena* -yellow pond lily**
Description: Leaves are heart-shaped (20-40 cm long) with pointed lobes and a triangular notch at the base. Most of the leaves are emergent and protrude at different angles from the surface. Found in water 2 meters or less deep.



Near Water

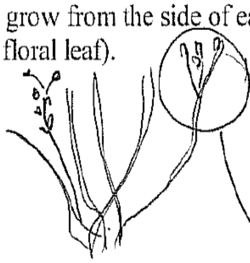
***Juncus effusus*- common rush, mat rush**

Description: smooth, cylindrical stems (1m or more tall) that emerge from a dense rootstalk. Reddish-brown sheaths at the base of the stem. Flower clusters appear to grow from the side of each stem (beyond the flowers is a slender floral leaf).



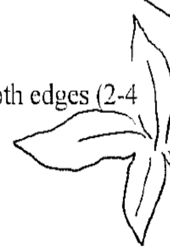
***Juncus militaris*- Bayonet rush**

Description: similar to *Juncus effusus*



***Menyanthes trifoliata*- Bog bean, buck bean**

Description: three succulent green leaves with smooth edges (2-4 inches long, 1-2 inches wide).



***Dulichium arudinaceum*- three-way sedge**

Description: stiff stems (30 cm-1 m tall) with fairly short and stiff leaves that stand out from the plant. The stem is round and hollow. Found in shallow water (less than 1 m).

***Cladiuem mariscoides*-Twig Rush**

Description: relatively large, coarse sedge with narrow grass-like leaves. The stem is stiff, round, and sometimes reaches a height of 1 m.

Bog

***Chamaedaphne calyculata* - leather leaf**

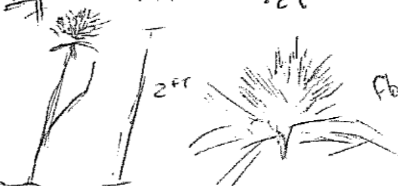
Description: Small plant usually growing through moss, "skeleton of the bog," Leaves alternate, elliptical with complete edges (no ridges). Leaves are leathery with cinnamon scales beneath, usually pointed upwards.

***Sphagnum* spp- sphagnum moss**

Description: Densely packed moss, you should know this! Moss on moss -grows on decaying moss, Builds mats of bogs, Sometimes green, sometimes red (females).

***Eriophorum* sp.- cotton grass**

Description: Tall grass, usually in bogs, grows up to 3 ft tall. Grow in loose colonies, usually spread out. Flowers resemble cotton and remain on plant. Slender wiry stem

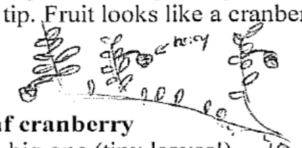


***Sarracenia purpurea* -pitcher plant**

Description: Carniverous plant, Base grows within the bog mat, has a pitcher like cup 4 to 8 inches long, with a wing down one side. Usually reddish to green and mottled, solitary or in small bunches, flower extends high above pitcher on ground.

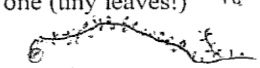
***Vaccinium macrocarpon* -large-leaf cranberry**

Description: Small shrubs, low to ground with branching trailing forked stems. Leaves alternate along stem, evergreen, pale beneath, oval and rounded at the tip. Fruit looks like a cranberry (cuz it is!) red and pale white.



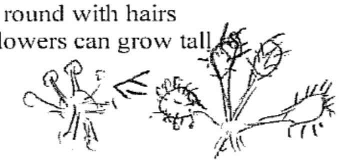
***Vaccinium oxycoccos* -small-leaf cranberry**

Description: Just smaller than the big one (tiny leaves!)



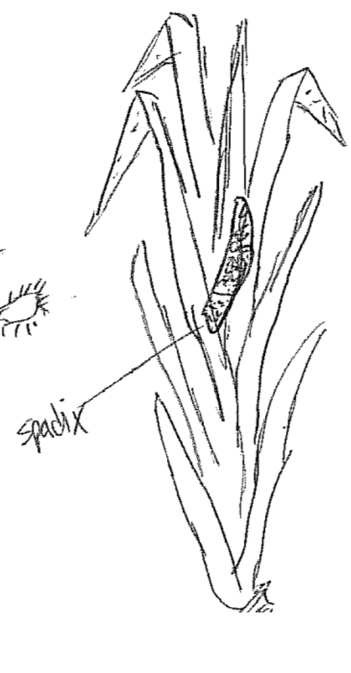
***Drosera sp.* - sundew**

Description: Small reddish plant, leaves are round with hairs tipped with sticky liquid drops. Stem with flowers can grow tall (8 in) above leaves.



***Acorus calamus* - sweet flag**

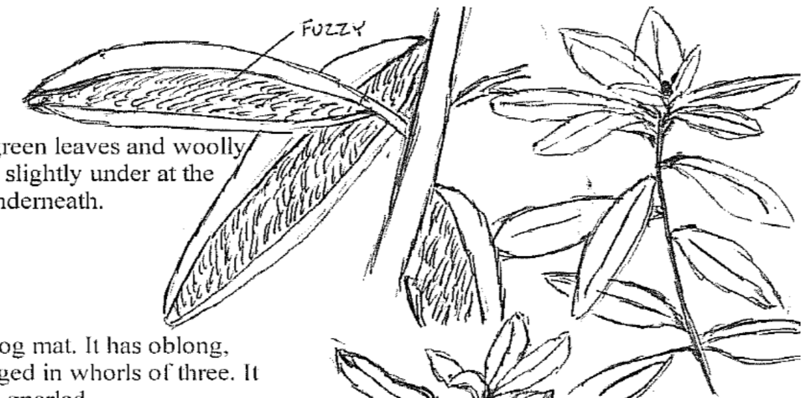
A sedge, 1-4' tall, with a cluster of basal leaves emerging from the rootstock.They are flattened, with a ridge on one side (almost triangular). A cylindrical, 2-4" reproductive spadix emerges from the side of some leaves. It is found on the edge of the marsh along the water.



Bog

***Ledum groenlandicum* - labrador tea**

Description: A low mat shrub with evergreen leaves and woolly branches. The leaves are leathery, curled slightly under at the edges, with light or rusty colored hairs underneath.



***Kalmia angustifolia* - sheep laurel**

Description: A low shrub found on the bog mat. It has oblong, entire, blue-green evergreen leaves arranged in whorls of three. It has brown bark, and the stems tend to be gnarled.

***Andromeda glaucophylla* - Bog Rosemary**

Description: A small, upright shrub found on the bog mat. It has narrow, alternate leaves with edges that curl sharply under. The evergreen leaves are dark, waxy, and shiny on top but lighter underneath. Looks like *Kalmia polifolia.*

***Spiraea latifolia* - Meadow Sweet**

A small wetland shrub/wildflower, with toothed leaves 2-3 times as long as they are wide. Flowers are arranged in 4-6" long oblong, terminal spikes. Its bark is reddish-brown and smooth.

***Hypericum virginicum*-Marsh St. Johns wort**

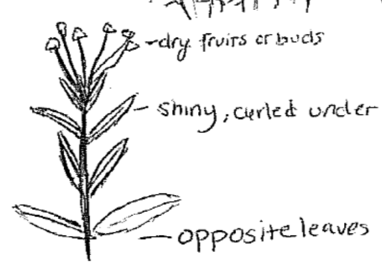
Description: A low, bushy, marsh wildflower that grows in wet, often sandy conditions near the water. Its oblong leaves are dotted with translucent glands on the bottom. Reddish purple.

***Polytrichum commune* -Hair Cap moss**

Description: A dark green or brown moss, usually between 4 and 15 cm tall. Male plants have green, tufted heads, females produce sporophyte stalks.

***Kalmia polifolia* -bog laurel, pale laurel**

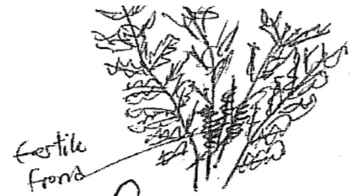
Description: Low evergreen shrub with waxy leaves arranged oppositely on the branch. The leaves, especially higher on the stem, curl under at the edges. Found on the mat.



Larger

***Osmunda cinnamomea*- cinnamon fern**

Description: Fronds twice divided. Fronds arise from a central point. Whitish velvety coating on lower stems and fiddleheads, with a central cinnamon-colored fertile frond. Most common fern in the area.

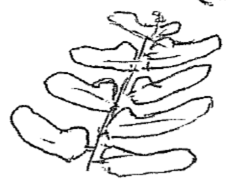


***Woodwardia virginica*- virginia chain fern**

Description: Fronds arise singly. Fronds twice divided. Alternating lancolate divisions from stem. Sori (spore producing structures on underside of leaves) are arranged in chains.

***Polystichum acrostichoides*- Christmas Fern**

Fronds once divided. Individual segments look like Christmas stockings.



***Larix laricina* - tamarack, larch**

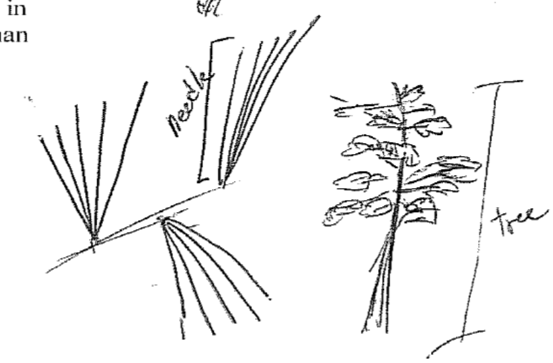
Description: 3-sided needles, 0.75" to 1.25" long, bluish green in color. Needles in clusters of 10-20 on spurs which are spirally arranged on long shoots. Buds are resinous, and dark reddish-brown. Bark is scaly, gray to reddish brown. Larch is deciduous, and the needles turn yellow in the autumn. The cones are less than 2 cm in length.

***Picea mariana* - black spruce**

Description: Angular, spirally arranged needles, ¼ to ¾ inches long. Needles are straight or slightly curved, and bluntly pointed. Bark is thin, scaly, and grayish brown. Cones are dark/pruplish in the first year, becoming brown over time. Cones are no more than 1 ½ inches in length, pointing downward.

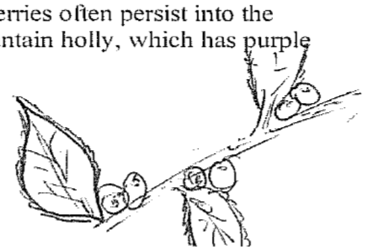
***Pinus strobus*- white pine**

Description: Needles in bundles of five. Needles thin and light green, 2-5 inches long. Branches often grow in disorganized bizarre directions.



***Ilex verticillata* – winterberry;**

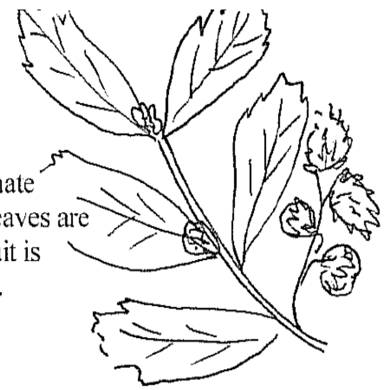
Description: A high shrub with 1.5-3" alternate leaves. It is deciduous, but its small, bright red berries often persist into the winter. Not to be confused with mountain holly, which has purple leaf petioles.



Larger

***Myrica gale-* Sweet Gale**

Discription: Densely branched shrub up to 6 ft tall. Alternate leaves tapering at the base, with rounded, toothed tips. Leaves are 2 inches long, and often have white hairs underneath. Fruit is small ovoid conelike nutlets which persist through winter.



***Alnus rugosa-* Speckled Alder**

Description: Leaves are alternate, 2-5 inches long, with doubly toothed margins. Leaves are dull dark green above, and light yellow-green and finely hairy underneath. Twigs are reddish-brown, moderately slender, with buds containing two or three bud scales. Bark is thin and smooth with conspicuous orange lenticils. Fruit in ½ inch winged nutlets.

***Nemopanthus mucronatus* - mountain holly**

Description: deciduous, branchy shrub up to 10 ft. Leaves are 1-2 inches long, sometimes with a finely serrated margin. Leaves on stalks ½ inch long. Flowers are white or yellow, and fruit is red containing 3-5 pits on a stem.

Appendix 7.B Common name, scientific name, and growth habitat for each species found on the Serpentine (From Crow and Hellquist 2000)

Species		Growing Habitat			
Common Name	Scientific Name	Aquatic	Marsh	Bog	Land
Arrowhead	*Sagittaria sp.*	X			
Aster	*Asteraceae sp.*		X	X	X
Bayonet Rush	*Juncus militaris*	X	X		
Bedstraw	*Galium sp.*		X	X	
Black Spruce	*Picea nigra*	X			
Bog Laurel	*Kalmia polifolia*			X	X
Bog Rosemary	*Andromeda glaucophylla*			X	X
Bogbean	*Menyanthes trifoliata*	X	X	X	
Bugleweed	*Ajuga reptans*		X	X	
Button Bush	*Cephalanthus occidentalis*		X	X	
Cattail	*Typha sp.*	X	X		
Cinnamon Fern	*Osmunda cinnamomea*		X		X
Common Rush	*Juncus effusus*	X	X		
Cotton Grass	*Eriophorum sp.*			X	
Duckweed	*Lemna sp*	X			
Floating Brownleaf	*Potamogeton natans*	X			
Grass	*Poaceae*		X	X	X
Great Bulrush	*Scirpus acutus*	X	X		
Haircap Moss	*Polytrichum commune*			X	X
Labrador Tea	*Ledum groenlandicum*			X	X
Larch	*Larix laricina*		X	X	X
Large Leaf Cranberry	*Vaccinium macrocarpon*		X	X	X
Leatherleaf	*Chamaedaphne calyculata*			X	
Marsh Fern	*Thelypteris palustris*		X	X	X
Meadowsweet	*Spiraea alba*		X	X	X
Pickerel Weed	*Pontederia cordata*	X	X		
Pitcher Plant	*Sarracenia purpurea*			X	X
Red Maple	*Acer rubrum*		X	X	X
River Bulrush	*Scirpus fluviatilis*		X		
Rush 1	*Juncaceae 1*	--	--	--	--
Rush 2	*Juncaceae 2*	--	--	--	--
Scented Pond Lily	*Nymphaea odorata*	X			
Sedge	*Cyperaceae*		X	X	
Shallow Sedge	*Carex lurida*		X		
Sheep Laurel	*Kalmia angustifolia*			X	X
Small Leaf Cranberry	*Vaccinium oxycoccos*			X	
Speckled Alder	*Alnus sp.*		X	X	X
Sphagnum Moss	*Sphagnum spp*		X	X	
St. John's Wort	*Hypericum virginicum*		X	X	
Summer Sweet	*Clethra alnifolia*		X	X	
Sweetgale	*Myrica gale*	X	X		X
Tape Grass	*Vallisneria americana*	X			
Meadow Rue	*Thalictrum sp.*		X	X	
Three-way Sedge	*Dulichium arudinaceum*	X	X	X	
Twig Rush	*Cladium mariscoides*		X	X	
Unknown 1	--	--	--	--	--
Water Hemlock	*Cicuta maculata*	X	X		
Water Shield	*Brasenia schreberi*	X			
Yellow Pond Lily	*Nuphar advena*	X	X		

Appendix 7.C Normalized Plant Importance Index (PII) by species

Species	Normalized Cover	Normalized Frequency	Normalized Plant Importance Index
Sphagnum Moss	0.365	0.807	52.8
Leatherleaf	0.230	0.785	32.3
Grass	0.078	0.296	4.2
Sweetgale	0.043	0.370	2.8
Cotton Grass	0.052	0.237	2.2
Large Leaf Cranberry	0.033	0.296	1.7
Small Leaf Cranberry	0.029	0.237	1.2
Bayonet Rush	0.024	0.119	0.5
Sheep Laurel	0.017	0.148	0.5
Bog Rosemary	0.016	0.148	0.4
Pickerel Weed	0.015	0.074	0.2
Sedge	0.009	0.104	0.2
River Bulrush	0.010	0.081	0.2
Duckweed	0.010	0.067	0.1
Pitcher Plant	0.005	0.126	0.1
Shallow Sedge	0.006	0.059	0.1
Cattail	0.003	0.096	0.1
Speckled Alder	0.004	0.059	< 0.1
Aster	0.003	0.067	< 0.1
Common Rush	0.003	0.067	< 0.1
Labrador Tea	0.005	0.037	< 0.1
Three-way Sedge	0.003	0.059	< 0.1
St. John's Wort	0.003	0.052	< 0.1
Meadowsweet	0.002	0.059	< 0.1
Haircap Moss	0.003	0.037	< 0.1
Yellow Pond Lily	0.003	0.037	< 0.1
Cinnamon Fern	0.002	0.059	< 0.1
Larch	0.002	0.059	< 0.1
Button Bush	0.002	0.030	< 0.1
Water Shield	0.002	0.030	< 0.1
Scented Pond Lily	0.001	0.030	< 0.1
Tape Grass	0.001	0.030	< 0.1
Great Bulrush	0.002	0.015	< 0.1
Bog Laurel	0.001	0.030	< 0.1
Bedstraw	0.002	0.015	< 0.1
Arrowhead	0.000	0.030	< 0.1
Rush 2	0.001	0.007	< 0.1
Twig Rush	0.001	0.007	< 0.1
Marsh Fern	0.001	0.015	< 0.1
Red Maple	0.001	0.015	< 0.1
Black Spruce	0.001	0.007	< 0.1
Floating Brownleaf	0.001	0.007	< 0.1
Rush 1	0.001	0.007	< 0.1
Summer Sweet	0.001	0.007	< 0.1
Unknown 1	< 0.001	0.015	< 0.1
Bogbean	< 0.001	0.007	< 0.1
Bugleweed	< 0.001	0.007	< 0.1
Thalictrum Spp.	< 0.001	0.007	< 0.1
Water Hemlock	< 0.001	0.007	< 0.1

Appendix 7.D Rank abundance curves by transect with species names.