Ecological response of a shallow mesotrophic lake to multiple environmental stressors: a paleolimnological assessment of White Lake, Ontario

by

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Abstract

White Lake, located in Eastern Ontario, Canada is a large (surface area 56.08 km^2), shallow (mean depth = 3.1 m), recreational lake that has a recent history of poor water quality due to water level changes, nutrient loading and invasive species. With monitoring data only extending to 2015, lake managers lack the long-term data needed to make informed decisions regarding lake management strategies. A paleolimnological study was conducted to assess historical water quality change in White Lake using diatoms as indicators of water quality. The recent introduction of zebra mussels (*Dreissena polymorpha*) has lowered nutrient levels and greatly reduced turbidity with Secchi depth reading jumping from 1.8 m to 7.5 m depth. However, the largest single change in the diatom assemblage of White Lake likely relates to water level changes through the damming of the lake in 1845 and subsequent changes to the water level management plan for the lake.

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Chapter 1.0 Introduction

Shallow, freshwater lakes are important sources of drinking water, habitat for biota and provide space for recreation. Despite these functions, and being more numerous than deep-water lakes, they are generally understudied in comparison to larger deep-water lakes (Schindler and Scheuerell, 2002). This makes it difficult for lake managers as many of the concepts that are developed to help make decisions are based on deep water lakes that stratify in the summer and may not be applicable to shallower systems where much of the benthic environment is available for the growth of photosynthetic algae and plants (Jeppesen, 1998). These problems are especially evident when shallow lakes face environmental stresses, many of which are directly or indirectly the result of human activities.

White Lake is a large, shallow lake (56.06 km^2 and mean depth of 3.1 m) located in Eastern Ontario, Canada that is a popular recreation site (Figure 1.1). White Lake has had historical problems with lake level management, algae blooms and invasive species. Residents around this lake are concerned about the potential for deterioration of water quality and loss of associated ecosystem services provided by the lake.

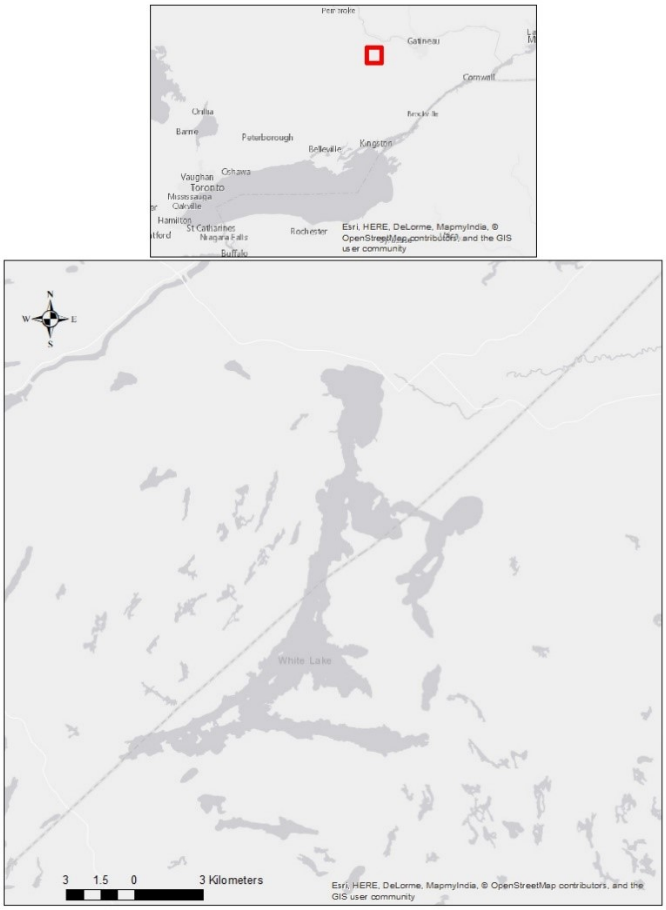

Figure 1.1 Location of White Lake with a reference to the location of the cities of Ottawa and Toronto. The red box in the top figure indicates the boundary of the bottom figure.

White Lake has had various water level regimes over the last 100 years as lake managers tried to balance ecological needs with the needs of lake users. High water level regimes have resulted in large declines in fish populations while lower regimes have been problematic for lake users as they limit recreation on the lake (von Rosen, 1989). The current management strategy for lake levels in White Lake was chosen as a compromise between the problems associated with water levels that are too high or too low (White Lake Preservation Project, 2018; Figure 1.2). Algae blooms have also been a historical problem on White Lake, with reported blooms occurring since the 1940s (Mathers and Kerr, 1998). Nutrient loading from septic systems and surface runoff have been linked to more frequent toxic algae blooms in White Lake. However, open water phosphorus concentrations have been declining in recent years due, in part, to the establishment of zebra mussels (*Dreissena polymorpha*). Zebra mussels established in White Lake in 2015 and populations have increased dramatically since that time. As a result, Secchi depths have doubled and sufficient light for photosynthesis now reaches most of the lake bottom. Water temperatures have also been rising in White Lake in response to climate change. Water temperatures in 2018 reached 27°C in the surface waters, 2.2°C higher than any other year measured (White Lake Preservation Project, 2018). Understanding how the water management strategies and problems interacted is of great importance to lake managers. Without knowing how these strategies and problems interacted, the lake could experience unforeseen conditions that make management decisions more difficult. With this in mind, the research objective of this thesis project was to provide a long-term (>100 year) perspective on water quality changes in White Lake to give historical context for recent changes in water level management and to provide baseline water quality information to assess the impact of recent multiple stressors (invasive species, nutrient enrichment, and climate change) on White Lake. These data can help inform lake management plans by providing lake managers with important baseline information on historical water quality.

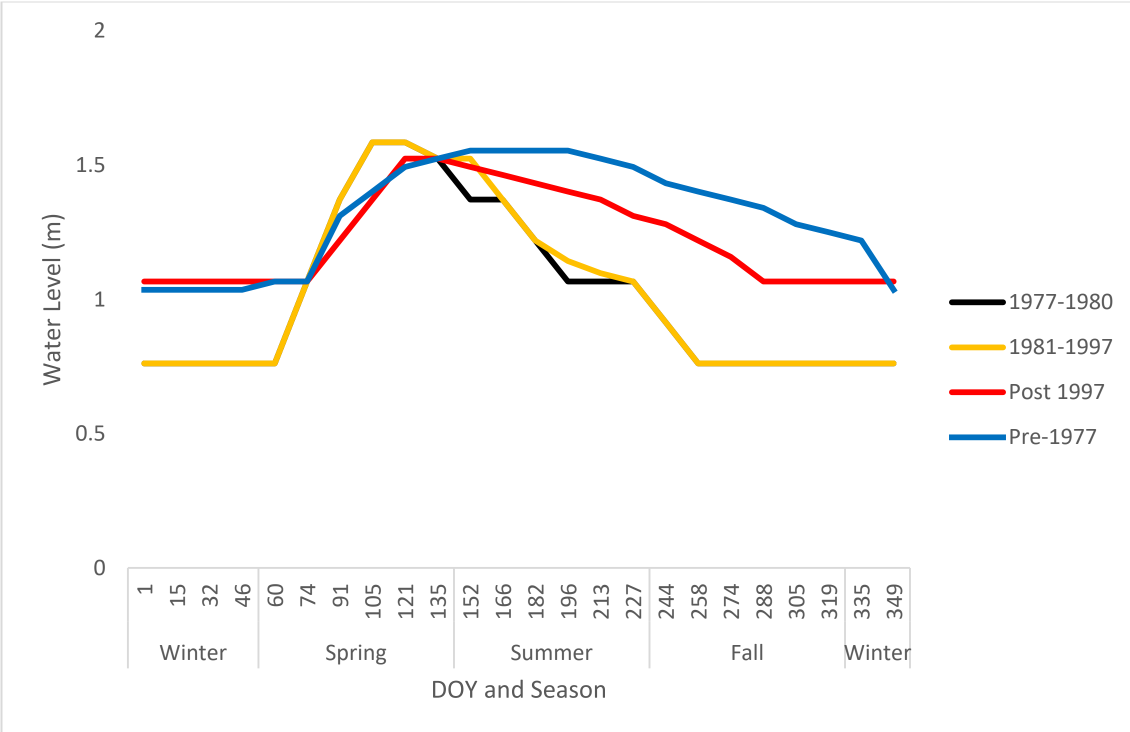

Figure 1.2 Water level management strategies on White Lake. The red line represents the current management strategy and the orange, black and blue lines represent previous strategies. The current management strategy was seen as a compromise between the previous strategies. Values shown only represent target lake levels, actual lake levels fluctuate with the weather (White Lake Preservation Project, 2018).

To meet these objectives, in Chapter 2.0, shallow lake systems were examined using a literature review to determine key components of the system and how each of the stressors can influence the system. As well, interactions between multiple stressors were also assessed in the context of shallow lake systems. In Chapter 3.0, I analyzed two sediment cores and historical water quality data from White Lake. Sediment cores were analyzed for organic content and diatom assemblages to assess long term changes in the lake. Results from diatom analysis were compared to historical water data to determine how stressors controlled water quality over time in White Lake.

Chapter 2.0 Literature Review

2.1 Freshwater Ecosystems

Freshwater ecosystems provide important functions such as supplying drinking water and providing habitat for fish. They also provide space for recreation and avenues for transportation (Postel & Carpenter, 1997). Additionally, freshwater habitats represent only 0.8 % of the Earth's surface but support 6 % of the known species and one third of all vertebrate species. Even with all the services that freshwater ecosystems provide, they are considered to be extremely vulnerable to environmental change and human activities (Reid *et al.,* 2019; Dudgeon *et al.,* 2005). The ecosystem services that freshwater habitats provide make them highly used by humans which has resulted in substantial negative impacts. There are several key drivers of these negative impacts which include pollution, invasive species and climate change (Strayer & Dudgeon, 2010).

Research on freshwater ecosystems has generally focused on deep lakes even though the majority of lakes worldwide are shallow (Messager *et al.,* 2016; Vadeboncoeur *et al.,* 2002). Shallow lakes (mean depth <5 m) exhibit several key differences from deep lakes, such as the lack of thermal stratification, a higher degree of sediment/water interaction, and more macrophyte biomass (Schindler & Scheuerell, 2002; Jeppesen, 1998). These differences between shallow and deep lakes make transferring ecological knowledge to shallow lakes from deep lake studies problematic as they have different ecological structure and processes (Jeppesen, 1998).

2.2 Importance of Shallow Lake Systems and How They Function

Shallow lakes are important ecosystems that are represented by approximately 300 million water bodies worldwide (Downing *et al.,* 2006). These ecosystems provide a large littoral habitat relative to their size and are usually more productive per unit area than deeper lakes (Schindler & Scheuerell, 2002). Shallow lakes have many complex interactions that make modelling outcomes of change difficult. Tan & Ozesmi (2006) developed a general model of the interactions within shallow lakes and how the different components of the ecosystem influence each other (Figure 2.1).

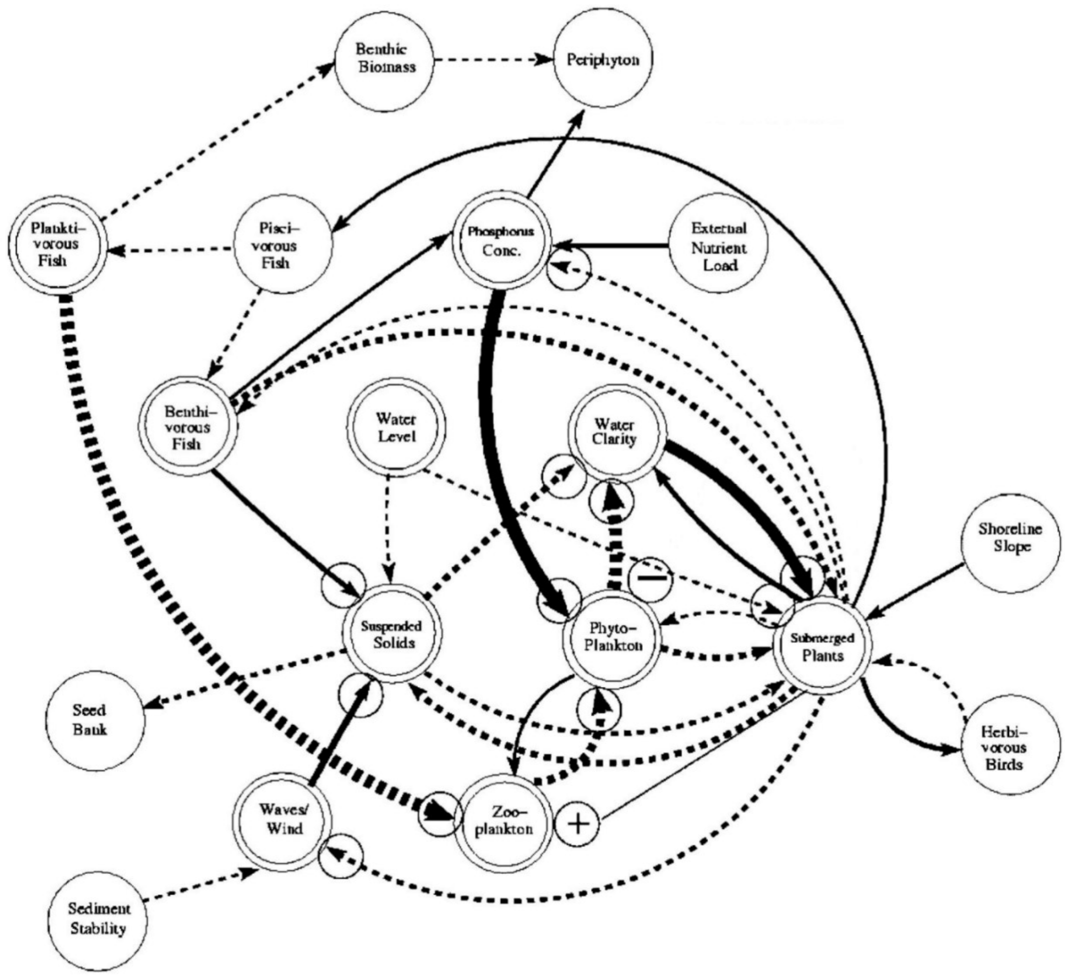

Figure 2.1 A generalized ecosystem model for shallow lakes. Thicker lines represent stronger interactions, solid lines are positive interactions and dashed lines are negative interactions. Double circles around components indicate that they are also shown in the ecosystem model by Scheffer *et al.* 1993 and circles around the arrowheads indicate connections that are also shown be Scheffer *et al.* 1993 (Tan & Ozesmi, 2006).

Schindler & Scheuerell (2002) stress that links between different habitats in aquatic ecosystems must be explored to get a fully integrated understanding of these systems. The links between benthic and pelagic habitats are complex and have both positive and negative feedbacks (Tan & Ozesmi, 2006; Vadeboncoeur *et al.,* 2002). Submerged macrophytes are an especially important component of aquatic systems as many other components share strong interactions with them (Figure 2.1). The series of interactions linking phytoplankton, water clarity and submerged macrophytes represent the alternative stable states for shallow lakes (Scheffer *et al.,* 1993). In the alternative stable state model, greater phytoplankton concentrations, as a result of higher phosphorus levels, will reduce water clarity and shade out submerged macrophytes which further benefits phytoplankton concentrations, perpetuating the new turbid water stable state. Similarly, submerged macrophytes increase water clarity and promote more plant growth which represents the other stable state (Scheffer *et al.,* 1993). These stable states are governed by phosphorus concentrations that control phytoplankton growth.

Internal loading of phosphorus from lake sediments that contribute to phytoplankton growth is another link between benthic and pelagic habitats that has ecosystem wide impacts (Schindler & Scheuerell, 2002). Coops *et al.,* (2003) showed that changes in water levels can also lead to shifts between alternative stable states that occur independently of changing nutrient concentrations. The model by Tan & Ozesmi (2006) does not include seasonality, which is an important aspect of many lakes. Scheffer & Van Nes (2007) showed that lakes exhibit ‘memory’ during the winter months and that the system generally returns to the previous state the following summer. However, it has also been shown that ice can damage and remove macrophytes depending on the water level (Coops *et al.,* 2003) possibly reducing the stability of the clear water state.

2.3 Common Ecological Stressors of Lake Systems

Lake systems are exposed to many different ecological stressors that impact the system through various mechanisms. Some of the most common anthropogenic stressors that pressure lake systems include invasive species, nutrient loading, climate change and water level changes. Invasive species will be explored using zebra mussels (*Dreissena polymorpha*) as an example.

Zebra mussels are a species of invasive bivalves that now exist in close to 1000 inland lakes across North America (Karatayev *et al.,* 2015). In order to feed, they filter particulate matter out of the water. Zebra mussels are able to filter between one and five litres of water per day per mussel (Miller & Watzin, 2007). With such a large volume of water being filtered, changes in water quality occur simultaneously with zebra mussel colonization. Nutrient ratios can change as a result of zebra mussel colonization as it has been shown that zebra mussel excrement increases the relative amount of phosphorus to nitrogen in the water column (Ruginis *et al.,* 2017; Karatayev *et al.,* 2015; Higgins & Zanden, 2010; Strayer, 2009; Miller & Watzin, 2007; Qualls *et al.,* 2007; Bykova *et al.,* 2006; Mellina *et al.,* 1995). It has also been shown that zebra mussels can greatly reduce the abundance of phytoplankton living in the water column. If filtering rates are higher than phytoplankton growth rates, open water species of phytoplankton may be reduced. A reduction in algal biomass is commonly measured by a decrease in the chlorophyll *a* content in the water (Qualls *et al.,* 2007). By removing phytoplankton at such a high rate without removing any phosphorus, the chlorophyll *a*/phosphorus relationship that was established by Schindler (1974) can become decoupled (Mellina *et al.,* 1995). The decoupling of the chlorophyll *a*/phosphorus relationship is important to note as it indicates that phosphorus is no longer the limiting control of algae growth as the removal of algae by zebra mussels is now greater than the production rate of algae (Strayer, 2009; Qualls *et al.,* 2007; Mellina *et al.,* 1995).

Zebra mussels also change water clarity during colonization. With much of the particulate matter being removed from the water column, water clarity increases once zebra mussels become established (Karatayev *et al.,* 2015; Miller & Watzin, 2007; Strayer *et al.,* 1999). Qualls *et al* (2007) found that Secchi depths increase during zebra mussel colonization with the degree of increase being specific to each site. Oxygen and carbon dioxide levels have also been shown to change as a result of zebra mussels (Ruginis *et al.,* 2017; Johannsson *et al.,* 2000). When zebra mussel population densities peak, they have been seen to represent between 90-99 % of the benthic invertebrate biomass in a lake. This can result in large changes in respiration as zebra mussels account for the majority of benthic production in the lake (Johannsson *et al.,* 2000). In temperate systems, this can result in seasons where carbon dioxide levels and demand for oxygen increases as a result of zebra mussel respiration (Ruginis *et al.,* 2017).

Nutrient loading has long been known to drastically alter lake systems. When phosphorus concentrations increase, large algae blooms and anoxic conditions develop. This is best seen through the chlorophyll *a* and phosphorus relationship where, as phosphorus concentrations increase, so do chlorophyll *a* levels (Schindler, 1977; Schindler, 1974). Nutrient loading is often a direct result of human inputs into the lake or the watershed. Agricultural runoff and sewage discharge are common causes of nutrient loading and represent two types of nutrient loading; non-point source and point source respectively. Non-point sources generally account for a larger portion of the nutrient load as they are more difficult to control than point sources (Anderson *et al.*, 2002). Internal loading of nutrients from the sediment can also represent a significant source of nutrients that are difficult to control. Phosphorus can be released to overlying water from the sediment under aerobic conditions if iron concentrations are low in the sediment and under anaerobic conditions even when iron concentrations are higher. The input of phosphorus to the water column from the sediment is greater under anaerobic conditions (Orihel *et al.,* 2015; Nürnberg, 2009; Moore *et al.,* 1998).

One of the consequences of nutrient enrichment is the occurrence of algae blooms. Algae blooms, specifically cyanobacteria blooms, pose problems for both water quality and human health. Cyanobacteria blooms can release toxins into the water that are harmful to biota in the lake and humans using the lake (Orihel *et al.,* 2015). Dense algae colonies can also be harmful by causing anoxic conditions and shading out submerged vegetation that supports fish habitat (Anderson *et al.,* 2002). The anoxic conditions from these dense algae colonies can further promote algae growth through internal loading of phosphorus (Orihel *et al.,* 2015; Anderson *et al.,* 2002).

Climate change represents an important stressor to lake ecosystems and is often termed a "threat multiplier" as it can impact many different aspects of the ecosystem and exacerbate undesirable ecological conditions. Water temperatures have been rising in many lakes as a direct response to rising air temperatures. This can result in changes in vertical mixing and the depth of the thermocline (Rühland *et al.,* 2015). It is suggested that these changes in mixing can lead to mixing regimes that promote fewer full turnover events (Adrian *et al.,* 2009). As well, higher temperatures lead to lower oxygen saturation levels which will further impact the oxygen poor waters created by fewer mixing events (Hecky *et al*., 2010; Adrian *et al.,* 2009). Even normally well-mixed lakes, such as shallow lakes, could show phosphorus release from the sediment as a result of high water temperatures (Jeppesen *et al.* 2009). Anoxic conditions brought on by climate change will also increase the amount of phosphorus loading by lake sediment (Adrian *et al.,* 2009). Jeppesen *et al.* (2009) have shown phosphorus loading is expected to increase from external sources as a result of changes in weather patterns. Increased runoff from higher rates of intense precipitation can deposit phosphorus into lakes. Coupled with the changes to agricultural practices that suggest there could be longer bare soil conditions in autumn, phosphorus loading from external sources is expected to increase between 3.3 % and 16.5 % over the next 100 years in temperate regions (Jeppesen *et al.,* 2009).

Climate change is expected to disrupt trophic interactions in lakes which could have lake wide impacts on food webs. The disruptions are predominately in the timing of predator-prey interactions. Diatom blooms in some temperate lakes are occurring weeks earlier than historical blooms due to warmer water conditions. *Daphnia* populations are not increasing at the same time and the majority of *Daphnia* are unable to exploit the high density of diatoms (Winder & Schindler, 2004). Smol *et al.* (2005) have also shown that longer growing seasons from climate warming have caused shifts in algae and invertebrate communities across arctic lakes since 1850. Temperate lakes, such as Lake of the Woods, in Northwestern Ontario, have also undergone changes in the algal community that were driven by climate warming and a longer ice-free period. Rühland *et al.* (2008) showed similar shifts in diatom communities across North American and European lakes, tied to a longer ice-free season.

Water level fluctuations can impact lakes in a variety of different ways as water levels rise and fall. Changes in light attenuation, thermal climate and where the influence of wave action occurs can all change available habitat and result in lake wide impacts (Wantzen *et al.,* 2008). Climate change is expected to alter the hydrologic regime in many areas across the globe, resulting in more extreme droughts and flooding that greatly impact lake levels. Littoral habitat is particularly vulnerable to water level fluctuations as water level determines the type of macrophytes and invertebrates that can live there (Brauns *et al.,* 2008). Lower lake levels can kill off large numbers of invertebrates as many species are not mobile enough to escape to deeper waters. Macrophyte communities dry out during these low water level events and habitat for other aquatic species can be lost (Brauns *et al.,* 2008). High water levels can also be detrimental to macrophyte communities as emergent macrophytes can be covered during flooding events (Nechwatal *et al.,* 2008).

In addition to more natural variations in water level driven by climate, managed lake levels can also be harmful to biota as water level fluctuations differ from naturally occurring patterns. With many of the managed lakes being dammed for hydroelectricity, water levels are drawn down in the winter and raised in the summer. The influence of the spring melt is usually moderated and winter lake levels are substantially lower than natural lake levels. Deviation from natural patterns has been shown to negatively impact macrophytes, invertebrates and fish communities. Managed lakes in temperate regions are drawn down to below naturally occurring levels, which can lead to sediment freezing and flushing out as the ice retreats. The removal of this sediment negatively impacts macroinvertebrates by removing nutrients and has cascading impacts through the lake system (Aroviita & Hämäläinen, 2008).

2.4 Stress, Resilience and Alternative Stable States in Lakes

Lake ecosystems are under ecological stress as a result of human activities. Ecological stressors can be many different factors and can result in the degradation of the system (i.e., eutrophication). Changes in nutrient concentrations, fires, invasive species, climate change, water level fluctuations, or storms can all cause stress on lake ecosystems and result in a lake wide changes to water quality (Carpenter & Cottingham, 1997). Holling (1973) defined the resilience of a system as the ability of an ecosystem to withstand stresses or disturbances while still maintaining the same stable state. However, resilience must be considered over a variety of spatial and temporal scales. Small changes over long periods of time can lead to the system taking longer to return to a stable state. This can be seen as the system having lower resilience which makes it more prone to changes of state from a short-term disturbance (Ludwig *et al*., 1997).

Understanding the resilience of an ecosystem is crucial for preventing undesirable regime shifts. Regime shifts are changes in stable states that are difficult to predict, occur rapidly, and are extremely difficult to reverse. These changes are brought on by the system passing a threshold that results in a transition to a new stable state (Folke *et al.,* 2004). This concept of regime shifts is well illustrated by the shallow lake model of Scheffer *et al.* (1993), where the presence of macrophytes in lakes is influenced by turbidity and nutrients as more turbid water and higher algae biomass from increased nutrient concentrations shades out macrophyte communities (Figure 2.2). As turbidity increases, the system approaches a critical turbidity. Before the critical turbidity is reached, the system can correct itself and no regime shift occurs. But once the critical turbidity is exceeded, vegetation rapidly disappears and the system is in a new turbid-water stable state with little submerged macrophyte cover. Changes in turbidity and nutrients are now bound by a new stable state. In order to have submerged vegetation restored in the system, nutrients must be lowered considerably to pass the critical turbidity to revert to the preferred state (Scheffer *et al.,* 1993). Blindow *et al.* (1993) showed that when a system with alternative stable states is at equilibrium, it resists change and maintains the state as long as the critical threshold is not crossed.

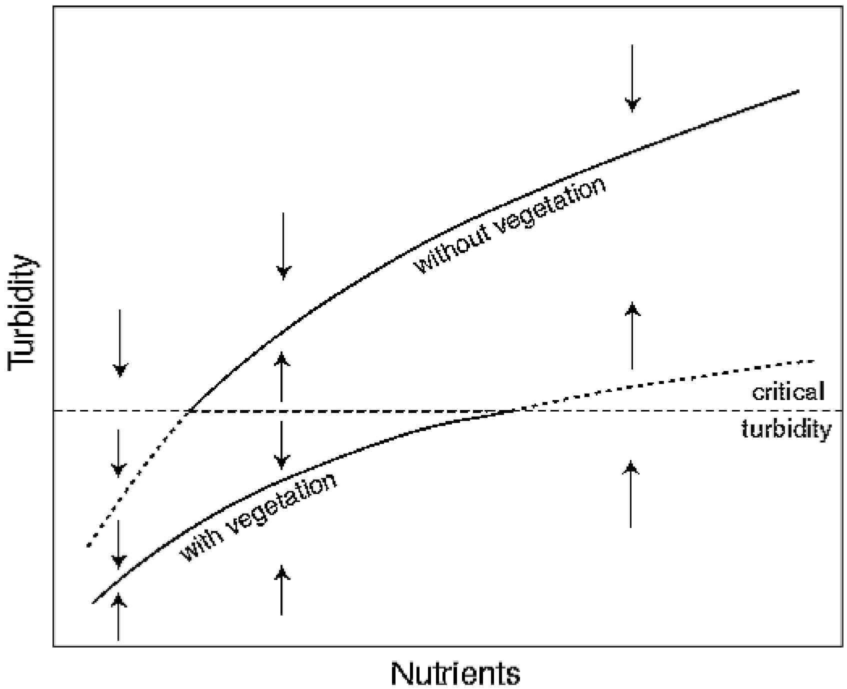

Figure 2.2 Regime shifts in lake systems with two alternative stable states. Solid lines represent the equilibrium that the system maintains in the given state. The arrows show which direction the system will recover to after a disturbance at varying nutrient concentrations and turbidity. Dashed lines show the equilibrium of the system after it has crossed the critical turbidity. The critical turbidity line represents the turbidity that must be achieved for the system to change between states (Scheffer *et al.*, 1993).

Detecting regime shifts is extremely difficult as the impacts of incremental changes over time are usually small until they reach a critical threshold (Scheffer & Carpenter, 2003). In order to effectively mitigate against regime shifts, drivers of potential shifts must be managed and early warning signs are required (Biggs *et al*., 2009). It is argued that one of the problems in detecting these changes is that indicators of regime shifts are not well understood on the spatial or temporal scales needed to accurately detect shifts (Biggs *et al.,* 2009; Blindow *et al.,* 1993). Gunderson (2000) showed that current management practices that focus on controlling economically important ecosystem services lower resilience by failing to account for the natural uncertainty and complexity in the system. It is argued that these shortcomings are a result of narrow scientific studies focused on parts of the system instead of the system as a whole (Gunderson, 2000).

Resilience in shallow lakes is governed by the interactions between the components shown by Tan & Ozesmi (2006) as well as external disturbances. Carpenter & Cottingham (1997) summarize how several of these components increase resilience in lake systems. Riparian zones control nutrient loading by catching surface runoff before it enters the lake (Osborne & Kovacic, 1993). Submerged macrophytes also control nutrients by reducing the rate of internal loading by supplying oxygen to the water (Carpenter & Cottingham, 1997). Wetlands provide many ecosystem functions that increase resilience in lake systems. Wetlands uptake water and mitigate against flooding events. They also hold nutrients and reduce large inputs of external nutrients (National Research Council, 1992).

2.5 Multiple Stressors in Lake Systems

A single ecological stressor can present problems for aquatic systems, but outcomes can sometimes be predicted and mitigation efforts can be put in place. But when multiple stressors are present in the system, unexpected ecological changes can arise. These changes arise due to the complexity of ecosystems coupled with the interactions of multiple stressors (Jackson *et al.,* 2016). Stressors can interact in a variety of ways which increase impacts (synergistic), lessen impacts (antagonistic) or have no change on the impacts (additive). Synergistic interactions result in larger impacts than would have been predicted if the stressors were acting on their own (additive). Antagonistic interactions are the opposite of this, with the impacts being less than predicted (Piggott *et al.,* 2015). Antagonist interactions have been found to be more prevalent than either synergistic or additive interactions (Jackson *et al.,* 2016; Piggott *et al.,* 2015). Understanding how stressors interact with each other is important for lake managers to prevent serious impacts (Jackson *et al.,* 2016). Ormerod *et al.* (2010) showed that freshwater ecosystems are particularly sensitive to negative impacts from multiple stressors and that this sensitivity is increasing with climate change.

Doyle *et al.* (2005) showed that interactions between climate change and nutrient loading act synergistically on phytoplankton growth. They found that increased temperature and nutrient concentrations (both nitrogen and phosphorus) contributed to significantly higher growth rates in phytoplankton. It was shown that higher temperatures in the epilimnion and atmospheric nitrogen deposition led to higher concentrations of *Fragilaria* and *Asterionella* diatom species in alpine lakes (Doyle *et al.,* 2005). It is expected that these species will continue to increase in concentration as the stressors become stronger over time. Coors & De Meester (2008) showed that predation and parasitism interact additively to impact the size and age at maturity as well as the size of offspring in *Daphnia* populations, an important zooplankton group in aquatic ecosystems. They suggest that predation and parasitism influence size and age at maturity and size of offspring through different mechanisms as the shift was along increasing growth rates or reproduction. It is argued that even though these impacts do not seem to be of the same magnitude as synergistic interactions, the ecological importance of a slower rate of maturity is more important. Coors & De Meester (2008) also showed that predation, parasitism and pesticide contamination interacted antagonistically to impact the amount of living first-brood offspring in *Daphnia* populations. The interaction resulted in no net difference from the control group in the amount of living offspring. They suspect that stress from predation results in larger offspring and higher amounts of living first-brood offspring while parasitism and pesticide contamination reduce the amount of offspring (Coors & De Meester, 2008). Responses of *Daphnia* to predation can be seen as benefiting their resistance to other stressors like parasitism and pesticide contamination. Various stressors can also make a system more prone to other stressors. Strayer (2010) has shown that nutrient enrichment and more frequent disturbances allow for invasive plant species to establish themselves. As well, climate change can increase the intensity of disturbances which can result in higher rates of colonization by invasive species (Strayer, 2010).

2.6 Using Paleolimnology to Study Multiple Stressors

Bio-indicators are species or communities that are used to analyze the state of a system. They are useful for tracking changes in ecosystems over time as they are continuously influenced by the environment around them and each species exists over a known range of conditions (Holt & Miller, 2011). Using bio-indicators that preserve well in lake sediment records is especially useful as it allows for the instrumental monitoring record to be extended long into the past. These indicators allow for the reconstruction of past environments, food webs and chemical characteristics and provide insight into the driving influences of the ecosystem. In aquatic systems, common bio-indicators that preserve well in the sediment are pollen, diatoms, macroinvertebrates and fish (Sayer *et al.,* 2010). Diatoms are one of the widely used bio-indicators in paleolimnological studies due to their well-defined taxonomy, established environmental preferences, and excellent preservation. Diatoms are a group of siliceous algae that often make up a considerable portion of the total phytoplankton in lakes. They exist over a wide range of conditions and are made up of a large group of diverse species. This diversity makes them excellent bio-indicators as each species has well defined tolerances for water quality conditions (Rühland *et al.,* 2015; McCormick & Cairns, 1994). Diatom taxa can be separated into planktonic and periphytic categories (Ruhland *et al.,* 2015). Planktonic and tychoplanktonic species of diatoms live free-floating in the water column and move through the water column due to turbulence (Ruhland *et al.,* 2015). In temperate systems, such as White Lake, they have seasonal blooms that occur when the water column mixes and nutrient and light conditions support rapid growth (Winder *et al.,* 2008). Periphytic (benthic) species of diatoms are considered as species attached to a surface at the lake bottom or in the lake sediment. Species that live within the sediment migrate closer to the sediment water interface during the day and sink back down at night. They do so as the main control over these periphytic diatoms is light availability since diatoms are photosynthetic algae (Du *et al.,* 2012).

Using diatoms to analyze the impacts of multiple stressors is commonly done as diatoms respond to a variety of water quality characteristics. Randsalu-Wendrup *et al.* (2014) studied the diatom record along with water quality data to assess the state of a shallow, eutrophic lake. They used the diatom record to infer when regime shifts occurred and how long the recovery process took. Diatom records show an increase in nutrient concentrations that resulted in a regime shift from a clear water to a turbid water state. It also showed when submerged macrophyte communities declined through a loss in species that attach to plants. Diatom communities also responded to changing light conditions after the lake became eutrophic and the recovery of the lake to a clear water state is easily seen (Randsalu-Wendrup *et al.,* 2014). Quinlan *et al.* (2008) used a diatom record to study the impacts of multiple stressors on Canadian Shield lakes and found that the response of the biologic community can differ even when water quality characteristics recover. It was shown that even though pelagic total phosphorus had returned to historic levels, the biota had not returned to the historical, pre-disturbance community assemblage. The resulting differences between water quality characteristics and the diatom community demonstrates the importance in using paleolimnology to assess the recovery of lakes to multiple stressors (Quinlan *et al.,* 2008).

Understanding how water quality has changed over long time periods (>100 years) is crucial for providing historical context on recent stressors. White Lake lacked this long-term baseline data and did not have the historical knowledge to understand the current stressors on the lake. The objective of this project was to provide long-term (>100 years) information on water quality to better understand the interactions of recent multiple stressors.

Chapter 3.0- Ecological response of a shallow mesotrophic lake to multiple environmental stressors: a paleolimnological assessment of White Lake, Ontario

Michael J.J. Murphy, D. Conrad Gregoire, and Jesse C. Vermaire

This chapter will be submitted to a peer reviewed journal.

3.1 Introduction

The ecological health of freshwater ecosystems is under threat from a complex mix of anthropogenic stressors (Reid et al. 2019). Understanding key stressors that drive environmental changes and how they interact is crucial for lake managers to make informed decisions to conserve the ecosystems services that humans depend on (Smol 2010). Many of these stressors, such as climate change, invasive species, and nutrient loading, pre-date most monitoring programs and, in many cases, lake managers are required to make decisions without baseline environmental data (Quinlan et al. 2008, Rühland et al. 2010). In addition, there is limited understanding on how multiple stressors interact over time to alter lake ecosystems. In many cases, multiple ecological stressors can lead to unexpected ecological responses (Quinlan et al. 2008, Strayer 2010, Jackson et al. 2016). This is especially true for shallow lake ecosystems where modest changes in water level or turbidity can disproportionally and rapidly alter the whole lake ecosystem by modifying what proportion of the benthic environment has sufficient sunlight for photosynthetic organisms to grow (Scheffer & van Nes 2007, Vadeboncoeur et al. 2008, Velghe et al. 2012).

Historical water quality can be inferred through paleolimnological methods which employ biological, chemical, and physical indicators in lake sediment records to reconstruct past lake and watershed conditions (Smol 2008). One widely used paleolimnological indicator of eutrophication (Christie & Smol 1996, Bradshaw et al. 2002, Whitmore et al. 2018) and climate change impacts (Winder et al. 2009, Rühland et al. 2010) on lakes are diatoms. Diatoms are a group of siliceous algae that often make up a considerable portion of the phytoplankton community in aquatic ecosystems. Diatoms make excellent paleolimnological indicators because they are found over a wide range of environmental conditions, are made up of a large group of diverse and identifiable taxa, and some taxa have well-defined optima and narrow tolerances for some ecological conditions (Rühland et al. 2015). Diatoms exhibit known and rapid responses to environmental changes, which makes them ideal for examining the interactions between stressors and offers the opportunity to extend monitoring records for many aquatic ecosystems (Smol 2010, Rühland et al. 2015). For example, changes in diatom community assemblages have been used to elucidate the effects of climate change (Winder et al. 2009, Smol 2010, Rühland et al. 2010, Rühland et al. 2015), water level fluctuations (Brugan et al. 1998, Laird et al. 2010), invasive species (Idrisi et al. 2001) and nutrient loading (Bennion et al. 1995, Bradshaw et al. 2002, Reavie et al. 2014) on aquatic ecosystems.

White Lake, a popular recreational lake located in Eastern Ontario, Canada, has a history of anthropogenic stressors resulting in the deterioration of water quality (Fig. 1). Variations in water levels and nutrient loading have caused problematic algae blooms and local fisheries suffered from the destruction of shoreline spawning habitat during the late 1960s and early 1970s when water levels were artificially manipulated (von Rosen 1989). While water levels were stabilized in the 1990s, problems with nutrient loading and invasive species persisted. Extensive monitoring data for White Lake exists since 2015 with only sporadic data collected on Secchi depth since approximately 1960. Furthermore, baseline data for most water quality variables are absent. Current interactions between environmental stressors is resulting in new problems for lake managers as water quality is rapidly changing under the influence of the recent invasion zebra mussels (*Dreissena polymorpha*) in 2015, while still being impacted by land-use and climate change (White Lake Preservation Project 2018). The objectives of this study were to investigate how the diatom community in White Lake has been impacted by environmental changes over the last few decades (nutrient enrichment, water level management, invasive species, and climate change). Then, to assess if these environmental stressors have altered the White Lake ecosystem outside its historical baseline conditions to aid management of this shallow lake ecosystem.

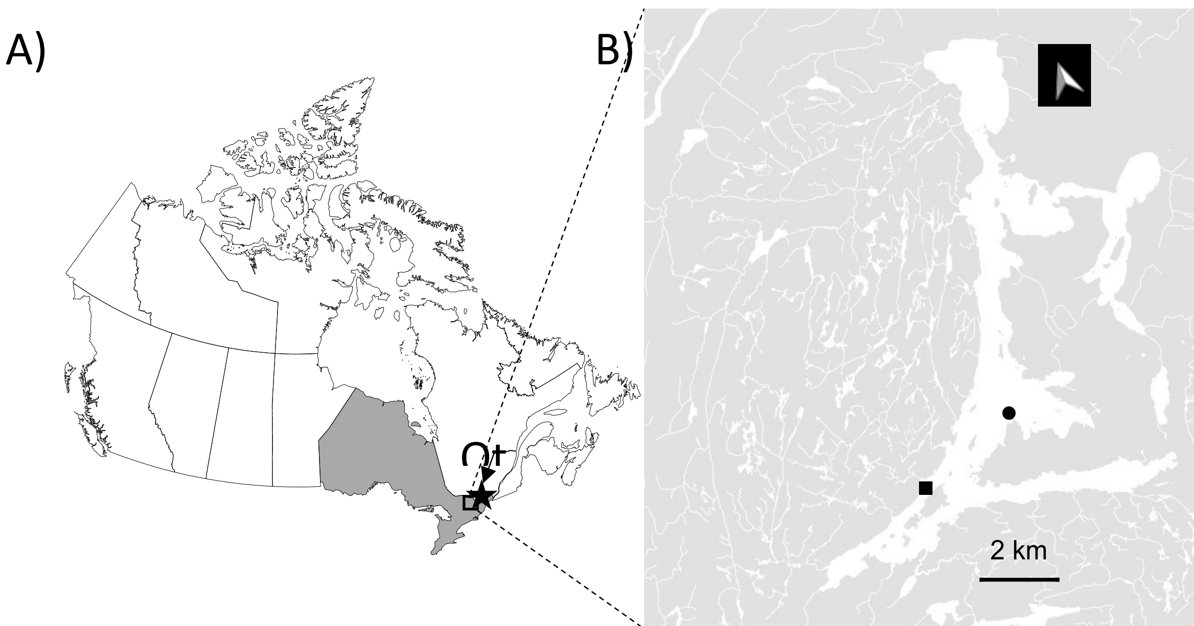

Figure 1 A) The location of White Lake, Ontario. B) A map of White Lake showing the locations of the coring sites. The circle indicates the location of the Deepest Pickerel Bay core while the square indicates the location of the North Hardwood Island core.

3.1.1 Study Site

White Lake is a large (22.5 km^2), shallow (mean depth 3.1 m), mesotrophic (average total phosphorus of 13 μg/L) lake located in Eastern Ontario, Canada (Fig. 1). The lake is a popular recreational site with numerous cottages, homes, and campgrounds along the shoreline but has a history of reduced water quality as a result of nutrient loading. Total phosphorus concentrations were a historical problem in White Lake, with concentrations reaching as high as 66 μg/L in 2006. Since 2006, phosphorus concentrations have decreased and are currently around 13 μg/L. Secchi depths increased substantially since the arrival of zebra mussels in 2015, increasing from a max Secchi depth of 3.8 m prior to 2015 to a max of 7.5 m after 2015 (Fig. 2). Water clarity has continued to increase as the zebra mussel population expanded, and the amount of lake bottom exposed to sunlight has increased from an estimated 27 % of the lake area in 2015 to approximately 90 % in 2017 (White Lake Preservation Project 2018) opening much more habitat in the lake for benthic primary producers.

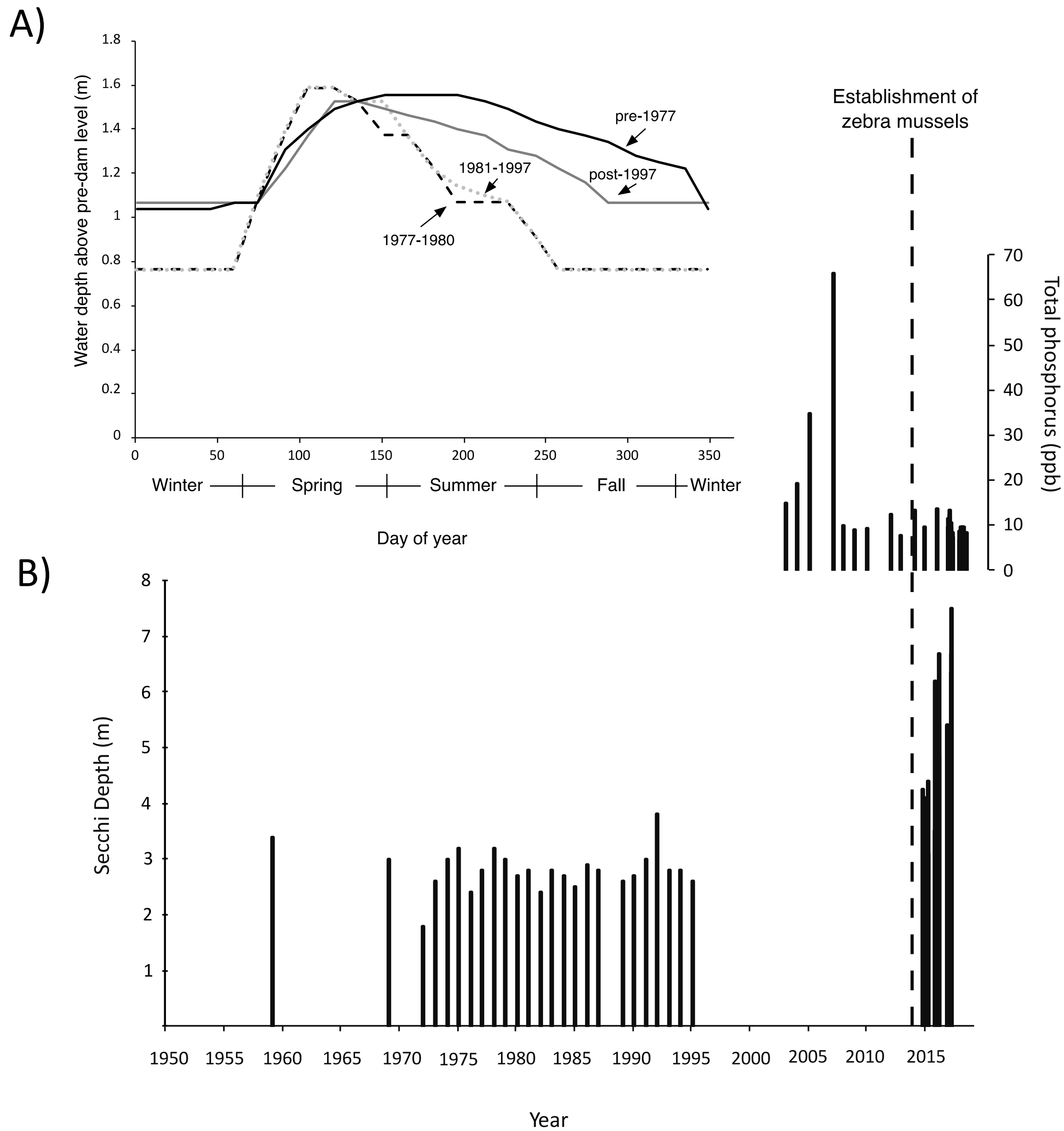

Figure 2 A) Water level management strategies on White Lake. The solid grey line represents the current management strategy. Values shown only represent target lake levels, actual lake levels fluctuate with the weather. B) Total phosphorus levels and Secchi depths over time in White Lake (White Lake Preservation Project, 2018).

White Lake was originally three small waterbodies that were connected into one large waterbody in 1845 after the Waba Creek outflow on the north end of the lake was dammed for logging operations. The lake has 97.9 km of shoreline and a surface area of 22.5 km^2, with approximately 60 % of this surface area made up of large shallow bays less than approximately 3 m deep. The deepest area of the lake is in Pickerel Bay at 9 m water depth and the mean depth of the lake is 3.1 m. White Lake has a watershed area of 211 km^2 that is located primarily on Precambrian Shield rock that is rich in marble deposits (Mathers and Kerr 1998). Water levels are actively managed in White Lake and three distinct management regimes have existed on the lake since 1968 (Fig. 2). Prior to 1977, water levels promoted Walleye (*Sander vitreus*) populations with summer water levels kept high, around 1.5 m above the pre-dammed lake level. Many lake users were unhappy with this plan and water levels were changed in 1977 to promote boating with higher spring levels of 1.6 m above pre-dam levels and a rapid drawdown to lower late summer levels of 1.2 m above pre-dammed lake levels. Overwinter levels in this regime were 0.8 m, 0.2 m lower than the previous regime. By 1981, many Walleye populations were in decline due to spawning habitats being covered in silt due to a reduced flushing rate of the lake, allowing silt to cover spawning shoals (von Rosen 1989, Mathers & Kerr 1998), though this water level regime remained until 1998. The current water level regime, that was brought in in 1998, is an intermediate to the two previous regimes with summer levels of approximately 1.4 m above pre-dammed levels and slower drawdowns to winter levels of one meter above pre-dammed levels.

3.2 Methods and Materials

3.2.1 Sediment Core Collection and Analysis

Sediment cores were collected from White Lake in the summer of 2014 and 2017 (Fig. 1). The first sediment core was 20 cm long and was collected in 2014 from a location near North Hardwood Island (45°16'09.7"N, 76°33'12.2"W) at a water depth of 5 m. The second sediment core was collected in 2017 near Deepest Pickerel Bay (45°16'48.6"N, 76°31'37.8"W) at a water depth of 9 m and was 35 cm long. Both cores were taken using a gravity corer (ARI corer for the North Hardwood Island core and Uwitec gravity corer for the Deepest Pickerel Bay core). The North Hardwood Island core was sectioned at 1 cm intervals, whereas the Deepest Pickerel Bay core was sectioned at 0.5 cm intervals. Both cores captured a well-defined sediment-water interface suggesting that the most recent ecological conditions in the sediment record were preserved. All sediment samples were stored in a cold room at 4 C prior to analysis.

To calculate the organic content of the sediment a 1 cm^3 subsample of sediment was taken from each sediment interval for loss-on-ignition (LOI) analysis following standard protocol (Dean 1974, Heiri et al. 2001). Briefly, samples were weighed for wet weight before being placed in a furnace at 110 C for a minimum of 12 hours to be dried. Once dried, samples were weighed for dry weight before being placed in a furnace at 550 C for four hours to burn any organic matter present in the sediment. Samples were then weighed for a final time and the water and organic content of the sediments were calculated.

An age-depth model for the North Hardwood Island core was developed using ^{210}Po measured by Alpha Spectroscopy to infer ^{210}Pb concentrations assuming a rapid equilibrium and ^{137}Cs measured using Gamma Spectrometry at Flett Research Ltd (Winnipeg, Manitoba, Canada). The age-depth model was created using a Constant Rate of Supply (CRS) model and verified using six independent ^{137}Cs readings by Flett Research Ltd (Appleby & Oldfieldz 1983).

3.2.2 Diatom Preparation and Analysis

Diatom slides were prepared following standard procedures (Battarbee et al. 2001). Briefly, a small amount of sediment (~0.1 g) was transferred into 20 ml glass scintillation vials and 10 ml of 10 % hydrochloric acid and 10 ml of deionized water were added to the vial. Samples were left to settle overnight. Subsequently, ~10 ml of the upper portion of the sample was pipetted from the vials, being careful not to disturb the settled diatoms, and 10 ml of deionized water was added. This step was repeated seven times, with the samples being allowed to settle overnight in between each step. After the seventh rinse, 10 ml of 30 % hydrogen peroxide was added to the samples. Samples were then placed in a water bath and brought to a temperature of ~70 C for eight hours. After heating, the samples were left overnight to cool. Once cool, the rinsing procedure was repeated with 10 ml of sample being removed from the vial using a pipette and 10 ml of deionized water added (Battarbee et al. 2001). After seven rinses with deionized water, with the diatoms allowed to settle overnight between rinses, a few drops of 10 % hydrochloric acid were added to each sample to aid diatom dispersion on the coverslips. One milliliter of sample was transferred to a test tube and 9 ml of deionized water was added and the sample was thoroughly mixed. A few millilitres of sample were then transferred to a clean glass coverslip using a pipette. A one-half dilution series was repeated until four concentrations from each sample were made. In a fume hood, dried coverslips were mounted onto slides using Naphrax. At least 400 diatoms were counted per slide using a Leica DM2500 microscope at 1000x magnification with the aid of taxonomic references from Krammer and Lange-Bertalot (1986).

3.2.3 Statistical Analysis

Species counts were transformed into relative abundance data and species with a relative abundance of less than 2 % in at least one sample were removed from analysis (Patterson & Fishbein 1989). Stratigraphic plots showing the relative abundance of diatoms were produced. For statistical analysis, the relative abundance data were square-root transformed to reduce the influence of abundant species. Cluster analyses were determined using square-root transformed abundance data and the constrained hierarchical clustering with a broken stick model using the R package 'riojia' (Juggins 2017) in the R environment (R Core Team 2013). To elucidate major trends in the diatom data, Principal Components Analysis (PCA) was performed using the R package 'vegan' (Oksanen et al. 2007). Ellipses showing 95 % confidence intervals of the centroid of the mean of the group were added to PCA plots to denote the significant clusters determined by the constrained hierarchical clustering to visualize how the clusters related to each other. Square chord distances dissimilarity measures were calculated to assess the magnitude of change from the diatom assemblage from the bottom of the cores to all other sediment layers analyzed for diatoms, using the bottom layer of each core as a reference for historic conditions. Values ranged between 0, for samples that were identical, to the square root of two, for samples that were completely different (Overpeck et al. 1985, Bennion et al. 2004).

3.3 Results

^{210}Pb and ^{137}Cs data indicated that the top 9 cm of the North Hardwood Island core represented a time period from 1884 to present (Fig. 3). The ^{137}Cs peak occurred at approximately 4 cm sediment core depth at an estimated age of 1953 years based on the CRS model. ^{137}Cs peaks at the height of atmospheric nuclear bomb test (~1962) and the consistency of our ^{137}Cs peak with the ages estimated from ^{210}Pb dating suggests that our CRS age model for the North Hardwood Island core provides a reliable estimate of sediment ages in the upper portion of this core (Fig. 3).

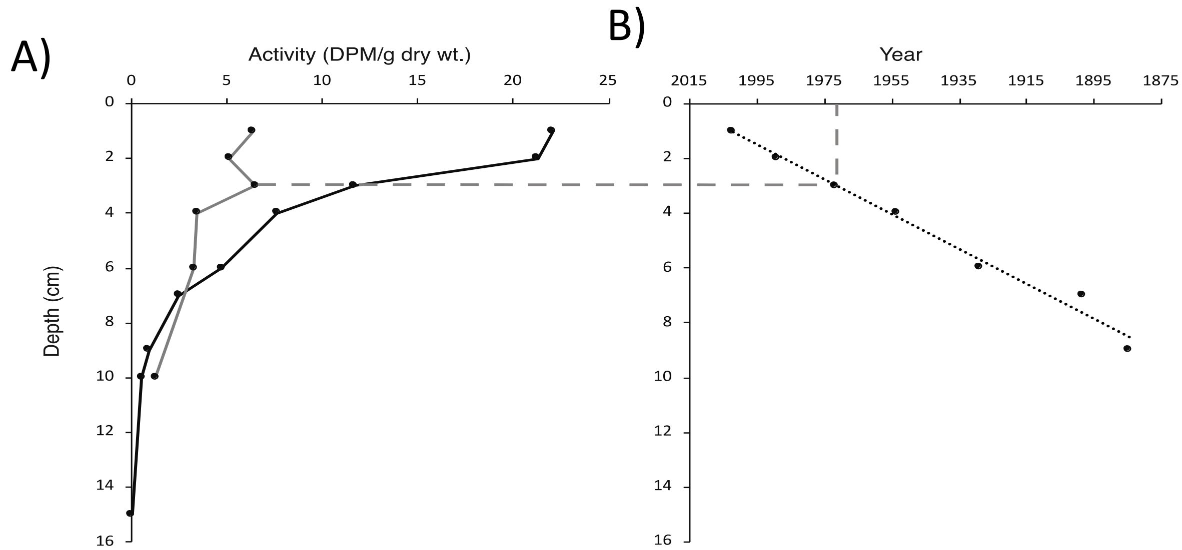

Figure 3 A) ^{210}Po and ^{137}Cs activity over depth of the North Hardwood Island core with an uncertainty of ±11 % B) The age/depth model based on ^{210}Pb activities and developed using a Constant Rate of Supply model (Appleby & Oldfieldz, 1983)

The Deepest Pickerel Bay core had greater organic matter content (~70 %) at the bottom part of the core (35-22 cm), followed by a decline in organic matter content (61-66 %) in the middle (21-6 cm) of the core (Fig. 4). The organic matter content then increased to ~70 % in the top 5 cm of the core, similar to what was observed in the lower portion of the sediment record. The North Hardwood Island core had relatively constant organic matter content (approximately 71-74 %) from 20 cm to 12 cm. The greatest organic matter content (74-77 %) in the core was from 11 cm to 8 cm (~1895), followed by a rapid decline in organic matter near the top of the core with the lowest organic matter content levels (60-69 %) in the upper 7 cm of the core (~1909-Present). Changes in organic matter in both cores occurred simultaneously with changes in the diatom assemblages of the cores suggesting that these shifts in organic content represent lake-wide ecosystem changes (Fig. 4).

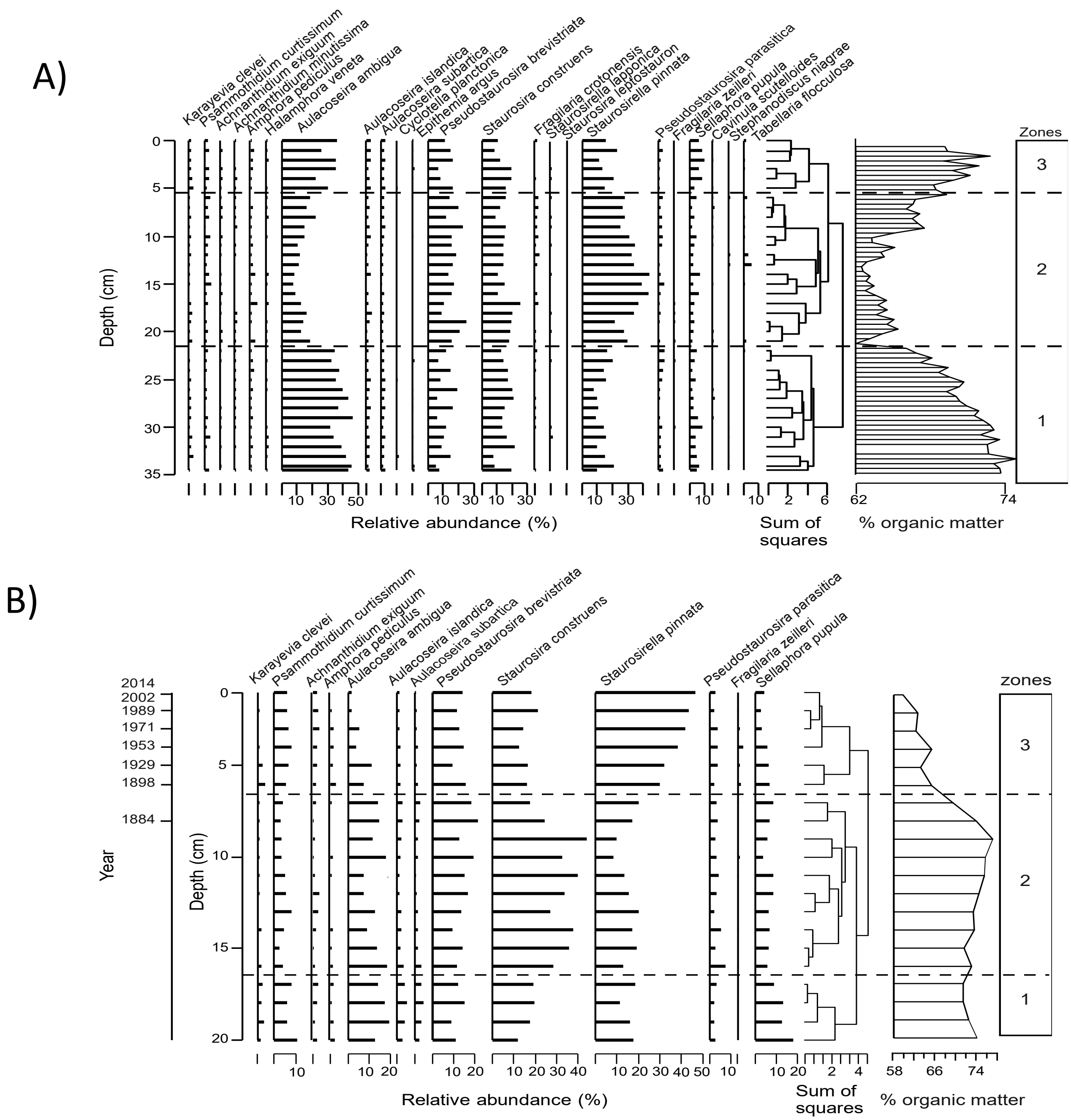

Figure 4 A) Diatom assemblages of 2017 core in Deepest Pickerel Bay. Three significant zones were found using a broken stick model and groups are separated by solid horizontal lines. B) Diatom assemblages of 2014 core from North Hardwood Island. Three significant zones were found using a broken stick model and groups are separated by solid horizontal lines.

Diatom assemblages in the deeper water sediment core from Deepest Pickerel Bay contained 86 taxa with 23 taxa having a greater than 2 % relative abundance in at least one sample (Fig. 4). Not surprisingly, there was a greater proportion of planktonic diatom taxa observed in this deeper water sediment core than the shallower water (water depth of 5 m) North Hardwood Island core. The diatom community of the Deepest Pickerel Bay core consisted of alternating groups of planktonic *Aulacoseira* species and small benthic Fragilaria (*sensu lato)*. Three zones were identified by constrained hierarchical clustering analysis. Zone one (35-22 cm) was dominated by *Aulacoseira ambigua,* with relative abundance between 33 % and 47 %. Benthic Fragilaria (*sensu lato*) species ranged between 8 % and 21 % in this zone, suggesting higher lower relative benthic diatom production at this time compared to the entire sediment record. Zone two (21-7 cm) was defined by a relative shift to benthic taxa with *Staurosirella pinnata* increasing from a relative abundance of approximately 8 % in zone one, up to 44 % in zone two. The relative abundance of *Aulacoseira ambigua* ranged between 8 % and 22 % in zone two. The transition between zones one and two represented a large shift in the relative importance on planktonic versus benthic diatom production. In zone three (6-0 cm), the diatom assemblage transitioned back to being dominated by the tychoplanktonic *Aulacoseira ambigua,* with relative abundances up to 36 % (Fig. 4), suggesting a transition to deeper water levels. Relative abundances of *Staurosirella pinnata* ranged between 11 % and 28 % in zone one.

Diatom assemblages in the North Hardwood Island core contained 85 taxa and were dominated by 13 taxa which had relative abundances greater than 2 % in at least one sample. Of these taxa, shifts among small benthic Fragilaria (*sensu lato)* and *Aulacoseira* species represented the largest changes in the stratigraphic record (Fig. 4). Similar to the Deepest Pickerel Bay sediment core, three zones were identified by constrained hierarchical clustering analysis. Zone one (20-17 cm), at the base of the core was dominated by benthic diatoms *Staurosirella pinnata* (relative abundance between 11 and 18 %) and *Staurosira construens* (relative abundance between 12 and 19 %) and the tychoplanktonic diatom *Aulacoseira ambigua,* (relative abundance between 12 and 19 %). Zone two (16-7 cm or pre-1884 to 1909) showed a relative shift to benthic *Staurosira construens,* with relative abundances up to 44 %, suggesting a greater relative proportion of benthic production at this time. The relative abundance of *Aulacoseira ambigua* decreased slightly in this zone, ranging between 7 and 18 %. In zone three (6-0 cm or 1929 to Present) the diatom record continued to be dominated by benthic taxa however there was a marked shift from *Staurosira construens* that declined from 44 % in zone two, to 13 % in zone three to *Staurosirella pinnata* that increased from a relative abundance of 9 % in zone two up to 46 % in zone three. Tychoplanktonic *Aulacoseira ambigua* abundances continued to decline in zone three, falling to 2 % (Fig. 5).

The Principal Components Analysis of the Deepest Pickerel Bay core showed that PC1 explained 51 % of the variation in the diatom assemblage of the core and was largely driven by a shift in samples dominated by the benthic *S. pinnata* versus those samples where the planktonic *A. ambigua* were more common in the core, again suggesting that changes in water depth were a driving force in changes in the diatom assemblage of White Lake (Fig. 5). The broken stick model indicated only one significant principal component axis for the Deepest Pickerel Bay core. Ellipses showing the zones created by constrained hierarchal clustering clearly displayed that zone one and zone three are closely related while zone two has a more unique diatom assemblage than the other two zones (Fig. 5). This relationship was also seen in the stratigraphic plots where the diatom assemblages in zones one and three had similar diatom communities. Assemblages in zones one and three were dominated by tychoplanktonic *A. ambigua* while zone two was dominated by benthic *S. pinnata*. The increase in benthic *S. pinnata* in zone two was an indication of increased light availability at depth (Fig. 5).

Similarly, the PCA of the North Hardwood Island core showed that the differences between *S. pinnata, S. construens* and *A. ambigua* explained the greatest amount of variation in the core. A broken stick model indicated that there were two significant axis, PC1 and PC2 which explained 47 % and 22 % of the variation in the diatom assemblage respectively. A shift between sediment samples dominated by the benthic *S. pinnata* and the planktonic *A. ambigua* were the major drivers of change along PC1 suggesting a transition from a shallower to a deeper water system. A shift between benthic taxa *S. pinnata* and *S. construens* was the major driver of change along PC2, suggesting a shift in benthic production, possibly related to increasing nutrient enrichment or increasing turbidity. Ellipses showing the zones created by constrained hierarchal clustering showed three distinct groups with differing diatom assemblages (Fig. 5).

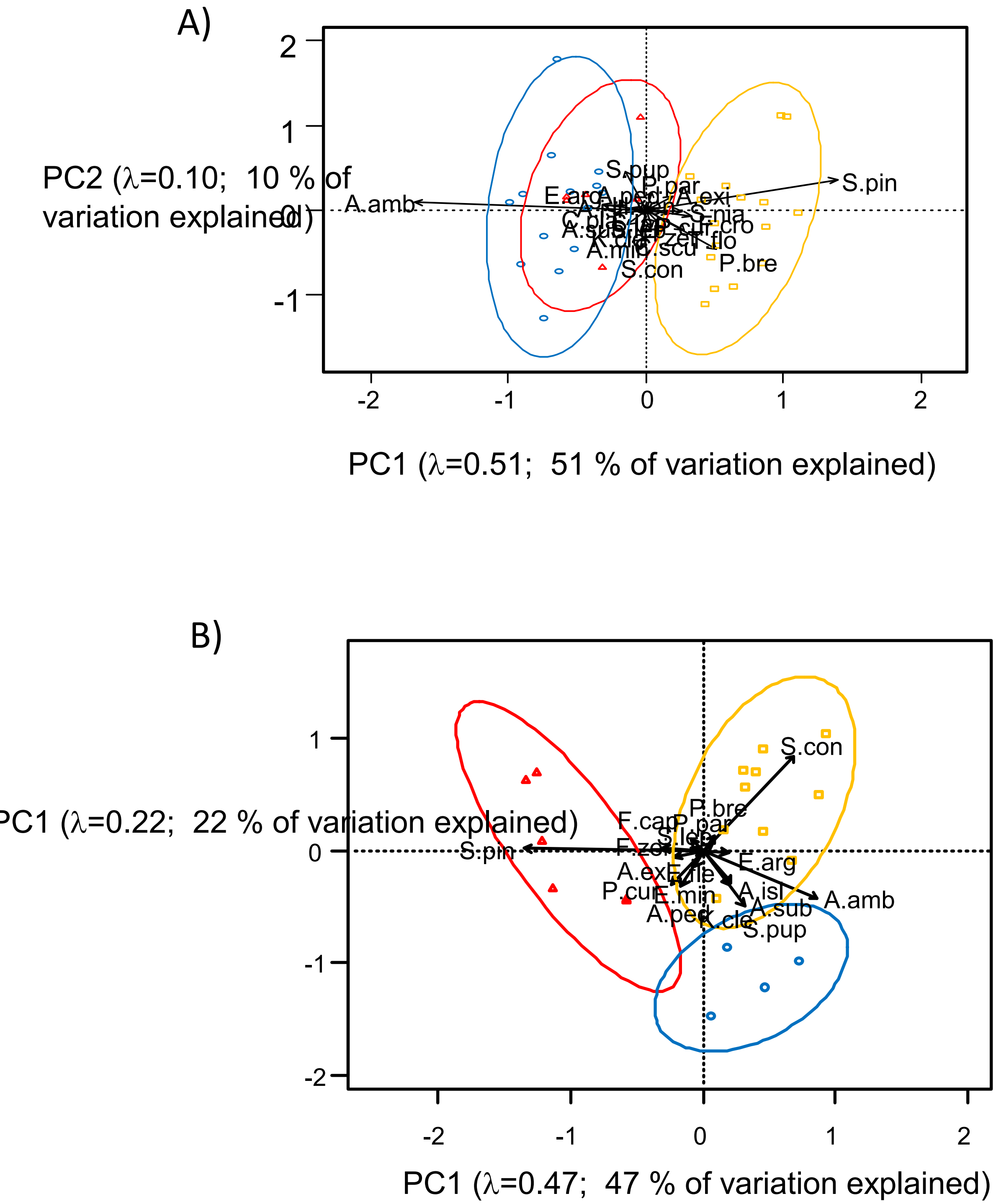

Figure 5 Principal components analysis of A) Deepest Pickerel Bay and B) North Hardwood Island cores. Red triangles correspond to zone three, orange squares correspond to zone two and blue circles correspond to zone one.

The dissimilarity measure square chord distances showed that the Deepest Pickerel Bay core diatom community of zone two was the most dissimilar to historical diatom assemblages recorded in the bottom most sediment sample at the bottom of the sediment core with square chord values up to 0.86 (Fig. 6). In contrast the diatom communities of zone three and zone one were more similar with square chord values as low as 0.34 and 0.18 respectively. The diatom zone three of the North Hardwood Island core was more dissimilar than zone two when compared to historical conditions recorded in the bottom most sediment sample. Zone three had square chord values up to 0.54 while zone two had square chord values up to 0.41. Zone one was the most similar to the diatom assemblage in the bottom most sediment sample with square chord values as low as 0.15 (Fig. 6). The Deepest Pickerel Bay core generally had higher square chord distance values than the North Hardwood Island core, indicating that the shifts in the diatom community in the Deepest Pickerel Bay core were more substantial (Fig. 6).

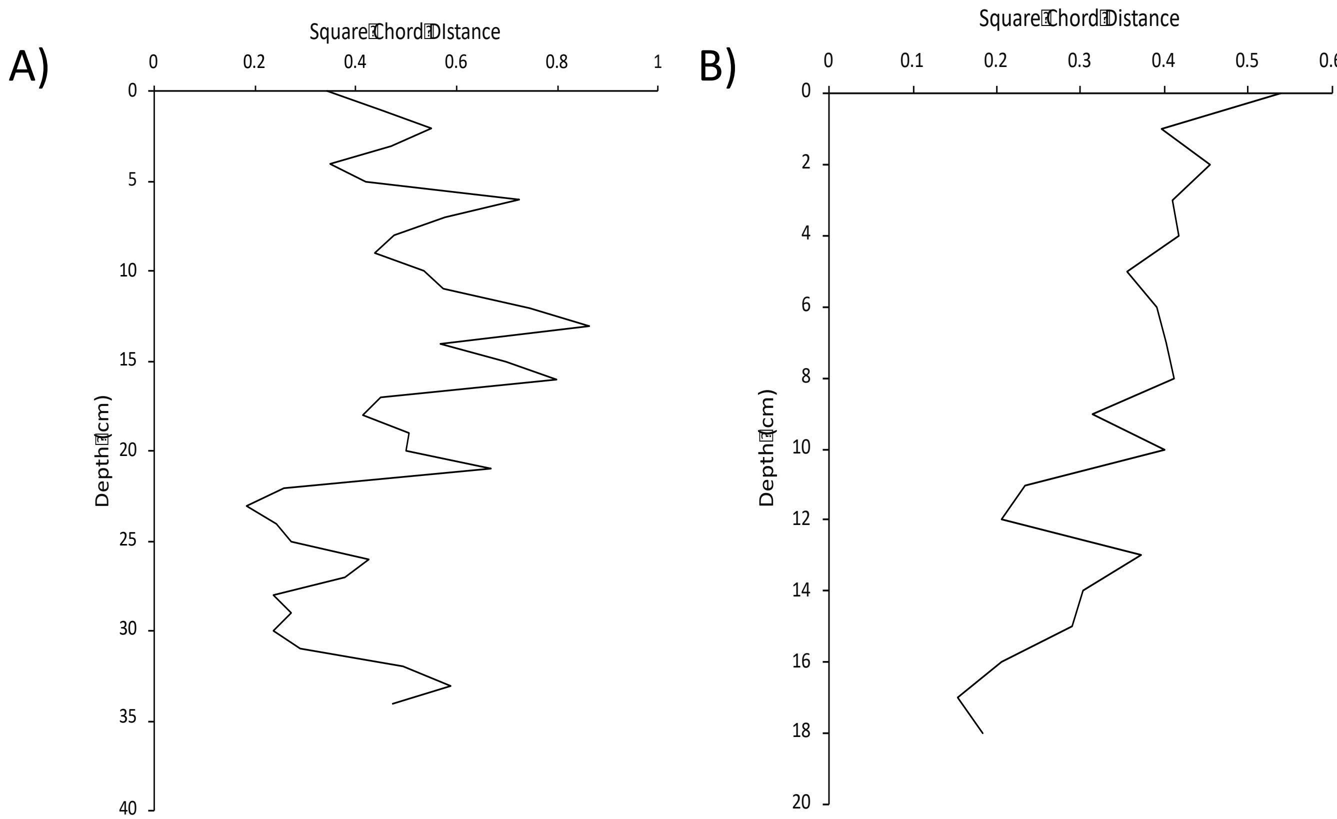

Figure 6 Square chord distances of the A) Deepest Pickerel Bay core assessing dissimilarity between diatom assemblages. Higher square chord distances correspond with higher dissimilarity between the given depth and the bottom of the core. B) Square chord distances of the North Hardwood Island core assessing dissimilarity between diatom assemblages. Higher square chord distances correspond with greater dissimilarity between the diatom assemblage at the bottom of the core and the given depth of the sample.

3.4 Discussion

3.4.1 Diatom Zone One

The diatom community in zone one of the Deepest Pickerel Bay core was characterized by high relative abundances (greater than 30 %) of *A. ambigua,* indicating greater productivity and frequent mixing of this shallow lake system (Anderson 1989). Benthic *S. pinnata* and *S.*

construens began to show moderate increases towards the top of zone one. The area surrounding where the Deepest Pickerel Bay core was taken likely remained relatively deep at around 8 m in the basin and 6 to 7 m in the surrounding water (Fig. 1). The deeper water surrounding the Deepest Pickerel Bay coring site would have favoured *A. ambigua* when lake productivity was elevated. Light penetration at depth may not have been sufficient to support a large benthic population under these conditions.

In contrast, the diatom community in zone one of the North Hardwood Island core was dominated by small benthic Fragilaria (*sensu lato)* species such as *S. pinnata,* and *S. construens* (relative abundances of approximately 20 %) that are very common in shallow lake ecosystems and have particularly high relative abundances in mesotrophic systems or where light limitation to the benthic environment may reduce benthic diatom diversity (Sayer 2001). The relatively even distribution of benthic and tychoplanktonic diatoms during this time could be influenced by less littoral habitat relative to planktonic habitat, which would have favoured a greater relative abundance (approximately 20 %) of tychoplanktonic species such as *A. ambigua,* which do well in nutrient rich shallow lakes where there is sufficient mixing by wind to keep them suspended in the water column (Vermaire et al. 2012). Prior to the lake being dammed, water levels were approximately one meter lower than present and with these lower water levels the littoral habitat in the lake would be substantially reduced as much of the very shallow (~1 m water depth) north and east bays of the lake would be wetlands as opposed to connected parts of the main body of the lake. This lower water level would have increased the relative proportion of planktonic versus benthic habitat which would have favoured higher relative abundances of tychoplanktonic species such as *A. ambigua*.

3.4.2 Diatom Zone Two

The diatom community in zone two of the North Hardwood Island Core was dominated by *S. construens* (relative abundance up to approximately 44 %). The relative abundance of *S. construens* increased until approximately the year 1884 (from 28 % in the beginning of zone two to approximately 44 %) from the community in zone one that had a higher proportion (approximately 20 %) of tychoplanktonic *A. ambigua*. The shift from a community dominated by *A. ambigua, S. pinnata* and *S. construens* to a community with a larger proportion of *S. construens* suggests a modest increase in benthic habitat as the benthic *S. construens* increased and the tychoplanktonic *A. ambigua* decreased.

In the Deepest Pickerel Bay core, *S. pinnata* had the highest relative abundances from 11 cm to 18 cm where they peaked at greater than 40 % relative abundance. The increased levels of benthic species in zone two suggests greater benthic habitat at this time. The subsequent damming of White Lake resulted in an increase in *A. ambigua* that began to occur around the 10 cm mark of the sediment core (Christie & Smol 1996). With water levels increasing by approximately one meter as a result of the dam, human impacts became more pronounced within the lake ecosystem. The resulting increase in productivity began the shift away from benthic *S. pinnata* in deeper waters, as greater water depth limited light availability to the benthic environment.

3.4.3 Diatom Zone Three (1929 to Present)

The diatom community in zone three of the North Hardwood Island core was characterized by high abundances of *S. pinnata* which exceeded 40 % relative abundance in the uppermost layers. The general trend away from *S. construens* began shortly after the lake was dammed in 1845. This shift away from *S. construens* towards *S. pinnata* may be indicative of a rise in productivity in White Lake as new areas of lands were consumed by the lake, as was also reported by Cremer et al. (2001). As White Lake was flooded, low-lying areas around the lake would have been submerged and turned into littoral habitat. The newly flooded and relatively large littoral area resulted in an increase in benthic production. A similar trend was also observed in the nearby Rideau River system after it was flooded for canal construction (Christie & Smol 1996). Further increases in *S. pinnata* may be the result of high total phosphorus levels that were prevalent during the late 1990s and early 2000s increasing turbidity in the lake. Toward the top of the core, where *A. ambigua* reached the lowest relative abundance seen in the record (2 % relative abundance). With good vertical mixing to promote the resuspension of sediments and greater Secchi depths relative to the 1950s to present, benthic species were continuously favoured in this shallower region of White Lake. Greater productivity in a shallow lake has been seen to favour benthic species as sediments can often be resuspended, negating the light requirements of the diatoms attached to the resuspended sediment (Whitmore et al. 2018).

Zone three of the Deepest Pickerel Bay core saw an increase in *A. ambigua* and decreases in small benthic Frailaria (*sensu lato)* species. Anderson (1989) showed increased relative abundances of planktonic species in deeper waters as a result of increased productivity. Increased productivity in White Lake occurred during the early 2000s as nutrient levels were rising prior to zebra mussel colonization. Shifts towards *S. pinnata* during recent years in the North Hardwood Island core and towards *A. ambigua* in the Deepest Pickerel Bay core may be explained by the different water depths of the coring sites. Anderson (1989) showed that deep water cores favour planktonic species during periods of high productivity, while cores taken from more shallow depths showed increases in benthic species.

The recent colonization (2015) of zebra mussels has substantially altered conditions in White Lake. Total phosphorus levels have declined from 66 µg/L to around 10 µg/L and Secchi depths have increased from 1.8 m to 7.5 m (Fig. 2). This substantial decline in turbidity should allow for even greater benthic production across the majority of lake bottom, and thereby a higher relative proportion of benthic diatoms to planktonic diatom as more sunlight is reaching the lake bottom. This increase in benthic production related to zebra mussel invasion was not well observed in our sediment core record as the colonization of zebra mussels was too recent (2015) to be evident in our cores given the sedimentation rate. Similarly, the modest variations in the water level management from 1977 to 1997, beyond the initial damming of the lake, did not have a major impact on the diatom assemblage in the sediment record.

Square chord distances indicate that much of the core had a different diatom assemblage than pre-disturbance conditions. The North Hardwood Island core had the highest square chord distances in zone three, indicating that the diatom community became increasingly different than pre-disturbance conditions over time. This change corresponded with the increase in *S. pinnata* and the decline in the relative abundance of *A. ambigua* suggesting that pre-disturbance conditions in shallow water environments had a higher proportion of tychoplanktonic species and more limited light conditions. The Deepest Pickerel Bay core had the highest square chord distances in zone two indicating that the diatom assemblage in the middle of the record was the most different to historical conditions. This corresponded with a shift toward *S. pinnata* and away from *A. ambigua*, showing that pre-disturbance conditions in deeper water environments favoured tychoplanktonic species and more limited light conditions.

Water quality in White Lake has undergone substantial changes as shown in the sediment record. Deep water environments have seen a return to conditions more similar to the pre-disturbance environment with *A. ambigua* being the most abundant taxa in zones one and three. The shallow water environment has not returned to pre-disturbance conditions and has instead continued to change over time, suggesting greater human modification of the benthic environment over time. An overall trend toward increased benthic production has been seen with tychoplanktonic species having their lowest relative abundances in zone three. Long-term trends in water quality in White Lake show increased production after the lake was dammed and human activity became more prevalent. However, the water clarity of White Lake has increased substantially with the recent colonization of zebra potentially limiting the negative impacts of phosphorus enrichment in the lake. This drastic increase in water clarity as the result of zebra mussel invasion has greatly increased the amount of open water environment suitable for benthic primary production that may have important consequences for the ecosystem of White Lake in the future.

3.5 Conclusion

White Lake has undergone substantial human impacts over the years with human modifications of water levels, nutrient enrichment, and the recent invasion of zebra mussels. These multiple stressors have modified the White Lake ecosystem, however, based on our diatom analyses these stressors appear to have had the greatest impact on both the quantity and quality of benthic habitat in the lake. The largest change in the diatom community occurred with the damming of White Lake that increased water levels approximately 1 m, creating vast shallow bays out of historical wetlands. Recent shifts in the diatom assemblages are modest in comparison to the changes resulting from the damming but due record a history of nutrient enrichment, particularly in the benthic diatom taxa.

Chapter 4.0 Conclusions

This thesis investigated the impacts of multiple stressors on water quality in White Lake, Ontario. White Lake has a legacy of algae blooms and poor water quality as a result of anthropogenic stressors. The primary objectives of this thesis were to assess how these stressors impacted diatom communities and to determine historical trends in the lake ecosystem based on the sedimentary diatom assemblage.

To complete this investigation, two sets of cores were analyzed in Chapter 3.0 to determine background conditions and assess long-term environmental change in White Lake. Shifts in the diatom assemblages of both the North Hardwood Island and Deepest Pickerel Bay cores showed changes among small benthic Fragilaria (*sensu lato*) species and tychoplanktonic *Aulacoseira ambigua* accounted for the majority of the variation in the lake. The Deepest Pickerel Bay core had shifts from tychoplanktonic *Aulacoseira ambigua* and to benthic *Staurosirella pinnata*. The increase in benthic species in shallow waters coincides with increased abundances of planktonic species in deep water core suggesting increased productivity after the lake was dammed and the littoral habitat was expanded (Christie & Smol, 1996). Square chord distances were used to assess how similar background conditions were to recent conditions (Bennion *et al.,* 2004; Overpeck *et al.,* 1985). The North Hardwood Island core showed decreasing diatom community similarity higher in the sediment record, indicating that conditions were becoming less analogous to historical conditions as time went on. The Deepest Pickerel Bay core had the highest square chord distances in the middle of the core coinciding to the damming of the lake. Changes in organic content of the sediment record occurred in both cores coinciding to changes in the diatom assemblages suggesting that these shifts represent lake-wide changes to the ecosystem. These results show that anthropogenic stressors, most importantly lake damming and nutrient loading, have driven changes in water quality in White Lake over the last few centuries.

In the early 2000s, trends in total phosphorus concentrations and Secchi depths showed that White Lake was vulnerable to undergo a regime shift to a algae dominated system. The introduction of zebra mussels resulted in a reduction in total phosphorus concentrations and increased Secchi depths, making White Lake more resilient toward a regime shift to turbid water conditions. The interaction between higher nutrient concentrations and zebra mussels was an antagonistic interaction between stressors, with zebra mussels reducing the threat of a regime shift brought on by high nutrient concentrations.

While this research provides insight into long-term trends in water quality in White Lake, some questions remain unanswered. Most notably, how have zebra mussels impacted biota? The dramatic increases in water clarity has exposed more of the lake bottom to sunlight, but there has been no investigation into how this increase in sunlight has impacted the macrophyte community, or by extension the fish community. The relationship between macrophytes and the rest of the lake system is clearly shown by Tan and Ozesmi (2006) and understanding how zebra mussels are impacting them will provide insight into how the system as whole is being impacted. Monitoring activities focussing on evaluating macrophyte growth would give valuable insight into how the increase in light penetration has impacted macrophyte growth. This would be especially valuable in a multiyear monitoring program that looks at changes in biovolume and locations of macrophyte beds. As well, a follow up study to the Mathers & Kerr (1998) fishery assessment would fill in a current gap in data as to how the current water management strategy has impacted fish populations. The previous study was conducted in response to changes in water management, but an evaluation of the current water management strategy has not been done.

This research is important as it provides valuable information to lake managers on how the damming of the lake and nutrient levels have altered the ecology of White Lake. This information will allow them to make better decisions on how the lake should be managed to best maintain water quality and support biota. In summary, this thesis provides long-term data for lake mangers on White Lake. This data will give them a better perspective to understand current changes impacting White Lake and make informed decisions on how to manage them. It also extends the monitoring record and provides insight into historical drivers of water quality change for this important recreational lake in Eastern Ontario, Canada.

Chapter 5.0 References

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Chapter 5.0 Appendices

Table A-1 Relative abundances of diatom species from North Hardwood Island core

Depth (cm)		Zone	K.clevei	P.curtissimum	P.distinctum	A.exiguum	E.flexella
0	1	1	0.00	6.11	0.00	1.96	0.00
1	2	1	0.98	5.88	0.00	2.21	0.00
2	3	1	0.25	6.63	0.00	2.70	0.00
3	4	1	1.23	8.09	0.00	1.72	0.00
4	5	1	2.96	6.67	0.00	1.73	1.23
5	6	1	3.69	5.42	0.00	1.48	0.00
6	7	2	1.41	3.99	0.00	1.17	0.00
7	8	2	0.99	2.72	0.00	0.50	0.00
8	9	2	1.23	3.19	0.00	0.74	0.00
9	10	2	1.24	3.22	0.00	0.50	0.00
10	11	2	1.22	4.88	0.00	0.73	0.00
11	12	2	0.99	5.71	0.00	2.73	0.00
12	13	2	0.48	7.95	0.00	2.65	0.00
13	14	2	2.47	4.44	0.00	1.48	0.00
14	15	2	0.74	2.22	0.00	0.49	0.00
15	16	2	2.00	3.74	0.00	0.75	0.00
16	17	3	2.71	7.88	0.00	2.46	0.00
17	18	3	2.21	6.14	0.00	1.72	0.00
18	19	3	3.35	6.22	0.24	0.72	0.00
19	20	3	1.97	10.57	0.00	1.72	0.00

Depth (cm)		Zone	A.minutissima	A.inariensis	A.libyca	A.pediculus	H.thumensis
0	1	1	0.24	0.00	0.00	0.24	0.00
1	2	1	0.00	0.00	0.00	0.74	0.00
2	3	1	0.00	0.00	0.00	1.72	0.00
3	4	1	0.49	0.00	0.00	1.47	0.00
4	5	1	0.25	0.00	0.00	0.99	0.00
5	6	1	0.00	0.00	0.00	2.71	0.99
6	7	2	0.47	0.00	0.00	0.47	0.00
7	8	2	0.74	0.00	0.25	0.00	0.00
8	9	2	0.25	0.00	0.98	0.00	0.00
9	10	2	0.99	0.00	0.25	1.24	0.00
10	11	2	0.24	0.00	0.24	0.73	0.24
11	12	2	0.74	0.25	0.00	0.00	0.25
12	13	2	0.24	0.00	0.00	0.00	0.00
13	14	2	0.00	0.00	0.00	0.99	0.00
14	15	2	0.00	0.00	0.25	0.49	0.00
15	16	2	0.00	0.00	0.00	1.25	0.00
16	17	3	0.25	0.00	0.25	1.48	0.00
17	18	3	0.00	0.00	0.00	0.49	0.00
18	19	3	0.24	0.00	0.00	1.67	0.00
19	20	3	0.00	0.00	0.00	1.97	0.00

Depth (cm)		Zone	H.veneta	A.ambigua	A.islandica	A.subartica	C.disculus
0	1	1	0.49	1.87	0.65	0.65	0.00
1	2	1	0.25	1.96	0.98	0.98	0.00
2	3	1	0.74	5.41	0.98	0.98	0.00
3	4	1	0.25	3.92	1.47	1.47	0.49
4	5	1	0.49	11.11	1.23	1.23	0.00
5	6	1	0.00	7.31	1.40	1.40	0.25
6	7	2	0.00	14.32	2.58	2.58	0.00
7	8	2	0.00	14.60	2.23	2.23	0.00
8	9	2	0.00	11.47	1.64	1.64	0.25
9	10	2	0.00	17.66	1.57	1.57	0.25
10	11	2	0.00	7.56	0.73	0.73	0.00
11	12	2	0.00	7.28	0.83	0.83	0.50
12	13	2	0.00	12.61	1.77	1.77	0.24
13	14	2	0.00	9.05	1.65	1.40	0.00
14	15	2	0.00	13.79	1.48	1.48	0.00
15	16	2	0.00	18.12	3.16	3.16	0.00
16	17	3	0.25	13.88	3.28	3.28	0.25
17	18	3	0.25	17.28	4.26	4.26	0.00
18	19	3	0.24	19.06	3.27	3.27	0.00
19	20	3	0.00	12.37	2.29	2.29	0.49

Depth (cm)		Zone	C.placentula	L.bodanica	P.comensis	C.distinguenda	L.fottii
0	1	1	0.00	0.00	0.00	0.00	0.00
1	2	1	0.00	0.00	0.00	0.00	0.00
2	3	1	0.25	0.00	0.00	0.00	0.00
3	4	1	0.00	0.02	0.02	0.02	0.02
4	5	1	0.00	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.00	0.00
6	7	2	0.00	0.23	0.00	0.00	0.00
7	8	2	0.00	0.00	0.00	0.00	0.00
8	9	2	0.00	0.02	0.02	0.02	0.02
9	10	2	0.00	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00	0.00
12	13	2	0.00	0.24	0.00	0.00	0.00
13	14	2	0.00	0.02	0.02	0.02	0.02
14	15	2	0.00	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.00	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00	0.00
18	19	3	0.24	0.24	0.00	0.00	0.00
19	20	3	0.00	0.49	0.00	0.00	0.00

Depth (cm)		Zone	C.iris	L.michiganiana	C.planctonica	C.praetermissa
0	1	1	0.00	0.00	0.00	0.00
1	2	1	0.00	0.00	0.00	0.00
2	3	1	0.00	0.00	0.00	0.00
3	4	1	0.02	0.02	0.02	0.02
4	5	1	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.00
6	7	2	0.00	0.23	0.00	0.00
7	8	2	0.00	0.00	0.00	0.00
8	9	2	0.02	0.02	0.02	0.02
9	10	2	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00
12	13	2	0.00	0.00	0.00	0.00
13	14	2	0.02	0.02	0.02	0.02
14	15	2	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00
18	19	3	0.00	0.00	0.00	0.00
19	20	3	0.00	0.00	0.00	0.00

Depth (cm)		Zone	D.pseudostelligera	D.rossii	C.affinis	E.cesatii	C.delicatala
0	1	1	0.00	0.00	0.00	0.00	0.00
1	2	1	0.00	0.00	0.00	0.00	0.00
2	3	1	0.25	0.00	0.00	0.00	0.00
3	4	1	0.02	0.02	0.00	0.00	0.00
4	5	1	0.00	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.00	0.00
6	7	2	0.00	0.00	0.06	0.06	0.06
7	8	2	0.00	0.00	0.00	0.00	0.00
8	9	2	0.02	0.02	0.00	0.00	0.00
9	10	2	0.00	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00	0.00
12	13	2	0.00	0.00	0.00	0.00	0.00
13	14	2	0.02	0.02	0.00	0.00	0.00
14	15	2	0.00	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.00	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00	0.00
18	19	3	0.24	0.00	0.00	0.00	0.24
19	20	3	0.25	0.00	0.00	0.00	0.00

Depth (cm)		Zone	E.herbridicum	E.latens	E.mesianum	E.minutum	E.silesiacum
0	1	1	0.00	0.00	0.00	0.73	0.00
1	2	1	0.00	0.00	0.00	0.25	0.00
2	3	1	0.00	0.00	0.00	0.74	0.00
3	4	1	0.00	0.00	0.00	0.74	0.00
4	5	1	0.00	0.00	0.00	0.25	0.00
5	6	1	0.00	0.00	0.00	0.25	0.00
6	7	2	0.06	0.06	0.06	0.29	0.06
7	8	2	0.00	0.00	0.50	0.74	0.00
8	9	2	0.00	0.00	0.00	0.25	0.00
9	10	2	0.00	0.00	0.00	0.25	0.00
10	11	2	0.00	0.00	0.24	0.00	0.00
11	12	2	0.00	0.00	0.25	0.50	0.00
12	13	2	0.24	0.00	0.48	0.48	0.00
13	14	2	0.00	0.00	0.00	0.00	0.00
14	15	2	0.00	0.00	0.25	0.25	0.00
15	16	2	0.00	0.00	0.00	0.25	0.00
16	17	3	0.00	0.00	0.00	1.23	0.00
17	18	3	0.00	0.00	0.00	0.98	0.00
18	19	3	0.00	0.00	0.00	0.72	0.00
19	20	3	0.00	0.00	0.00	0.25	0.00

Depth (cm)		Zone	E.bilunaris	E.circumborealis	E.diodon	E.incisa	E.glacialis
0	1	1	0.00	0.00	0.00	0.00	0.00
1	2	1	0.00	0.00	0.00	0.00	0.00
2	3	1	0.00	0.00	0.00	0.00	0.00
3	4	1	0.00	0.00	0.00	0.00	0.00
4	5	1	0.00	0.00	0.00	0.00	0.00
5	6	1	0.25	0.00	0.00	0.00	0.00
6	7	2	0.00	0.00	0.00	0.00	0.00
7	8	2	0.00	0.00	0.00	0.00	0.00
8	9	2	0.00	0.00	0.00	0.00	0.00
9	10	2	0.00	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00	0.00
12	13	2	0.00	0.00	0.00	0.00	0.00
13	14	2	0.00	0.00	0.00	0.00	0.00
14	15	2	0.00	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.25	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00	0.00
18	19	3	0.00	0.00	0.00	0.00	0.00
19	20	3	0.04	0.04	0.04	0.04	0.04

Depth (cm)		Zone	E.minor	E.praerupta	E.argus	P.brevistriata	F.capucina
0	1	1	0.00	0.00	0.00	14.18	0.00
1	2	1	0.00	0.00	0.00	11.60	0.57
2	3	1	0.00	0.00	0.00	12.45	1.64
3	4	1	0.00	0.00	0.00	14.71	0.00
4	5	1	0.00	0.00	0.00	9.38	0.49
5	6	1	0.00	0.00	0.00	15.76	0.00
6	7	2	0.00	0.00	0.00	18.31	0.70
7	8	2	0.00	0.00	0.00	21.53	0.00
8	9	2	0.00	0.00	1.23	12.53	0.25
9	10	2	0.00	0.00	0.25	19.47	0.66
10	11	2	0.00	0.00	0.00	15.37	0.00
11	12	2	0.00	0.00	0.25	16.63	0.00
12	13	2	0.00	0.00	0.24	13.73	0.00
13	14	2	0.00	0.00	0.00	9.63	0.00
14	15	2	0.00	0.00	0.00	14.04	0.25
15	16	2	0.00	0.00	0.00	11.72	0.25
16	17	3	0.00	0.00	0.00	12.07	0.00
17	18	3	0.00	0.00	0.25	15.23	0.00
18	19	3	0.00	0.00	0.24	9.09	0.00
19	20	3	0.04	0.04	0.49	10.81	0.00

Depth (cm)		Zone	S.construens	F.crotonensis	S.lapponica	S.leptostauron	S.pinnata
0	1	1	18.09	0.00	0.24	0.00	46.45
1	2	1	21.41	0.33	0.33	1.80	43.46
2	3	1	14.66	0.16	0.41	0.16	41.93
3	4	1	12.50	0.00	0.49	0.00	38.48
4	5	1	16.54	0.00	0.00	0.74	32.35
5	6	1	16.26	0.00	0.25	0.00	29.80
6	7	2	17.37	0.00	0.23	0.00	20.19
7	8	2	24.26	0.00	0.00	0.00	17.08
8	9	2	44.23	0.00	0.00	0.00	9.83
9	10	2	32.59	0.66	0.66	0.66	8.09
10	11	2	39.76	0.00	0.24	0.00	13.41
11	12	2	33.75	0.00	0.00	0.25	15.38
12	13	2	26.75	0.00	0.00	0.48	20.24
13	14	2	37.53	0.00	0.25	0.00	17.28
14	15	2	35.71	0.00	0.00	0.25	18.97
15	16	2	28.43	0.00	0.00	0.25	12.97
16	17	3	18.97	0.00	0.00	0.00	18.47
17	18	3	19.41	0.00	0.00	0.00	11.30
18	19	3	17.70	0.00	0.00	0.00	16.03
19	20	3	11.79	0.00	0.00	0.98	17.69

Depth (cm)		Zone	P.parasitica	F.zeilleri	G.acuminatum	N.cari	C.cuspidata
0	1	1	2.69	0.24	0.00	0.01	0.01
1	2	1	2.29	0.57	0.00	0.00	0.00
2	3	1	3.60	1.15	0.00	0.00	0.00
3	4	1	3.68	2.45	0.00	0.00	0.00
4	5	1	3.95	1.23	0.00	0.00	0.00
5	6	1	2.46	1.72	0.00	0.00	0.00
6	7	2	3.52	0.70	0.00	0.03	0.03
7	8	2	3.96	0.00	0.00	0.00	0.00
8	9	2	2.95	0.00	0.00	0.00	0.00
9	10	2	3.14	0.91	0.00	0.00	0.00
10	11	2	4.39	0.49	0.24	0.00	0.00
11	12	2	3.47	0.00	0.00	0.00	0.00
12	13	2	2.17	0.00	0.00	0.01	0.01
13	14	2	5.19	0.49	0.00	0.01	0.01
14	15	2	2.71	0.25	0.00	0.00	0.00
15	16	2	7.48	0.50	0.00	0.00	0.00
16	17	3	3.20	0.00	0.00	0.00	0.00
17	18	3	2.46	0.00	0.00	0.00	0.00
18	19	3	2.15	0.24	0.00	0.01	0.01
19	20	3	2.70	0.00	0.00	0.00	0.00

Depth (cm)		Zone	P.crucicula	N.cryptocephala	N.dealpina	N.digitoradiata	P.gastrum
0	1	1	0.01	0.01	0.26	0.01	0.01
1	2	1	0.00	0.00	0.00	0.00	0.00
2	3	1	0.00	0.00	0.00	0.00	0.00
3	4	1	0.00	0.00	0.25	0.00	0.00
4	5	1	0.00	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.00	0.00
6	7	2	0.03	0.03	0.50	0.03	0.03
7	8	2	0.00	0.00	0.00	0.00	0.00
8	9	2	0.00	0.00	0.00	0.00	0.00
9	10	2	0.00	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00	0.00
12	13	2	0.01	0.01	0.01	0.01	0.01
13	14	2	0.01	0.01	0.01	0.01	0.01
14	15	2	0.00	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00	0.00
16	17	3	0.00	0.25	0.25	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00	0.00
18	19	3	0.01	0.01	0.01	0.01	0.01
19	20	3	0.00	0.25	0.25	0.25	0.00

Depth (cm)		Zone	L.goeppertiana	N.gottlandica	S.laevissima	S.pupula	N.oblonga
0	1	1	0.01	0.01	0.01	4.41	0.01
1	2	1	0.00	0.00	0.00	2.70	0.00
2	3	1	0.00	0.00	0.00	3.19	0.00
3	4	1	0.00	0.00	0.25	5.64	0.00
4	5	1	0.00	0.00	0.00	6.17	0.00
5	6	1	0.00	0.00	0.00	7.14	0.00
6	7	2	0.03	0.03	0.03	8.48	0.03
7	8	2	0.00	0.00	0.00	6.68	0.00
8	9	2	0.00	0.00	0.00	5.65	0.00
9	10	2	0.00	0.00	0.00	3.71	0.00
10	11	2	0.00	0.00	0.00	8.29	0.00
11	12	2	0.00	0.00	0.00	8.68	0.00
12	13	2	0.01	0.01	0.01	6.28	0.01
13	14	2	0.01	0.01	0.01	7.17	0.01
14	15	2	0.00	0.00	0.00	6.16	0.00
15	16	2	0.00	0.00	0.00	5.99	0.00
16	17	3	0.00	0.00	0.00	8.87	0.00
17	18	3	0.00	0.00	0.00	13.02	0.00
18	19	3	0.01	0.01	0.01	12.69	0.01
19	20	3	0.00	0.00	0.00	17.69	0.00

Depth (cm)		Zone	N.oppugnata	N.radiosa	N.rhynchocephala	C.pseudoscutiformis
0	1	1	0.01	0.01	0.01	0.01
1	2	1	0.00	0.00	0.25	0.00
2	3	1	0.00	0.00	0.00	0.00
3	4	1	0.00	0.00	0.00	0.00
4	5	1	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.00
6	7	2	0.03	0.03	0.03	0.03
7	8	2	0.00	0.00	0.00	0.00
8	9	2	0.00	0.00	0.00	0.00
9	10	2	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00
12	13	2	0.01	0.01	0.01	0.01
13	14	2	0.01	0.01	0.01	0.01
14	15	2	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00
18	19	3	0.01	0.01	0.01	0.01
19	20	3	0.00	0.00	0.00	0.00

Depth (cm)		Zone	C.scutelloides	N.subrhynchocephala	N.trivialis	A.tuscula
0	1	1	0.01	0.01	0.01	0.01
1	2	1	0.00	0.00	0.00	0.00
2	3	1	0.00	0.00	0.00	0.00
3	4	1	0.00	0.00	0.00	0.00
4	5	1	0.49	0.00	0.00	0.00
5	6	1	0.74	0.00	0.00	0.00
6	7	2	0.74	0.03	0.03	0.03
7	8	2	0.00	0.00	0.00	0.00
8	9	2	0.49	0.00	0.00	0.00
9	10	2	0.25	0.00	0.00	0.00
10	11	2	0.24	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00
12	13	2	0.01	0.01	0.01	0.01
13	14	2	0.01	0.01	0.01	0.26
14	15	2	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.00	0.00
17	18	3	0.00	0.00	0.00	0.00
18	19	3	0.01	0.25	0.01	0.01
19	20	3	0.00	0.00	0.00	0.00

Depth (cm)		Zone	N.vulpina	N.bisulcatum	N.iridis	N.alpina	T.angustata
0	1	1	0.01	0.00	0.00	0.00	0.00
1	2	1	0.00	0.00	0.00	0.00	0.00
2	3	1	0.00	0.00	0.00	0.00	0.00
3	4	1	0.00	0.00	0.00	0.00	0.00
4	5	1	0.00	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.25	0.00
6	7	2	0.03	0.00	0.00	0.00	0.00
7	8	2	0.00	0.25	0.25	0.00	0.00
8	9	2	0.00	0.00	0.00	0.00	0.25
9	10	2	0.00	0.00	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00	0.00
12	13	2	0.01	0.00	0.00	0.72	0.00
13	14	2	0.01	0.00	0.00	0.06	0.06
14	15	2	0.00	0.00	0.00	0.25	0.00
15	16	2	0.00	0.00	0.00	0.00	0.00
16	17	3	0.00	0.00	0.00	0.00	0.00
17	18	3	0.25	0.00	0.00	0.25	0.00
18	19	3	0.25	0.00	0.00	0.96	0.00
19	20	3	0.00	0.25	0.00	0.55	0.06

Depth (cm)		Zone	P.borealis	P.karelica	P.maior	P.nodosa	P.rupestris
0	1	1	0.00	0.00	0.00	0.00	0.00
1	2	1	0.00	0.00	0.00	0.00	0.00
2	3	1	0.00	0.00	0.00	0.00	0.00
3	4	1	0.00	0.00	0.00	0.00	0.00
4	5	1	0.25	0.00	0.00	0.00	0.00
5	6	1	0.00	0.00	0.00	0.00	0.00
6	7	2	0.04	0.04	0.04	0.04	0.04
7	8	2	0.00	0.00	0.00	0.00	0.00
8	9	2	0.00	0.00	0.25	0.00	0.00
9	10	2	0.00	0.25	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00	0.00	0.00
11	12	2	0.00	0.00	0.00	0.00	0.25
12	13	2	0.00	0.00	0.00	0.00	0.00
13	14	2	0.00	0.00	0.00	0.00	0.00
14	15	2	0.00	0.00	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00	0.00	0.00
16	17	3	0.04	0.04	0.29	0.04	0.04
17	18	3	0.04	0.04	0.04	0.04	0.04
18	19	3	0.00	0.00	0.00	0.00	0.00
19	20	3	0.00	0.25	0.00	0.00	0.00

Depth (cm)		Zone	P.stomatophora	R.gibberula	T.flocculosa
0	1	1	0.00	0.00	0.00
1	2	1	0.00	0.00	0.49
2	3	1	0.00	0.00	0.00
3	4	1	0.00	0.00	0.00
4	5	1	0.00	0.00	0.25
5	6	1	0.00	0.00	0.49
6	7	2	0.04	0.00	0.23
7	8	2	0.00	0.50	0.00
8	9	2	0.00	0.49	0.00
9	10	2	0.00	0.00	0.00
10	11	2	0.00	0.00	0.00
11	12	2	0.00	0.50	0.00
12	13	2	0.00	0.00	0.00
13	14	2	0.00	0.00	0.00
14	15	2	0.00	0.00	0.00
15	16	2	0.00	0.00	0.00
16	17	3	0.04	0.00	0.00
17	18	3	0.04	0.00	0.00
18	19	3	0.00	0.00	0.00
19	20	3	0.00	0.00	0.49

Table A-2 Relative abundances of diatom species from Deepest Pickerel Bay core

Depth (cm)		Zone	K.clevei	P.curtissimum	P.distinctum	A.exiguum	E.flexella
0.0	1.0	1	1.42	2.61	0.00	0.47	0.00
1.0	1.5	1	1.66	2.84	0.95	1.42	0.00
2.0	2.5	1	1.42	1.18	0.00	0.24	0.00
3.0	3.5	1	1.66	3.08	0.24	1.42	0.00
4.0	4.5	1	2.37	3.32	0.00	1.42	0.00
5.0	5.5	1	3.08	1.90	0.24	0.95	0.00
6.0	6.5	2	0.95	3.79	0.00	1.18	0.00
7.0	7.5	2	0.47	2.61	0.00	1.42	0.71
8.0	8.5	2	1.18	2.84	0.00	1.66	0.00
9.0	9.5	2	0.95	0.71	0.00	0.47	0.00
10.0	10.5	2	1.42	3.79	0.00	2.13	0.00
11.0	11.5	2	0.47	2.37	0.00	0.95	0.24
12.0	12.5	2	1.18	2.37	0.00	1.18	0.00
13.0	13.5	2	0.47	1.66	0.24	0.24	0.00
14.0	14.5	2	0.71	2.84	0.00	0.71	0.00
15.0	15.5	2	0.71	4.27	0.00	0.71	0.00
16.0	16.5	2	0.00	1.66	0.71	1.66	0.00
17.0	17.5	2	1.42	2.13	0.00	1.18	0.00
18.0	18.5	2	1.90	1.18	0.47	1.18	0.95
19.0	19.5	2	1.18	1.66	0.00	0.24	0.24
20.0	20.5	2	0.95	2.61	0.00	1.66	0.47
21.0	21.5	2	1.90	1.90	0.00	1.90	0.24
22.0	22.5	3	0.24	2.37	0.00	0.95	0.00
23.0	23.5	3	0.95	1.66	0.00	0.71	0.00
24.0	24.5	3	0.95	1.66	0.00	0.00	0.00
25.0	25.5	3	1.18	0.71	0.00	0.24	0.00
26.0	26.5	3	0.95	1.90	0.00	0.00	0.00
27.0	27.5	3	1.42	1.42	0.00	0.00	0.24
28.0	28.5	3	1.42	0.95	0.00	1.18	0.00
29.0	29.5	3	1.66	2.37	0.00	1.18	0.71
30.0	30.5	3	0.95	1.42	0.95	0.71	0.24
31.0	31.5	3	2.13	3.55	0.24	0.24	0.00
32.0	32.5	3	1.18	1.66	0.00	0.95	0.00
33.0	33.5	3	2.61	0.00	0.24	0.47	0.24
34.0	34.5	3	0.00	0.47	0.00	1.18	0.00
34.5	35.0	3	0.71	3.32	0.00	0.47	0.00

Depth (cm)		Zone	A.minutissima	A.commutata	A.inariensis	A.libyca	A.ovalis
0.0	1.0	1	0.24	0.00	0.00	0.00	0.00
1.0	1.5	1	0.00	0.00	0.00	0.24	0.00
2.0	2.5	1	0.00	0.00	0.00	0.00	0.00
3.0	3.5	1	0.24	0.00	0.00	0.00	0.00
4.0	4.5	1	1.42	0.00	0.00	0.00	0.00
5.0	5.5	1	0.71	0.00	0.24	0.00	0.00
6.0	6.5	2	0.47	0.00	0.00	0.00	0.00
7.0	7.5	2	0.71	0.03	0.03	0.03	0.03
8.0	8.5	2	0.47	0.00	0.00	0.00	0.00
9.0	9.5	2	0.95	0.00	0.00	0.00	0.00
10.0	10.5	2	0.00	0.00	0.00	0.00	0.00
11.0	11.5	2	0.24	0.00	0.00	0.00	0.00
12.0	12.5	2	0.47	0.00	0.00	0.00	0.00
13.0	13.5	2	0.00	0.00	0.00	0.24	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	1.18	0.00	0.00	0.00	0.00
19.0	19.5	2	0.95	0.00	0.00	0.00	0.00
20.0	20.5	2	0.71	0.00	0.00	0.00	0.00
21.0	21.5	2	0.24	0.00	0.00	0.00	0.00
22.0	22.5	3	0.24	0.00	0.00	0.00	0.00
23.0	23.5	3	0.24	0.00	0.00	0.24	0.00
24.0	24.5	3	0.24	0.61	0.14	0.14	0.14
25.0	25.5	3	0.24	0.47	0.00	0.00	0.47
26.0	26.5	3	0.24	0.00	0.00	0.00	0.00
27.0	27.5	3	0.24	0.00	0.00	0.00	0.00
28.0	28.5	3	0.47	0.00	0.00	0.00	0.00
29.0	29.5	3	0.47	0.00	0.00	0.47	0.00
30.0	30.5	3	0.71	0.00	0.00	0.00	0.00
31.0	31.5	3	0.00	0.47	0.00	0.00	0.00
32.0	32.5	3	0.47	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.00
34.0	34.5	3	0.00	0.00	0.24	0.00	0.00
34.5	35.0	3	0.24	0.00	0.00	0.00	0.00

Depth (cm)		Zone	A.pediculus	H.thumensis	H.veneta	A.ambigua	A.islandica
0.0	1.0	1	0.95	0.00	0.47	36.33	3.40
1.0	1.5	1	1.90	0.00	0.71	26.22	3.48
2.0	2.5	1	1.18	0.24	1.18	35.62	3.16
3.0	3.5	1	1.42	0.00	0.00	35.15	1.97
4.0	4.5	1	0.71	0.00	0.00	22.27	2.13
5.0	5.5	1	0.95	0.00	0.95	30.25	3.00
6.0	6.5	2	0.00	0.00	0.71	18.33	1.74
7.0	7.5	2	1.22	0.03	0.51	16.59	2.37
8.0	8.5	2	0.71	0.00	1.18	22.20	1.82
9.0	9.5	2	0.71	0.00	0.24	15.09	2.29
10.0	10.5	2	0.95	0.00	0.47	15.17	2.84
11.0	11.5	2	1.42	0.00	0.24	10.27	1.74
12.0	12.5	2	0.71	0.00	0.00	11.93	1.26
13.0	13.5	2	1.66	0.24	0.00	11.22	1.50
14.0	14.5	2	2.61	0.00	1.66	8.06	3.32
15.0	15.5	2	0.24	0.00	0.47	7.50	0.39
16.0	16.5	2	0.24	0.00	0.00	8.85	1.74
17.0	17.5	2	4.50	0.71	1.18	12.64	1.97
18.0	18.5	2	0.71	0.00	0.00	16.19	3.63
19.0	19.5	2	0.47	0.00	0.71	14.22	2.13
20.0	20.5	2	0.00	0.00	0.47	12.56	1.18
21.0	21.5	2	2.61	0.24	0.47	18.72	1.90
22.0	22.5	3	0.47	0.00	0.24	34.91	1.97
23.0	23.5	3	1.18	0.00	0.47	32.62	1.82
24.0	24.5	3	2.03	0.14	0.14	37.52	1.97
25.0	25.5	3	0.71	0.00	0.71	35.15	2.92
26.0	26.5	3	1.18	0.00	0.47	39.97	2.53
27.0	27.5	3	0.95	0.00	0.00	43.92	1.74
28.0	28.5	3	0.47	0.00	0.00	36.81	2.92
29.0	29.5	3	1.18	0.00	0.00	46.76	2.21
30.0	30.5	3	0.95	0.00	0.47	32.07	1.74
31.0	31.5	3	0.47	0.00	1.18	33.81	2.29
32.0	32.5	3	1.42	0.24	1.18	39.18	2.21
33.0	33.5	3	0.47	0.00	0.71	42.34	2.53
34.0	34.5	3	0.71	0.00	0.24	45.97	1.42
34.5	35.0	3	0.95	0.00	0.47	43.29	2.29

Depth (cm)		Zone	A.subartica	C.schumanniana	C.disculus	C.neodiminuta	C.placentula
0.0	1.0	1	2.92	0.00	0.24	0.00	0.00
1.0	1.5	1	1.58	0.00	0.00	0.00	0.00
2.0	2.5	1	2.45	0.00	0.00	0.00	0.00
3.0	3.5	1	1.97	0.00	0.24	0.00	0.00
4.0	4.5	1	2.13	0.00	0.00	0.00	0.00
5.0	5.5	1	2.53	0.00	0.24	0.00	0.00
6.0	6.5	2	1.50	0.00	0.00	0.00	0.00
7.0	7.5	2	2.13	0.00	0.00	0.00	0.00
8.0	8.5	2	1.82	0.00	0.00	0.00	0.00
9.0	9.5	2	2.29	0.00	0.00	0.00	0.00
10.0	10.5	2	1.90	0.00	0.00	0.00	0.00
11.0	11.5	2	0.79	0.24	0.00	0.00	0.00
12.0	12.5	2	0.79	0.00	0.00	0.00	0.00
13.0	13.5	2	1.03	0.00	0.71	0.00	0.00
14.0	14.5	2	0.95	0.00	0.24	0.00	0.00
15.0	15.5	2	0.39	0.00	0.00	0.00	0.00
16.0	16.5	2	1.74	0.00	0.00	0.00	0.00
17.0	17.5	2	0.79	0.00	0.00	0.00	0.00
18.0	18.5	2	1.74	0.00	0.00	0.00	0.00
19.0	19.5	2	1.18	0.00	0.00	0.00	0.00
20.0	20.5	2	1.18	0.00	0.00	0.00	0.00
21.0	21.5	2	1.18	0.00	0.00	0.00	0.00
22.0	22.5	3	1.97	0.00	0.00	0.00	0.00
23.0	23.5	3	1.82	0.00	0.08	0.08	0.08
24.0	24.5	3	1.97	0.00	0.00	0.00	0.00
25.0	25.5	3	2.92	0.00	0.00	0.00	0.00
26.0	26.5	3	2.53	0.00	0.00	0.00	0.24
27.0	27.5	3	1.50	0.00	0.00	0.00	0.00
28.0	28.5	3	2.92	0.00	0.00	0.00	0.00
29.0	29.5	3	2.21	0.00	0.00	0.00	0.00
30.0	30.5	3	1.26	0.00	0.47	0.00	0.00
31.0	31.5	3	2.29	0.00	0.47	0.00	0.00
32.0	32.5	3	2.21	0.00	0.00	0.00	0.00
33.0	33.5	3	1.82	0.00	0.00	0.00	0.00
34.0	34.5	3	1.42	0.00	0.24	0.00	0.00
34.5	35.0	3	2.29	0.00	0.00	0.00	0.00

Depth (cm)		Zone	L.bodanica	P.comensis	C.distinguenda	L.fottii	C.iris
0.0	1.0	1	0.00	0.00	0.00	0.00	0.00
1.0	1.5	1	0.00	0.00	0.00	0.00	0.00
2.0	2.5	1	0.00	0.00	0.00	0.00	0.00
3.0	3.5	1	0.00	0.00	0.00	0.00	0.00
4.0	4.5	1	0.00	0.00	0.00	0.00	0.00
5.0	5.5	1	0.00	0.00	0.00	0.00	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00	0.00
7.0	7.5	2	0.02	0.02	0.26	0.02	0.02
8.0	8.5	2	0.24	0.00	0.00	0.00	0.00
9.0	9.5	2	0.00	0.00	0.00	0.00	0.24
10.0	10.5	2	0.00	0.00	0.00	0.00	0.00
11.0	11.5	2	0.00	0.00	0.00	0.24	0.00
12.0	12.5	2	0.00	0.00	0.00	0.00	0.00
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.00	0.00	0.00	0.00
19.0	19.5	2	0.02	0.02	0.02	0.02	0.02
20.0	20.5	2	0.00	0.00	0.00	0.00	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.00
22.0	22.5	3	0.47	0.00	0.00	0.00	0.00
23.0	23.5	3	0.24	0.00	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.00	0.00
25.0	25.5	3	0.00	0.00	0.00	0.00	0.00
26.0	26.5	3	0.02	0.02	0.02	0.02	0.02
27.0	27.5	3	0.00	0.00	0.00	0.00	0.00
28.0	28.5	3	0.00	0.00	0.00	0.00	0.00
29.0	29.5	3	0.02	0.02	0.02	0.02	0.02
30.0	30.5	3	0.00	0.00	0.00	0.00	0.00
31.0	31.5	3	0.05	0.05	0.05	0.05	0.05
32.0	32.5	3	0.00	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.00
34.0	34.5	3	0.00	0.24	0.00	0.00	0.00
34.5	35.0	3	0.02	0.02	0.02	0.02	0.02

Depth (cm)		Zone	L.michiganiana	C.planctonica	C.praetermissa	D.pseudostelligera
0.0	1.0	1	0.00	0.00	0.00	0.00
1.0	1.5	1	0.00	0.00	0.00	0.71
2.0	2.5	1	0.00	0.00	0.00	0.47
3.0	3.5	1	0.00	0.00	0.00	0.24
4.0	4.5	1	0.00	0.00	0.00	0.00
5.0	5.5	1	0.00	0.24	0.00	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00
7.0	7.5	2	0.02	0.02	0.02	0.02
8.0	8.5	2	0.00	0.00	0.00	0.24
9.0	9.5	2	0.00	0.00	0.00	0.00
10.0	10.5	2	0.24	0.00	0.00	0.47
11.0	11.5	2	0.00	0.00	0.00	0.00
12.0	12.5	2	0.00	0.00	0.00	0.24
13.0	13.5	2	0.00	0.00	0.00	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.00	0.00	0.00
19.0	19.5	2	0.02	0.02	0.02	0.26
20.0	20.5	2	0.00	0.00	0.00	0.24
21.0	21.5	2	0.00	0.00	0.00	0.00
22.0	22.5	3	0.00	0.00	0.00	0.24
23.0	23.5	3	0.24	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.24
25.0	25.5	3	0.00	0.47	0.00	0.00
26.0	26.5	3	0.02	0.02	0.02	0.02
27.0	27.5	3	0.00	0.00	0.00	0.00
28.0	28.5	3	0.00	0.00	0.00	0.71
29.0	29.5	3	0.02	0.02	0.02	0.26
30.0	30.5	3	0.00	0.00	0.00	0.00
31.0	31.5	3	0.05	0.05	0.05	0.05
32.0	32.5	3	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	1.18	0.00	0.00
34.0	34.5	3	0.00	0.00	0.00	0.00
34.5	35.0	3	0.02	0.02	0.02	0.02

Depth (cm)		Zone	D.rossii	C.solea	C.affinis	E.cesatii	C.delicatala
0.0	1.0	1	0.00	0.00	0.04	0.04	0.04
1.0	1.5	1	0.00	0.00	0.00	0.00	0.00
2.0	2.5	1	0.00	0.00	0.00	0.00	0.24
3.0	3.5	1	0.00	0.24	0.24	0.00	0.00
4.0	4.5	1	0.00	0.00	0.00	0.00	0.00
5.0	5.5	1	0.00	0.00	0.00	0.00	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00	0.00
7.0	7.5	2	0.02	0.00	0.00	0.00	0.00
8.0	8.5	2	0.00	0.00	0.00	0.00	0.00
9.0	9.5	2	0.00	0.00	0.00	0.00	0.00
10.0	10.5	2	0.00	0.00	0.00	0.00	0.00
11.0	11.5	2	0.00	0.00	0.00	0.00	0.00
12.0	12.5	2	0.00	0.00	0.00	0.00	0.00
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.24	0.00	0.00	0.00	0.00
19.0	19.5	2	0.02	0.00	0.00	0.00	0.00
20.0	20.5	2	0.00	0.00	0.00	0.00	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.00
22.0	22.5	3	0.00	0.00	0.00	0.00	0.00
23.0	23.5	3	0.00	0.00	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.00	0.00
25.0	25.5	3	0.00	0.00	0.00	0.00	0.00
26.0	26.5	3	0.02	0.00	0.00	0.00	0.00
27.0	27.5	3	0.00	0.00	0.00	0.00	0.00
28.0	28.5	3	0.00	0.00	0.00	0.00	0.00
29.0	29.5	3	0.02	0.00	0.00	0.00	0.00
30.0	30.5	3	0.00	0.00	0.00	0.00	0.00
31.0	31.5	3	0.05	0.00	0.24	0.47	0.00
32.0	32.5	3	0.00	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.00
34.0	34.5	3	0.47	0.00	0.00	0.00	0.00
34.5	35.0	3	0.02	0.00	0.00	0.00	0.00

Depth (cm)		Zone	E.latens	E.minutum	E.silesiacum	E.circumborealis	E.incisa
0.0	1.0	1	0.04	0.75	0.04	0.00	0.00
1.0	1.5	1	0.00	0.00	0.00	0.00	0.00
2.0	2.5	1	0.00	0.00	0.00	0.00	0.00
3.0	3.5	1	0.00	0.00	0.00	0.00	0.24
4.0	4.5	1	0.00	0.71	0.00	0.00	0.00
5.0	5.5	1	0.00	0.00	0.24	0.00	0.00
6.0	6.5	2	0.00	0.71	0.00	0.00	0.00
7.0	7.5	2	0.00	0.24	0.00	0.00	0.00
8.0	8.5	2	0.00	0.71	0.00	0.00	0.00
9.0	9.5	2	0.00	0.47	0.00	0.00	0.00
10.0	10.5	2	0.00	0.00	0.00	0.00	0.00
11.0	11.5	2	0.00	0.24	0.00	0.00	0.00
12.0	12.5	2	0.00	0.00	0.00	0.00	0.00
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.24	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.00	0.00	0.00	0.00
19.0	19.5	2	0.00	0.00	0.00	0.00	0.00
20.0	20.5	2	0.00	0.47	0.00	0.00	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.00
22.0	22.5	3	0.00	0.24	0.00	0.00	0.00
23.0	23.5	3	0.00	0.71	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.00	0.00
25.0	25.5	3	0.00	0.71	0.00	0.00	0.00
26.0	26.5	3	0.00	0.24	0.00	0.00	0.00
27.0	27.5	3	0.00	0.24	0.00	0.00	0.00
28.0	28.5	3	0.00	0.24	0.00	0.00	0.00
29.0	29.5	3	0.00	0.00	0.00	0.00	0.00
30.0	30.5	3	0.00	0.00	0.00	0.00	0.00
31.0	31.5	3	0.00	0.00	0.00	0.00	0.00
32.0	32.5	3	0.00	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.00
34.0	34.5	3	0.00	0.00	0.00	0.24	0.00
34.5	35.0	3	0.00	0.95	0.00	0.00	0.00

Depth (cm)		Zone	E.glacialis	E.minor	E.praerupta	E.argus	E.cistula
0.0	1.0	1	0.00	0.00	0.24	0.71	0.00
1.0	1.5	1	0.00	0.00	0.00	0.47	0.24
2.0	2.5	1	0.00	0.00	0.00	0.47	0.00
3.0	3.5	1	0.00	0.00	0.00	1.42	0.00
4.0	4.5	1	0.00	0.00	0.00	0.71	0.00
5.0	5.5	1	0.00	0.00	0.00	0.24	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00	0.00
7.0	7.5	2	0.00	0.00	0.00	0.00	0.00
8.0	8.5	2	0.00	0.00	0.00	0.00	0.00
9.0	9.5	2	0.24	0.00	0.00	0.24	0.00
10.0	10.5	2	0.00	0.00	0.00	0.47	0.00
11.0	11.5	2	0.00	0.00	0.00	0.00	0.00
12.0	12.5	2	0.00	0.00	0.00	0.24	0.00
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.24	0.00
18.0	18.5	2	0.00	0.00	0.00	0.24	0.00
19.0	19.5	2	0.00	0.00	0.00	0.24	0.00
20.0	20.5	2	0.00	0.00	0.00	0.24	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.00
22.0	22.5	3	0.00	0.00	0.00	0.24	0.00
23.0	23.5	3	0.00	0.00	0.00	1.42	0.00
24.0	24.5	3	0.00	0.00	0.00	0.24	0.00
25.0	25.5	3	0.00	0.00	0.00	0.24	0.00
26.0	26.5	3	0.00	0.00	0.00	0.47	0.00
27.0	27.5	3	0.00	0.00	0.00	0.47	0.00
28.0	28.5	3	0.00	0.47	0.00	0.47	0.00
29.0	29.5	3	0.00	0.00	0.00	0.24	0.00
30.0	30.5	3	0.00	0.00	0.00	0.24	0.00
31.0	31.5	3	0.00	0.00	0.00	0.95	0.24
32.0	32.5	3	0.00	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.47	0.00
34.0	34.5	3	0.00	0.00	0.00	1.18	0.00
34.5	35.0	3	0.00	0.00	0.24	1.66	0.00

Depth (cm)		Zone	P.brevistriata	F.capucina	S.construens	F.crotonensis	S.lapponica
0.0	1.0	1	10.90	0.00	10.66	0.95	0.00
1.0	1.5	1	15.17	0.00	8.29	0.00	0.00
2.0	2.5	1	16.35	0.00	12.32	0.00	0.00
3.0	3.5	1	6.64	0.24	19.19	0.00	0.47
4.0	4.5	1	8.16	0.00	19.06	0.11	0.34
5.0	5.5	1	16.11	0.00	15.64	0.00	0.00
6.0	6.5	2	13.74	0.00	15.88	1.90	0.24
7.0	7.5	2	20.14	0.00	12.09	1.90	0.00
8.0	8.5	2	12.11	0.00	9.27	1.21	0.26
9.0	9.5	2	22.64	0.00	16.01	1.32	0.37
10.0	10.5	2	15.40	0.00	14.93	1.90	0.00
11.0	11.5	2	15.88	0.00	14.45	0.47	0.24
12.0	12.5	2	18.48	0.00	13.98	2.37	0.00
13.0	13.5	2	16.35	0.24	13.98	0.95	0.00
14.0	14.5	2	13.51	0.00	10.66	0.00	0.71
15.0	15.5	2	17.11	0.00	15.22	0.05	0.05
16.0	16.5	2	15.88	0.24	10.66	1.18	0.00
17.0	17.5	2	10.43	0.71	25.36	1.90	0.00
18.0	18.5	2	8.77	0.00	20.38	0.00	0.24
19.0	19.5	2	25.36	0.00	19.67	0.00	0.00
20.0	20.5	2	20.80	0.00	18.43	0.42	0.42
21.0	21.5	2	15.40	0.24	18.25	0.47	0.00
22.0	22.5	3	11.90	0.00	12.61	1.47	0.05
23.0	23.5	3	6.71	0.00	14.06	0.55	0.55
24.0	24.5	3	14.56	0.00	17.40	0.11	0.11
25.0	25.5	3	8.53	0.47	17.54	0.00	0.00
26.0	26.5	3	18.96	0.00	20.14	0.00	0.00
27.0	27.5	3	6.29	0.00	21.22	0.13	0.13
28.0	28.5	3	16.03	0.95	14.85	0.16	0.16
29.0	29.5	3	5.61	0.00	13.19	0.16	0.16
30.0	30.5	3	11.66	0.47	13.32	0.76	0.29
31.0	31.5	3	10.69	0.47	16.14	0.03	1.21
32.0	32.5	3	9.00	0.00	21.56	0.00	0.00
33.0	33.5	3	14.69	0.00	7.58	0.00	0.00
34.0	34.5	3	5.45	0.47	8.06	0.00	0.00
34.5	35.0	3	7.08	0.00	19.40	0.21	0.21

Depth (cm)		Zone	S.leptostauron	S.pinnata	P.parasitica	F.zeilleri	G.acuminatum
0.0	1.0	1	0.24	15.64	1.66	0.24	0.00
1.0	1.5	1	0.00	22.99	2.84	0.00	0.00
2.0	2.5	1	0.00	10.90	1.66	0.00	0.00
3.0	3.5	1	0.00	13.74	0.95	0.00	0.00
4.0	4.5	1	0.11	20.72	0.82	0.11	0.00
5.0	5.5	1	0.24	14.69	1.18	0.47	0.00
6.0	6.5	2	0.00	28.44	2.84	0.47	0.00
7.0	7.5	2	0.00	26.78	1.90	0.24	0.00
8.0	8.5	2	0.26	28.23	2.40	0.50	0.00
9.0	9.5	2	1.08	25.01	2.03	0.37	0.00
10.0	10.5	2	0.47	31.28	2.84	0.00	0.00
11.0	11.5	2	0.00	35.07	2.61	0.24	0.00
12.0	12.5	2	0.00	32.70	0.24	0.24	0.00
13.0	13.5	2	0.24	33.89	1.18	0.00	0.00
14.0	14.5	2	0.47	44.31	1.66	0.47	0.00
15.0	15.5	2	0.05	38.92	4.08	0.53	0.00
16.0	16.5	2	0.00	43.84	1.90	0.00	0.00
17.0	17.5	2	0.24	36.73	1.18	0.95	0.00
18.0	18.5	2	0.00	33.89	1.66	0.71	0.00
19.0	19.5	2	0.00	21.80	1.18	0.71	0.00
20.0	20.5	2	0.42	27.20	0.42	0.42	0.00
21.0	21.5	2	0.00	29.62	0.71	0.71	0.00
22.0	22.5	3	0.05	16.64	3.61	0.53	0.00
23.0	23.5	3	0.55	19.75	3.40	1.03	0.00
24.0	24.5	3	0.34	14.09	2.71	0.11	0.00
25.0	25.5	3	0.00	15.88	2.13	0.47	0.24
26.0	26.5	3	0.00	7.58	0.95	0.24	0.00
27.0	27.5	3	0.13	9.61	1.08	0.13	0.00
28.0	28.5	3	0.16	10.11	0.16	0.39	0.00
29.0	29.5	3	0.16	8.69	0.63	0.39	0.00
30.0	30.5	3	0.29	14.51	2.19	0.76	0.00
31.0	31.5	3	0.03	15.67	1.21	0.03	0.00
32.0	32.5	3	0.00	9.48	1.90	0.00	0.00
33.0	33.5	3	0.00	14.69	1.66	0.00	0.00
34.0	34.5	3	0.00	20.85	1.90	0.00	0.00
34.5	35.0	3	0.21	9.45	3.05	0.21	0.00

Depth (cm)		Zone	N.cari	C.cuspidata	P.crucicula	N.cryptocephala	N.dealpina
0.0	1.0	1	0.01	0.01	0.01	0.01	0.01
1.0	1.5	1	0.00	0.00	0.00	0.00	0.00
2.0	2.5	1	0.01	0.01	0.01	0.01	0.25
3.0	3.5	1	0.00	0.00	0.00	0.00	0.00
4.0	4.5	1	0.00	0.00	0.24	0.00	0.00
5.0	5.5	1	0.00	0.00	0.00	0.00	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00	0.00
7.0	7.5	2	0.25	0.01	0.01	0.01	0.01
8.0	8.5	2	0.00	0.00	0.00	0.00	0.00
9.0	9.5	2	0.00	0.00	0.00	0.00	0.24
10.0	10.5	2	0.00	0.00	0.00	0.00	0.24
11.0	11.5	2	0.00	0.00	0.00	0.00	0.24
12.0	12.5	2	0.02	0.02	0.02	0.02	0.02
13.0	13.5	2	0.00	0.00	0.00	0.00	0.24
14.0	14.5	2	0.01	0.01	0.01	0.01	0.01
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.00	0.24	0.00	0.00
19.0	19.5	2	0.00	0.00	0.00	0.00	0.00
20.0	20.5	2	0.00	0.00	0.00	0.00	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.00
22.0	22.5	3	0.02	0.02	0.02	0.02	0.02
23.0	23.5	3	0.00	0.00	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.00	0.00
25.0	25.5	3	0.01	0.01	0.01	0.01	0.25
26.0	26.5	3	0.00	0.00	0.00	0.00	0.00
27.0	27.5	3	0.01	0.01	0.01	0.25	0.01
28.0	28.5	3	0.00	0.00	0.00	0.00	0.00
29.0	29.5	3	0.00	0.00	0.00	0.24	0.00
30.0	30.5	3	0.01	0.01	0.01	0.01	0.01
31.0	31.5	3	0.01	0.01	0.01	0.01	0.01
32.0	32.5	3	0.00	0.24	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.00
34.0	34.5	3	0.00	0.00	0.00	0.00	0.00
34.5	35.0	3	0.00	0.00	0.00	0.00	0.00

Depth (cm)		Zone	N.digitoradiata	P.gastrum	L.goeppertiana	N.gottlandica	S.laevissima
0.0	1.0	1	0.01	0.01	0.01	0.01	0.01
1.0	1.5	1	0.00	0.00	0.00	0.00	0.00
2.0	2.5	1	0.01	0.01	0.01	0.25	0.01
3.0	3.5	1	0.00	0.00	0.00	0.00	0.00
4.0	4.5	1	0.00	0.00	0.00	0.00	0.00
5.0	5.5	1	0.00	0.00	0.00	0.00	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00	0.00
7.0	7.5	2	0.01	0.01	0.01	0.25	0.01
8.0	8.5	2	0.00	0.00	0.00	0.00	0.00
9.0	9.5	2	0.00	0.00	0.00	0.00	0.00
10.0	10.5	2	0.00	0.00	0.00	0.00	0.00
11.0	11.5	2	0.00	0.00	0.00	0.00	0.00
12.0	12.5	2	0.02	0.02	0.02	0.02	0.02
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.01	0.01	0.01	0.01	0.01
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.00	0.00	0.00	0.00
19.0	19.5	2	0.00	0.00	0.00	0.00	0.00
20.0	20.5	2	0.00	0.00	0.00	0.00	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.24
22.0	22.5	3	0.02	0.02	0.02	0.02	0.02
23.0	23.5	3	0.00	0.00	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.00	0.00
25.0	25.5	3	0.01	0.01	0.01	0.01	0.01
26.0	26.5	3	0.00	0.24	0.00	0.00	0.00
27.0	27.5	3	0.01	0.01	0.01	0.01	0.01
28.0	28.5	3	0.00	0.00	0.00	0.00	0.00
29.0	29.5	3	0.00	0.00	0.00	0.00	0.00
30.0	30.5	3	0.01	0.01	0.01	0.01	0.01
31.0	31.5	3	0.01	0.01	0.01	0.01	0.01
32.0	32.5	3	0.00	0.00	0.00	0.00	0.00
33.0	33.5	3	0.24	0.00	0.00	0.00	0.00
34.0	34.5	3	0.00	0.00	0.00	0.00	0.00
34.5	35.0	3	0.00	0.00	0.00	0.00	0.00

Depth (cm)		Zone	S.pupula	N.oblonga	N.oppugnata	N.radiosa	N.rhynchocephala
0.0	1.0	1	5.94	0.01	0.01	0.01	0.01
1.0	1.5	1	8.77	0.00	0.00	0.00	0.00
2.0	2.5	1	9.73	0.01	0.01	0.25	0.01
3.0	3.5	1	5.92	0.00	0.00	0.00	0.00
4.0	4.5	1	8.29	0.00	0.00	0.00	0.00
5.0	5.5	1	3.55	0.00	0.00	0.00	0.00
6.0	6.5	2	4.50	0.00	0.00	0.00	0.00
7.0	7.5	2	1.91	0.01	0.01	0.01	0.01
8.0	8.5	2	3.55	0.00	0.00	0.00	0.00
9.0	9.5	2	1.66	0.00	0.00	0.00	0.00
10.0	10.5	2	4.98	0.00	0.00	0.00	0.00
11.0	11.5	2	3.32	0.00	0.00	0.00	0.00
12.0	12.5	2	2.39	0.02	0.02	0.02	0.02
13.0	13.5	2	2.84	0.00	0.00	0.00	0.00
14.0	14.5	2	6.88	0.01	0.01	0.01	0.49
15.0	15.5	2	2.37	0.00	0.00	0.00	0.00
16.0	16.5	2	6.40	0.24	0.47	0.00	0.00
17.0	17.5	2	3.32	0.00	0.00	0.00	0.00
18.0	18.5	2	2.84	0.00	0.00	0.00	0.00
19.0	19.5	2	3.08	0.00	0.00	0.00	0.00
20.0	20.5	2	2.37	0.00	0.00	0.00	0.00
21.0	21.5	2	1.66	0.00	0.00	0.00	0.00
22.0	22.5	3	5.00	0.02	0.02	0.02	0.02
23.0	23.5	3	3.55	0.00	0.00	0.00	0.00
24.0	24.5	3	1.90	0.00	0.00	0.00	0.00
25.0	25.5	3	4.04	0.01	0.01	0.01	0.01
26.0	26.5	3	1.66	0.00	0.00	0.00	0.00
27.0	27.5	3	2.38	0.01	0.01	0.01	0.01
28.0	28.5	3	2.84	0.00	0.00	0.00	0.00
29.0	29.5	3	5.21	0.00	0.00	0.00	0.00
30.0	30.5	3	8.31	0.01	0.01	0.01	0.01
31.0	31.5	3	3.80	0.01	0.01	0.01	0.01
32.0	32.5	3	4.03	0.00	0.00	0.00	0.00
33.0	33.5	3	4.98	0.00	0.00	0.00	0.00
34.0	34.5	3	6.40	0.00	0.00	0.24	0.00
34.5	35.0	3	4.50	0.00	0.00	0.00	0.00

Depth (cm)		Zone	C.pseudoscutiformis	C.scutelloides	N.trivialis	N.vulpina	N.bisulcatum
0.0	1.0	1	0.01	0.49	0.01	0.01	0.00
1.0	1.5	1	0.00	0.24	0.00	0.00	0.24
2.0	2.5	1	0.01	0.96	0.01	0.01	0.00
3.0	3.5	1	0.00	0.24	0.00	0.00	0.00
4.0	4.5	1	0.00	0.24	0.00	0.00	0.00
5.0	5.5	1	0.00	0.95	0.00	0.00	0.00
6.0	6.5	2	0.00	0.47	0.00	0.00	0.00
7.0	7.5	2	0.01	1.43	0.01	0.01	0.00
8.0	8.5	2	0.00	0.47	0.00	0.00	0.00
9.0	9.5	2	0.00	0.47	0.00	0.00	0.00
10.0	10.5	2	0.00	0.47	0.00	0.00	0.00
11.0	11.5	2	0.00	0.95	0.00	0.00	0.00
12.0	12.5	2	0.02	0.26	0.02	0.26	0.00
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.01	0.01	0.01	0.01	0.00
15.0	15.5	2	0.00	0.71	0.24	0.00	0.00
16.0	16.5	2	0.24	0.24	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.00	0.00	0.00	0.00
19.0	19.5	2	0.00	0.24	0.00	0.00	0.00
20.0	20.5	2	0.00	0.71	0.00	0.00	0.00
21.0	21.5	2	0.00	0.71	0.00	0.00	0.00
22.0	22.5	3	0.02	0.26	0.02	0.02	0.00
23.0	23.5	3	0.00	0.24	0.00	0.00	0.00
24.0	24.5	3	0.00	0.24	0.00	0.00	0.00
25.0	25.5	3	0.01	0.01	0.01	0.01	0.00
26.0	26.5	3	0.00	0.47	0.00	0.24	0.00
27.0	27.5	3	0.01	1.43	0.01	0.01	0.00
28.0	28.5	3	0.00	0.00	0.00	0.00	0.00
29.0	29.5	3	0.00	0.95	0.00	0.00	0.00
30.0	30.5	3	0.01	0.01	0.01	0.01	0.00
31.0	31.5	3	0.01	0.01	0.01	0.01	0.00
32.0	32.5	3	0.00	0.24	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.00
34.0	34.5	3	0.00	0.00	0.00	0.00	0.00
34.5	35.0	3	0.00	0.00	0.00	0.00	0.00

Depth (cm)		Zone	N.iridis	N.alpina	N.amphibioides	T.angustata	N.lanceolata
0.0	1.0	1	0.00	0.24	0.00	0.00	0.00
1.0	1.5	1	0.00	0.30	0.06	0.06	0.06
2.0	2.5	1	0.00	0.24	0.00	0.00	0.00
3.0	3.5	1	0.00	0.24	0.00	0.00	0.24
4.0	4.5	1	0.00	0.00	0.00	0.00	0.00
5.0	5.5	1	0.00	0.00	0.00	0.00	0.00
6.0	6.5	2	0.00	0.00	0.00	0.00	0.00
7.0	7.5	2	0.00	0.06	0.06	0.06	0.06
8.0	8.5	2	0.00	0.47	0.00	0.00	0.00
9.0	9.5	2	0.00	0.00	0.00	0.00	0.00
10.0	10.5	2	0.00	0.00	0.00	0.00	0.00
11.0	11.5	2	0.24	0.00	0.00	0.00	0.00
12.0	12.5	2	0.00	0.00	0.00	0.00	0.00
13.0	13.5	2	0.00	0.00	0.00	0.00	0.00
14.0	14.5	2	0.00	0.00	0.00	0.00	0.00
15.0	15.5	2	0.00	0.00	0.00	0.00	0.00
16.0	16.5	2	0.00	0.00	0.00	0.00	0.00
17.0	17.5	2	0.00	0.00	0.00	0.00	0.00
18.0	18.5	2	0.00	0.06	0.06	0.06	0.06
19.0	19.5	2	0.00	0.00	0.00	0.00	0.00
20.0	20.5	2	0.00	0.00	0.00	0.00	0.00
21.0	21.5	2	0.00	0.00	0.00	0.00	0.00
22.0	22.5	3	0.00	0.00	0.00	0.00	0.00
23.0	23.5	3	0.00	0.47	0.00	0.00	0.00
24.0	24.5	3	0.00	0.71	0.00	0.00	0.00
25.0	25.5	3	0.00	0.00	0.00	0.00	0.00
26.0	26.5	3	0.00	0.47	0.00	0.00	0.00
27.0	27.5	3	0.00	0.00	0.00	0.24	0.00
28.0	28.5	3	0.00	0.00	0.24	0.00	0.00
29.0	29.5	3	0.00	0.18	0.41	0.18	0.18
30.0	30.5	3	0.00	0.00	0.00	0.00	0.00
31.0	31.5	3	0.00	0.24	0.00	0.00	0.00
32.0	32.5	3	0.00	0.00	0.00	0.00	0.00
33.0	33.5	3	0.00	0.00	0.00	0.00	0.24
34.0	34.5	3	0.00	0.00	0.00	0.00	0.00
34.5	35.0	3	0.00	0.00	0.00	0.00	0.00

Depth (cm)		Zone	P.karelica	P.maior	P.nodosa	P.stomatophora	S.niagrae
0.0	1.0	1	0.00	0.00	0.00	0.00	0.24
1.0	1.5	1	0.00	0.00	0.00	0.00	0.47
2.0	2.5	1	0.00	0.00	0.00	0.00	0.24
3.0	3.5	1	0.00	0.00	0.00	0.24	0.47
4.0	4.5	1	0.00	0.00	0.00	0.00	0.24
5.0	5.5	1	0.24	0.00	0.00	0.00	0.47
6.0	6.5	2	0.00	0.00	0.00	0.00	1.18
7.0	7.5	2	0.00	0.00	0.00	0.00	0.24
8.0	8.5	2	0.24	0.00	0.00	0.00	0.47
9.0	9.5	2	0.24	0.00	0.00	0.00	0.71
10.0	10.5	2	0.00	0.00	0.00	0.00	0.47
11.0	11.5	2	0.00	0.47	0.00	0.00	0.47
12.0	12.5	2	0.00	0.00	0.00	0.00	1.18
13.0	13.5	2	0.06	0.06	0.06	0.30	1.42
14.0	14.5	2	0.00	0.00	0.00	0.00	0.47
15.0	15.5	2	0.00	0.00	0.00	0.00	0.71
16.0	16.5	2	0.00	0.00	0.00	0.00	0.47
17.0	17.5	2	0.00	0.00	0.24	0.00	0.95
18.0	18.5	2	0.00	0.00	0.00	0.00	0.24
19.0	19.5	2	0.00	0.00	0.00	0.00	0.95
20.0	20.5	2	0.00	0.00	0.00	0.00	0.24
21.0	21.5	2	0.00	0.00	0.00	0.00	0.95
22.0	22.5	3	0.00	0.00	0.00	0.00	0.00
23.0	23.5	3	0.24	0.00	0.00	0.00	0.00
24.0	24.5	3	0.00	0.00	0.00	0.00	0.24
25.0	25.5	3	0.00	0.00	0.00	0.00	0.24
26.0	26.5	3	0.00	0.00	0.00	0.00	0.24
27.0	27.5	3	0.00	0.00	0.00	0.00	0.00
28.0	28.5	3	0.00	0.00	0.00	0.00	0.00
29.0	29.5	3	0.00	0.00	0.00	0.00	0.00
30.0	30.5	3	0.00	0.00	0.00	0.00	0.71
31.0	31.5	3	0.00	0.00	0.00	0.00	0.71
32.0	32.5	3	0.00	0.00	0.00	0.00	0.24
33.0	33.5	3	0.00	0.00	0.00	0.00	0.47
34.0	34.5	3	0.00	0.00	0.00	0.00	0.47
34.5	35.0	3	0.24	0.00	0.00	0.00	0.00

Depth (cm)		Zone	T.flocculosa
0.0	1.0	1	1.42
1.0	1.5	1	0.00
2.0	2.5	1	0.95
3.0	3.5	1	0.95
4.0	4.5	1	0.47
5.0	5.5	1	0.47
6.0	6.5	2	2.61
7.0	7.5	2	0.24
8.0	8.5	2	0.71
9.0	9.5	2	0.71
10.0	10.5	2	1.18
11.0	11.5	2	0.47
12.0	12.5	2	3.08
13.0	13.5	2	5.69
14.0	14.5	2	0.24
15.0	15.5	2	1.18
16.0	16.5	2	0.00
17.0	17.5	2	0.24
18.0	18.5	2	0.24
19.0	19.5	2	0.47
20.0	20.5	2	0.47
21.0	21.5	2	1.42
22.0	22.5	3	1.18
23.0	23.5	3	0.47
24.0	24.5	3	0.00
25.0	25.5	3	0.00
26.0	26.5	3	0.24
27.0	27.5	3	0.47
28.0	28.5	3	0.24
29.0	29.5	3	0.24
30.0	30.5	3	0.24
31.0	31.5	3	0.47
32.0	32.5	3	0.24
33.0	33.5	3	0.00
34.0	34.5	3	0.00
34.5	35.0	3	0.00