Developmental history of a cupriferous swamp in southeastern New Brunswick, Canada

by

Stacey MacDonald

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Science
in
Earth Sciences

Waterloo, Ontario, Canada, 2010

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

ABSTRACT

Cupriferous swamps are characterized by high concentrations of copper in the soil and water. The Aboushagan swamp, situated 8km northwest of Sackville, New Brunswick is a unique metalliferous wetland where copper is naturally sequestered in the peat without having a significant negative effect on the vegetation. This paleoecological history of this region is not well known and few studies have attempted to characterize the local vegetation trends. This study investigates the post-glacial vegetation history of the swamp as well as any relationship it may have with the copper present in the peat.

Surface peats (dry weight) have previously been found to contain up to 10% copper. This study found Cu content in two peat cores ranged from trace values to a high of 4800 µg/g and 25 000 µg/g (0.48 and 2.5 % dry weight copper). Despite the increased values, there was no detectable change in pollen due to copper concentration and any increase of copper in the peat material is likely a result of post depositional hydrological processes transporting copper into the layers of peat where it is being sequestered in the organic material and never becoming bioavailable to the surface vegetation.

Pollen revealed that following deglaciation, the Aboushagan swamp began to develop as a rich fen around 10.7 ka BP that transitioned into a poor fen with *Sphagnum* around 9.9 ka BP as the wetland basin filled in. Around 8290 ka BP, temperatures warmed and the soil dried up leading to more canopy cover and fern abundance which yielded a mixed coniferous-deciduous swamp with *Sphagnum* in the understory that persisted until approximately 1.4 ka BP. Maritime vegetation trends in other studies describe a pine maxima (7.5 ka BP) and hemlock maxima (6.5-4.5 ka BP), neither of which were not found in the pollen record here due to a lack of peat accumulation between 8290 and 4350 ka BP. This is likely due to a regional climatic change that increased temperatures and decreased summer precipitation between 8 and 4 ka BP. In the last 1.5ka BP, the swamp has been dominated by spruce but other trees such as pine, fir, and birch have grown in abundance in the last few hundred years. A decrease in overall pollen abundance and concentration near the top of the core may be evidence for the little ice age event (1450 cal years BP). Today the swamp is a typical mixed coniferous-deciduous swamp with *Picea mariana, Larix laricina, Acer rubrum*, and *Abies balsamea*.

An understanding of the swamp's ability to sequester copper from becoming bioavailable has implications for the rehabilitation of contaminated industrial landscapes with wetland technologies. This study also highlights the high sensitivity with which wetlands can be used to detect and differentiate between autogenic (local) and allogenic (regional) climatic and vegetation changes while describing the vegetation community succession in the Aboushagan basin since the last deglaciation.

AWKNOWLEDGEMENTS

Thank you to my supervisor Barry Warner. Thank you also to my committee members Paul Karrow and Sherry Schiff for agreeing to work with me despite our limited interactions. Thank you to Richard Elgood for providing lab equipment, space, and expertise and to William Mark for his instruction in isotope analysis. Thank you also to Sue Fisher for your guidance and for answering my stupid questions.

Thank you to Dr. Taro Asada for his help with sample collection in the field and for always being willing to help me in the lab whether it be research related or a mission for free food. Thank you to Allison Legg for introducing me to the wetlands lab and helping to acquaint me with graduate student life. Thank you to Miles Anderson for being great company in the lab after my long stay as the lone student. A sincere thanks to Dr. Paul Jasinski for his constant teaching and advising in the lab, making it possible for me to learn and distinguish between pollen grains and for engaging me in philosophical debate when the mood struck.

Thank you to the friends I’ve made during my time in Waterloo; you’ve made the transition to life in Ontario from the Maritimes enjoyable over the past two years. Thank you to my family who supported me in this endeavour despite the distance it put between us and to Kyle Wellband for being there to provide rational and emotional support in spite of it all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General introduction and objectives

Metalliferous wetlands containing high concentrations of both toxic and non-toxic metals are found all over the world (Boyle, 1977). High levels of metals can be toxic to both plant and animal life and understanding how these wetlands function is pivotal in providing future remediation efforts of metal contaminated areas. Many of these wetlands are formed in conjunction with natural deposits of metals rather than being exposed to them through human activities. When this happens, it provides a unique opportunity to understand the interactions between a potentially toxic substance and a thriving vegetative community.

The Aboushagan peat swamp in southeastern New Brunswick is a cupriferous swamp that contains up to 10% naturally occurring copper in dried peat while supporting abundant vegetation (figs 1 and 2) (Smith, 1960; Fraser, 1961a; Boyle, 1977; Warner and Asada, 2008). Cupriferous swamps are characterized as having high levels of copper in both their soils and water. In 1959, R.E. Beschel noted very high copper concentrations in the northern swamp and described certain species of plants and mosses that were growing in areas of soil amongst visible copper oxidation. In 1960, Smith published a paper on heavy metals in stream sediments in southeastern New Brunswick where he noted that the Aboushagan swamp is fed by many streams, all of which could contain copper. In 1961, D.C. Fraser published three papers on the copper content of the swamp, measuring Cu concentrations, soil pH values and organic content to try and determine how the plants were able to subsist. He noted that the pH of the swamp was slightly alkaline, likely catalyzing copper sequestering reactions. Boyle (1977) summarized the previous findings stating that copper values in the soil ranged from 2 to 6% in the swamp and stressed the importance of recognizing cupriferous swamps as indicators of copper mineralization in an area and worldwide. He found that streams that flowed through the swamp had lower copper concentrations when exiting the swamp as opposed to when they entered.

Peatlands are a type of wetland that is able to archive long-term natural changes in vegetation and climate over extended periods of time through the almost continuous accumulation of slowly decomposing peat (Payette and Rochefort, 2001; Charman, 2002; Robichaud and Bégin, 2009). New layers of incompletely decomposed material are deposited annually onto the forest floor each year that plant primary production exceeds net decomposition. Pollen, macrofossils, and plant material can be preserved for long periods of time as decomposition rates are very slow thus enabling each annual accumulation of peat to take an environmental snapshot of the year in which it was deposited (Wieder *et al.,* 2006). Varying soil depths can be representative of annual blocks of time and used to understand the dynamics of past and present ecosystem changes in the Aboushagan swamp in conjunction with the large presence of copper through paleoecological methods.

Peatlands have long been recognized for their use in palynological studies yet very few modern studies have been conducted on peatlands in Atlantic Canada. Many of the previous paleoecological studies of New Brunswick have looked at lake sediments or basal peat dating but have not examined the full vegetation history in the southeastern region of the province (fig. 1). While a few pollen studies have been done on Portey Pond and Wood's Pond near the Aboushagan swamp (sites 2 and 3; fig. 1), they were both conducted on lake sediments and the goal of the analysis was to characterize chironomid species rather than vegetation and climate (Walker and Paterson, 1983). Analysis of a peat core from the Aboushagan site will help broaden the ecological vegetation history of the area and further confirm Holocene vegetation observations made from limnological studies. This not only builds on the knowledge of metalliferous swamps and the vegetation history of southeastern New Brunswick but may also provide insight into using wetland technologies for the rehabilitation of contaminated industrial landscapes.

The main objective of this study is to reconstruct the history of the Aboushagan swamp in New Brunswick using paleoecological techniques, sediment characterization, and radiocarbon age dating. This study also hopes to assess the influence, if any, of copper on swamp peat communities by analyzing metal content and organic matter and to discuss the potential use of wetlands in landscape rehabilitation.

1.2 Bedrock Geology

Carboniferous rocks made up of conglomerates, sandstone, siltstone, shale, and some limestone in varying thicknesses underlie most of New Brunswick (Gussow, 1953). Late carboniferous formations such as the Pictou and Cumberland group overlie the eastern lowlands of the province. The region directly below the site of the Aboushagan swamp is underlain by the Boss Point Formation of the Cumberland group and the Salisbury Formation of the Pictou group (Gussow, 1953; Rampton *et al.,* 1984; Johnson, 2008). The Salisbury Formation is a made up of a mottled mudstone, siltstone, and grayish maroon fine-grained sandstone. Based on high copper contents in springs and streams of the Sackville-Memramcook area in the spring season, the copper found in the Aboushagan swamp is believed to originate from small copper deposits in the Boss Point Formation along the Dorchester anticline and fault (Beschel, 1959; Gussow, 1953; Fraser, 1961c). The Boss Point Formation is about 1494 metres thick in the Sackville area and roughly 60 m below the Aboushagan swamp (Gussow, 1953). It is composed of grey conglomerate and sandstone with minor amounts of siltstone and shale (Gussow, 1953; Boyle, 1977). Mineral occurrences of Cu, Pb, Zn, and Ag occur in the Formation in relation to continental red bed type carboniferous rocks. Records from the Dorchester Copper Mine suggest that copper occurs in fluvial channel sequences (grey sandstone and conglomerate, rich in organic material) at the base of the Boss Point Formation, immediately overlying Mabou Group red-beds (New Brunswick Department of Natural Resources). The deposit is lens shaped and approximately 1km x 2km long with high-grade 2 - 10% Cu sections. The copper mineralization found in the nearby Dorchester mine is primarily malachite ($Cu_2(CO_3)(OH)_2$) with some digenite (Cu_7S_5), brochanite ($Cu_4SO_4(OH)_6$), and covellite (CuS) with traces of bornite Cu_5FeS_4 and chalcocite (Cu_2S).

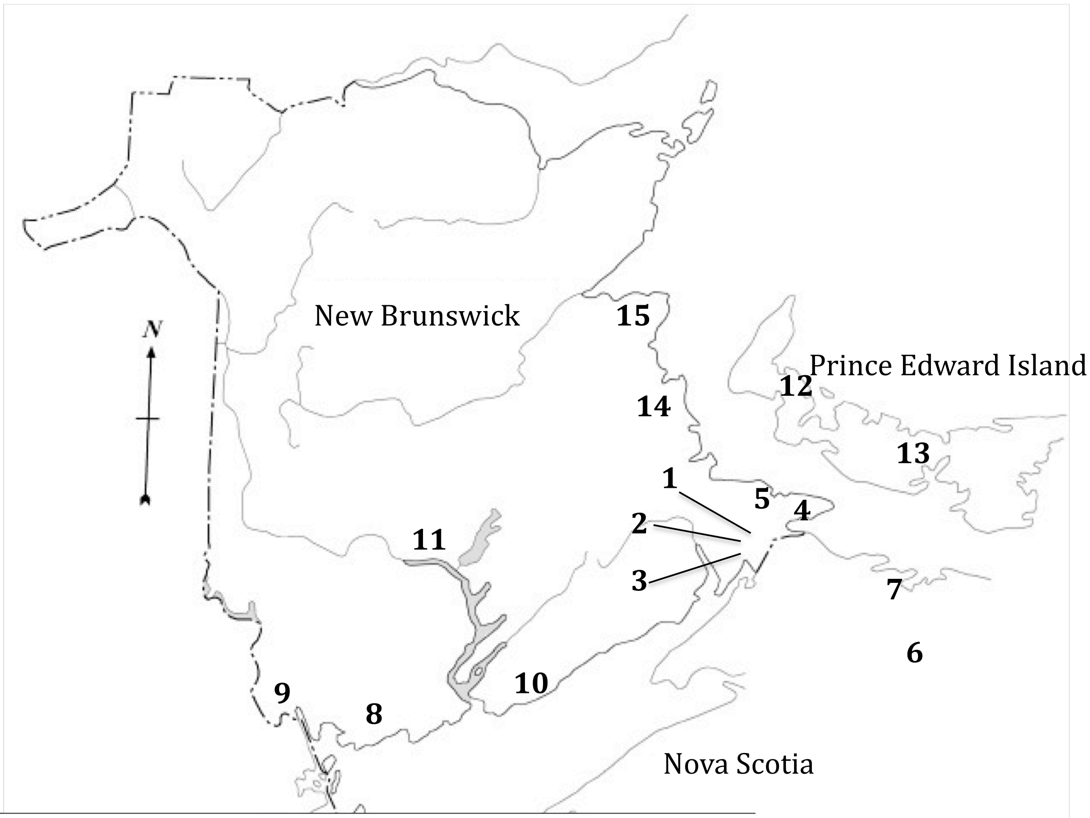
In some areas, the Boss Point Formation can also include calcareous and siliceous paleosoils (Johnson, 1998). The bedrock material at the bottom of the cupriferous Aboushagan swamp basin is made up of several layers of till, the topmost of which is sandy with sandstone blocks and stone. Boyle (1977) found that only the topmost region of till contained any copper.

1.3 Copper Geochemistry

Cupriferous (copper containing) swamps are characterized by high concentrations of copper in the soil and water. While copper is an essential metal used by living organisms, it can become toxic to plants and humans causing stunted growth or death in plants and stomach, intestinal, liver, and kidney problems in humans (Shotyk, 1988; Garedea-Torresdey *et al.,* 1996). In recent times wetlands have become the leading successful method in the natural ecosystem removal of heavy metal from water (Mays and Edwards, 2001). Certain wetland plants and mosses have the ability to accumulate metals in their tissues more than 200, 000 times the concentration of the surrounding soils with minimal negative effects on their own survival (Weis and Weis, 2004; Pinto *et al.,* 2004; Sheoran and Sheoran, 2006). Other methods of wetland metal removal involve conventional ion exchange, electrolyte or liquid extraction, electrodialysis, precipitation, cementation, and reverse osmosis; all of which are either economically unfavorable or technically complicated (Brown et. al, 2000). Peatlands are able to chemically adsorb copper and other toxic metals to the organic peat material by cation exchange or chemisorption in a manner that is inexpensive and efficient (Sheoran and Sheoran, 2006).

Metals such as Cu and Fe react with humic acids to form chelate rings that bind the metal ions and allow the release of H+ ions (Wei and Tobin, 2004). In peats, copper is most often adsorbed in the form of copper humates, which strongly adsorb to organic material. pH changes can also change metal speciation and solubility. Anion uptake is favored at low pH while cation biosorption is greater at higher pH. Soil's ability to adsorb copper increases in neutral to slightly alkaline conditions (pH 6.7-7.8) (Adriano, 1986). In higher pH, copper tends to precipitate, most often in the form of malachite, thus acidic conditions most favour copper mobility. While pH can be useful in broadly classifying wetland type, as Shotyk (1988) explains, the pH of peat is highly variable both horizontally and vertically in the peat column thus interpreting peat results based on pH must be done with caution.

Copper levels as low as 100 μg/g have been found to decrease the evolution of CO_2 in microbial communities by 25% (Cornfield, 1977). In terrestrial plants, values around 50 μg/g can decrease radicle growth in paper birch trees, significantly affecting their ability to produce successful saplings (Patterson and Olson, 1982). Values above this can have varying affects on plants including reduced growth and production of reproductive material such as pollen, dark green leaves and iron chlorosis, thick, short or barbed-wire roots, and depressed tillering (Kabata-Pendias and Pendias, 1991).



Map Location	Site name	Type of material	Pollen record	Basal ${}_{14}$C date	References
1	Aboushagan Swamp	peat	full	10745±40	this study
2	Wood's pond	lake sediment	full	9930±350	Walker and Paterson, 1983
3	Portey pond	lake sediment	full	-	Walker and Paterson, 1983
4	Collins Lake	lake sediment	full	5500±170	Green, 1976
5	Poucette Lake	lake sediment	partial	10500±170	Jetté and Mott, 1995
6	Folly Bog (Nova Scotia)	peat	full	10764±101	Livingstone, 1968
7	Wigmore Lake (Nova Scotia)	lake sediment	partial	6590±170	Jetté and Mott, 1995
8	Little Lake	lake sediment	full	9140±230	Mott, 1975a
9	Basswood Road Lake	lake sediment	full	12600±270	Mott, 1975a
10	Spruce Lake Bog	peat	full	-	Osvald, 1970
11	Fredericton Bog	peat	full	-	Mott, 1975a
12	Portage Bog (Prince Edward Island)	peat	full	3430±70	Anderson, 1980
13	Mermaid Lake (Prince Edward Island)	lake sediment	full	8630±180	Anderson, 1985
14	Birch Ridges pond	lake sediment	full	-	Korpijaakko, 1976
15	Escuminac Bog	peat	full	10900±130	Warner et al., 1991

Figure: 1 Localization map of pollen records taken from lake and peat sites. No full pollen and climate record from southeastern New Brunswick.

1.4 Aboushagan Swamp copper

The Aboushagan copper peat swamp first gained attention in 1898 when the farmer who owned the northern region of the swamp noticed that vegetation in a small area failed to grow back following a forest fire (Boyle, 1977). This was believed to be caused by increased radiation resulting in higher soil evaporation rate, which drew copper up to the surface (Kendrick, 1962). Vascular plants failed to re-establish themselves and plant roots along the periphery began to die due to copper exposure. This means that even today, the sparsely vegetated area continues to increase in size.

In the late 1940s prospectors visited the northern site until it was staked in 1950 by G.P MacKay of Halifax who estimated that there was 300 tons of copper in the swamp (Fraser, 1961a). He tried to determine the best way to extract the copper from the peat but the venture was deemed too costly due to a lack of easily harvestable ore. Mining companies and geologists continued to visit the site of the northern open area and later geochemical work by the Cyprus Exploration Corp. Ltd. outlined the margins of both the northern and the southern site, which is examined in this study (Boyle, 1977). Copper from the Boss Point Formation is believed to enter the Aboushagan swamp from underground water seepages and not through visible streams (Smith, 1960; Fraser, 1961a). This formation has been explored and mined near the village of Dorchester (15km south-west of the swamp) where copper was excavated from the beginning of the 20th century until 1917 when the mine was abandoned due to the small extent and low grade of ore (Smith, 1960; Boyle, 1977). The site was revisited in 1950 and 1951 for mining exploration but was once again abandoned. The most recent mineral report was conducted by Falconcrest Resources Inc in 1993 who determined that the copper could be removed through acid and microbial leaching however an extraction project was never initiated (Gilders and Cheung, 1993).

The copper originates from sulphide minerals that enter the swamp via seepages from the underlying bedrock (Sobolewski, 1999). Water entering the swamp contains up to 1 mg/l Cu whereas normal stream content is characterized as containing around 0.005 mg/l Cu (Drever, 1982). The copper occurring in the swamp is in the form of invisible stable metal organic complexes rather than megascopic clumps like those typically found in cupriferous swamps (Fraser, 1961b). Stable copper complexes in peats have been explained in other swamps through the presence of thiol groups (Ennis, 1962), however the Aboushagan swamp does not contain more than 0.2% sulfur, which Shotyk (1988) deemed too little to account for all of the roughly 10% dry weight peat copper concentrations. He suggested that nitrogen and oxygen containing functional groups must also be involved in the sequestration process and that he believed the copper complexes in the swamp were extremely stable.

According to Fraser (1961b) the copper cannot be separated from the peat using “gold panning,” heavy bromoform liquid settling, or the use of an isodynamic separator. He suggested that the copper has been strongly bonded to the organic material in the peat since the dispersion pattern of the copper within the peatland follows the pattern of organic material very closely. Kendrick (1962) was unable to detect any copper minerals using x-ray diffraction and Boyle (1977) used optical microscopy and then tried copper extraction with sodium acetate (2 N, pH 5.0) and aqua regia (17-h extract) that only released between 10 and 30% of the copper present. Only a perchloric digest of ashes was able to solubilize all of the copper. This suggests that the copper is bound to the organic material rather than minerals such as sulphides or carbonates. The consensus amongst previous studies is that the copper found in the vegetated areas of the Aboushagan swamp is tightly bound to organic material in the form of copper humates or chelate compounds (Smith, 1960; Fraser, 1961a; Kendrick, 1962; Boyle, 1977; Sobolewski, 1999).

Fraser suggested that these chelate compounds are able to form in great quantities in the Aboushagan copper swamp and not in other peatlands due to the water's unusually sub neutral to slightly alkaline pH. The higher pH promotes copper's bond to nitrogen and oxygen creating the chelate compounds (Wei and Tobin, 2004). Frasier (1961b) believed that the copper was immediately rendered immobile as it entered the swamp area through seepages. Boyle (1977) found more neutral to slightly acidic water in both the northern and southern cupriferous swamp sites and suggested that while chelation likely influences copper complexation, copper adsorption to humic matter was the primarily route through which copper, likely in the form of copper sulfides, is being removed from the water.

In the Aboushagan swamp, Dykeman and DeSousa (1966) suggested that the copper content of the plants is not related to the copper content of the soils. They found that the sequestration of copper in the peatland humic matter prevents it from becoming bioavailable for plant uptake. Stone and Timmer (1975) suggested that plants found in the Aboushagan swamp did not accumulate copper in their shoots or leaves but did take up some in their roots. Some root material containing copper could easily be deposited in the peat following plant mortality however most copper material is sequestered in peat as it enters the swamp, never becoming bioavailable or being in amounts too small to account for the large concentrations of copper found in the peat (Fraser, 1961c).

1.5 Deglaciation

The Fundy and Northumberland coasts of New Brunswick were deglaciated between 13.4 and 13 ka BP (Rampton *et al.,* 1984; Mayle and Cwynar, 1993). During the last glaciation, the Aboushagan swamp site was depressed below modern sea level by glacial ice by as much as 100 m. In the Sackville region, ice flow patterns were mostly north-south flowing from the Escuminac ice centre off the northwest tip of Prince Edward Island. Once the ice margins retreated inland, the rate of retreat slowed but by 12.4-12.1 ka BP most of inland New Brunswick was deglaciated (Mott, 1975a; Rampton *et al.,* 1984; Mayle and Cwynar, 1993; Cwynar *et al.,* 1994; Mott *et al.,* 2009).

As temperatures rose, New Brunswick's coasts were inundated by marine waters and as a result, ocean waters covered the area until the land rose at a rate fast enough to compensate for the rate of ocean level rise due to glacial melt (Flint, 1953; Gussow, 1953; Fraser, 1961a; Rampton et. al, 1984). The Chignecto isthmus connecting New Brunswick to Nova Scotia was likely flooded around 13 ka BP suggesting the Aboushagan swamp may also have been temporarily submerged. Shaw *et al.,* (2002) suggest that by 12 ka BP the inundation of New Brunswick's coasts was greatly reduced but Prince Edward Island was still separated from the mainland by the Northumberland Strait. There was a late glacial advance between 11 and 10 ka BP. Around 10 ka BP, a land bridge connected New Brunswick to Prince Edward Island. By 8 ka BP, the Northumberland Strait was still primarily a land mass but with large lakes throughout. By 6 ka BP the strait had filled in with water and looked much like it does today. The re-submergence timeline of the Northumberland Strait is not exact and some studies suggest that it was still emergent around 5 ka BP (Dyke and Prest, 1987).

1.6 Organic deposits

New Brunswick's organic deposits consist primarily of peat, gyttja, some muck, and rarely marl (Rampton et. al, 1984). Peats are most common in ombrotrophic bogs and poorly drained basins and depressions. Organic deposits in eastern New Brunswick consist primarily of *Sphagnum* peat underlain by varying thicknesses of sedge peats (Rampton et al, 1984). Peat thicknesses are often more than 2.5 m and have been found to exceed 8 m. Based on radiocarbon dating of basal peats in New Brunswick, Rampton et al. estimates organic deposits began to form no earlier than 10.5 ka since accumulation is limited by deglaciation and emergence of the terrain from the sea.

1.7 Post glacial climate

Following the most recent deglaciation in Eastern Canada, temperatures warmed significantly and plants began to re-colonize the landscapes. This did not last and another climatic shift occurred between 11 and 10 ka BP where temperatures cooled significantly and some studies note evidence of glaciers off the coasts of Nova Scotia as late as 10000 years BP (Stea and Mott, 1989). This was known as the widespread Younger Dryas event, detected all throughout North American stratigraphic records.

The period from 10000 to 8000 years BP marks the beginning of the Holocene marked by warmer temperatures than in the Younger Dryas. The first cooling event of the Holocene occurred around 9650 years BP and is known as the North Atlantic pre-boreal Oscillation (Anderson *et al.,* 2007). This event caused cooler conditions along the coastlines of Atlantic Canada as a result of cold wind blowing off of the retreating Laurentian ice sheet.

From 8000 to 4000, known as the hypsithermal interval, the warmest temperatures of the Holocene were as much as 2˚C above present seasonal temperatures in Nova Scotia (Anderson *et al.,* 2007). There was a brief break in warming between approximately 7650 and 7200 years BP known as the 8.2 cal ka BP cold event which is believed to have been caused by the final collapse of the Laurentian ice sheet and the draining of glacial lakes into the North Atlantic (Spooner *et al.,* 2002; Kurek *et al.,* 2004; Anderson *et al.,* 2007). This event was warmer than the Younger Dryas but cooler than the Little Ice Age that followed. Following the 8.2 ka BP event, temperatures continued to rise as they had prior to this oscillation.

The post hypsithermal period between 4000 years BP to present, saw gradual cooling and moist conditions throughout the Maritimes (Livingstone, 1968; Railton, 1975; Mott, 1992). A short but intense period of cooling known as the "Little ice age" occurred between the year 1450 and the late 1800s where glacial advance evidence has been found in morainal deposits. This period is not always detected in pollen samples because it is so brief (Gajewski, 1988).

Present day eastern Canada has a dynamic climate that is both influenced by easterly moving continental systems and the Atlantic Ocean (Anderson, 1985). Mean July temperatures are low along the coasts but warmer inland (Environment Canada, 2009). In winter, easterly winds off the Atlantic maintain high humidity and temperature inland, which creates an abundance of snow in winter. In spring and summer, onshore winds keep areas on the coasts cool. Temperatures can vary by several degrees between coastal and inland areas only a few kilometers apart (Livingstone, 1968).

New Brunswick is humid with cool summers and no dry season (Natural Resources Canada, 1957). It is also common to have fog along the Fundy coast. The average yearly precipitation in Sackville, New Brunswick is 1163.9 mm. The average daily temperature in January is -7.6°C and the average daily temperature in August is 17.5°C (Environment Canada, 2009).

1.8 Postglacial Vegetation History of Maritime Canada

Prior to 12 ka BP, vegetation in the Atlantic region consisted of *Populus* and/or *Picea* along with herb tundra that was limited to areas that had been deglaciated at least 1000 years earlier (Prest 1970; Mott, 1975a; Anderson, 1985; Ritchie, 1987; Cwynar *et al.,* 1994). Between 11.2 and 10.9 ka BP there was an emergence of shrub *Betula* but a brief cooling caused a decline in *Populus* and *Picea* whereas *Betula* and *Juniperus* increased. *Picea* dominance returned through 10.9-10.8 ka BP as temperatures became slightly warmer but *Betula* and *Populus* declined substantially. Mayle et al. (1993) suggested that spruce forest was well established in the Maritime region based on its high pollen abundance (40-60%) and the recovery of tree needles in lake sediments. Livingstone (1968) estimated *Picea* pollen abundance was 50% at Folly Bog, Nova Scotia around 10.7 ka BP.

From 11 to 10 ka BP intense cooling occurred as a result of the Younger Dryas event which greatly reduced *Picea* pollen percentages but allowed *Alnus*, Cyperaceae, and Poaceae to increase significantly (fig. 12) (Walker and Paterson, 1983; Mayle *et al.,* 1993). Mott et al. (2009) found that Cyperaceae reached upwards of 30% abundance in Pye Lake, Nova Scotia. This cooling event changed the overall vegetation from closed boreal forest/woodland to forest tundra or shrub tundra. There was also a decrease in

Juniperus species and an increase in *Dryopteris* type fern spores. *Pinus* is also present in this time period but likely due to long distance pollen transport by wind.

Between 10 and 9.5 ka BP, temperatures warmed considerably and *Picea*, *Abies*, *Larix*, and *Quercus* are common. These plant assemblages are the first post-glacial forest vegetation zone (Hadden, 1975). A rise in *Picea* abundance in this zone is consistent throughout the Atlantic Provinces and pollen diagrams indicate it dominated most forest landscapes between 9700 to 9500 years BP (Livingstone, 1968; Mott, 1975a; Anderson, 1985). Silver lake in Nova Scotia shows the peak in *Picea* to be around 9650 ka BP (Livingstone, 1968). Warming also caused arctic species such as *Salix herbacea* to disappear from pollen records (Cwynar *et al.,* 1994).

Mott's (1975a;b) studies of Basswood Road Lake and Little Lake in New Brunswick showed a large increase in *Pinus* pollen as it entered the area beginning around 9500 years BP. This also marked the end of the *Picea* pollen dominance at these sites. Between 9000 and 8000 years BP *Betula* abundance increased while *Picea* and some *Larix* are also present (Mott *et al.,* 2009). Warming trends after 8000 years BP shifted the tree dominance from *Picea* to *Pinus* and small abundances of hardwoods such as *Betula*, *Quercus*, *Ostrya/Carpinus*, *Fraxinu*s, and *Acer* (Mott, 1975a). *Pinus* reached a maximum in mainland New Brunswick by about 7500 years BP (Anderson, 1985). Anderson et al. (2007) note that the decline in *Picea* was due to a warm climate shift around 9650 years BP however areas along the eastern shores of New Brunswick, Prince Edward Island, and northern Nova Scotia were affected by the gulf of St. Lawrence which maintained cool temperatures until much later and the arrival of *Pinus* was delayed until between 8.0 and 7.7 ka BP.

Tsuga arrived in the Maritimes and became established between 6000 and 7000 years BP. Jetté and Mott (1995) described the forest of southern New Brunswick at this time as "mixed coniferous-deciduous with hemlock". *Tsuga* occurrence is consistent throughout all Maritime pollen records and it remains abundant along with *Pinus* between 6500 and 4500 years BP (Livingstone, 1968; Mott, 1975a; Anderson, 1980; Walker and Paterson, 1983; Anderson, 1985; Warner *et al.,* 1991; Mott *et al.,* 2009).

Approximately 5000 years BP, *Tsuga* populations decreased significantly which has been most popularly attributed to a rapid and widespread pathogen (Mott, 1975a; Anderson, 1980; Warner *et al.,* 1991; Mott *et al.,* 2009). In southern New Brunswick, *Fagus* pollen began to appear and species like *Betula* and *Alnus* began replacing *Tsuga* in the forest cover (Jetté and Mott, 1995).

From 5000 to 3300 years BP, *Betula* increased to abundances greater than 45% at Folly Bog and Pye Lake Nova Scotia (Livingstone, 1968; Mott *et al.,* 2009). This continued through until 1100 years BP when *Betula* abundance was joined by *Fagus*, *Abies*, and *Picea* along with the return of *Tsuga* around 3000 years BP (Mott, 1975a;b). Between 3000 and 1500 years BP there are intervals where the climate became cooler causing increases in *Picea*, Ericaceae, *Sphagnum*, and decreases in *Pinus*.

Between 1100 to 150 years BP, *Picea* and *Abies* increased sharply along with decreases in *Betula* and *Fagus*. Livingstone (1968) reported 20% *Abies* abundance in this zone at Folly Bog. Wood's Pond near Sackville New Brunswick shows increases in *Sphagnum* and fern spores as well (Walker and Paterson, 1983).

Fagus mixed with *Tsuga* and *Betula* declined along with all tree taxa between 100-150 years ago due to European settlement (Anderson, 1980). Graminae species, *Alnus*, *Ambrosia*, and other herbs and weeds also expand their ranges and become more prevalent in the pollen records. Wood's Pond had marked increases in Graminae, Cyperaceae, *Picea*, *Alnus* and all herb pollen in this region (Walker and Paterson, 1983).

In modern times, the vegetation of southeastern New Brunswick consists of wetland and shrub land areas transitioning into shrub and treed lands (Natural Resources Canada, 2006). New Brunswick was characterized by Rowe (1959) as the Acadian forest region with close connections to the Great Lakes St. Lawrence Region and the Boreal Region. Climax vegetation consists of *Picea glauca* and *rubens*, *Abies balsamea*, *Acer saccharum* and *rubrum*, *Fagus grandifolia*, *Betula lutea*, *Pinus strobus* and *Tsuga canadensis* (Rowe, 1959, 1972; Anderson, 1980).

CHAPTER 2

STUDY SITE

2.1 Location

The Aboushagan swamp is located eight kilometres north of Sackville, New Brunswick, Canada, on the western side of the Aboushagan road (45°58’13.7” N, 64°21’14.8” W) (figs 2 and 3). The site is situated north of the Chignecto Isthmus, a 24 km stretch of land connecting the provinces of New Brunswick and Nova Scotia, narrowly separating the Northumberland Strait from the Bay of Fundy.

2.2 Physical Setting

The Aboushagan swamp lies in a small hollow in the glacial drift approximately 17 m above sea level (fig. 3). The present day continuous tree line begins east of the site marking the beginning of more bog and marsh area which transitions into the relatively flat and prairie like Tantramar marshes that continue east through Sackville and across the Chignecto isthmus. The swamp is bordered on the west by higher ground in the direction of the village of Dorchester. The land rolls gently among hilly areas, with the highest hill at 168 m above sea level (fig. 3) (Smith, 1960). A *Sphagnum* bog is directly across the road surrounded by a man-made marshy area governed by the presence of levees (not to be mistaken for dykes like those in the surrounding area built by French settlers in the mid to late 1600s) (fig. 3).

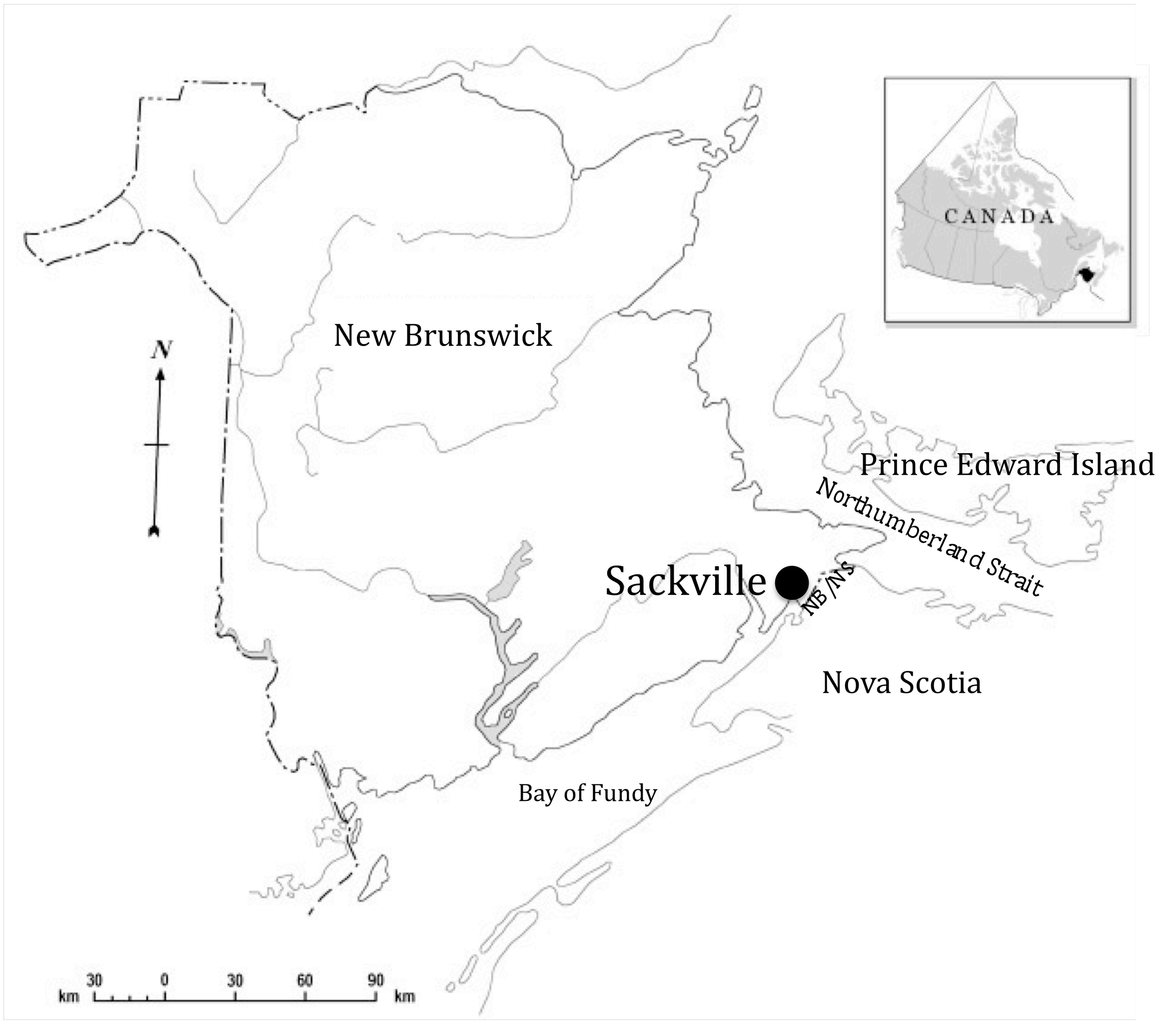


Fig 2: Map of the Maritime Provinces indicating the location of the Sackville area.

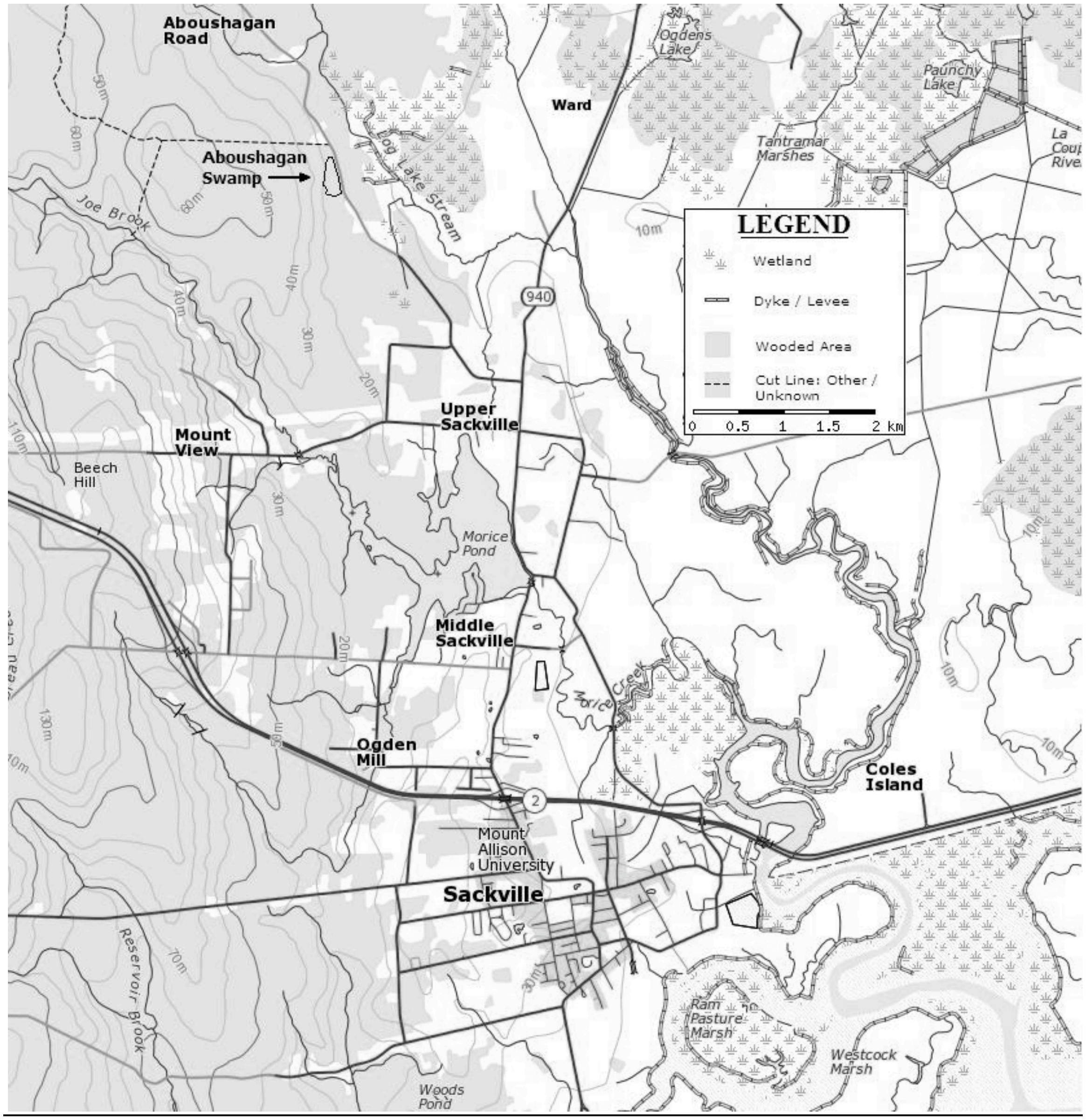


Fig 3: Map of the region surrounding the Sackville area in relation to the Aboushagan swamp (top left) (Natural Resources Canada, 2010).

Fig. 4: Aerial photograph of the study region. The swamp basin is outlined in black. Locations of sites B and C shown.

2.3 Vegetation

The Aboushagan swamp of present day is a typical mixed coniferous-deciduous forest. The margins of the swamp begin immediately west of the Aboushagan road. The road ditch is filled with shrubs and tall grasses until it connects with the swamp's tree line. In summer, most of the ground is covered in *Sphagnum* mosses and peat. The tree cover is mixed consisting of *Picea mariana, Pinus strobus, Abies balsamea, Acer rubrum, Larix laricina, Betula papyrifera*, and *Alnus rugosa*. The *Sphagnum* groundcover grades into a damp, less canopied, and more sunlit area with many species of fern including *Osmunda cinnamomea*, *claytoniana*, *Pteridium aquilinum*, and various species of *Dryopteris*. Further west into the swamp, the canopy becomes more closed leading to *Sphagnum* mosses as well as other forest and swamp plants such as *Aralia nudicaulis* and *Rhododendron tomentosum*. Overall, mosses do not dominate the visible surface vegetation.

2.4 Age of swamp

Radiocarbon dates taken from wood samples within a 25 km radius of the Aboushagan swamp report basal ages of around 10 ka BP (Walker and Paterson, 1983; Rampton et.al, 1984; Jetté and Mott, 1995). Radiocarbon dates of basal peat (overlying sand) from Fromm's Swamp, a bog 12km southwest of this study (45°57.2'N, 64°12.2'W) have been reported to be as old as 9300±140 years BP (Rampton *et al.,* 1984). Wood's Pond, 10km southwest of the swamp (45°53'N, 64°24'W) is 9930±350 years BP (Walker and Paterson, 1983). Approximately 20km north of the study, Poucette lake (46°03'N, 64°17'W) is the oldest record in the region at 10500±170 years BP (Rampton *et al.,* 1984). The range of dates from other peatland samples in New

Brunswick ranges from 9000 to 7500 years BP (Osvald, 1970; Mott, 1975a; Korpijaakko, 1976; Rampton *et al.,* 1984; Glaser and Janssens, 1986; Warner *et al.,* 1991; Robichaud and Bégin, 2009). These ages suggest that the glacial history of New Brunswick and particularly southeastern New Brunswick varies by area. Based on these data, the age of the Aboushagan swamp before sampling was estimated to fall somewhere between 9930 and 10500 years BP.

CHAPTER 3

METHODS

3.1 Field work

On August 6, 2008, soil core samples were taken from three sites within the Aboushagan copper swamp. In previous studies, the area the samples were retrieved from was designated as the southern portion of the swamp (Fraser, 1961a; Boyle, 1977). Random probing of the soil revealed the depth of peat varied greatly from site to site. Two locations where the peat was deepest were chosen for sampling and designated B, and C (fig. 3). Core C (210 cm depth) was taken for complete analysis and core B (depth 82 cm) was examined for metals and geochemistry.

Each core was removed from the soil at 50 cm increments using a side-wall peat corer and promptly wrapped intact in plastic wrap and aluminum foil, secured with tape and labeled for future identification (Jowsey, 1966). This was done until the corer made contact with what was believed to be bedrock material based on probing in the general area that did not go any deeper. A peat monolith was taken at site C, representing depths 0-40 cm. All samples were then shipped back to the University of Waterloo and refrigerated for preservation until they could be analyzed.

3.2 Laboratory techniques

3.2.1 Sediment description and sub sampling

Upon arrival in Waterloo, cores were sliced into 1 cm sections, labeled by depth, placed in whirl-packs, sealed, and kept refrigerated. Subsamples of the cores in 2 cm^3 volumes were taken at 5 cm intervals and placed in small plastic vials and refrigerated in preparation for further analysis. Any significant stratigraphic changes in the cores were recorded. Subsamples were also taken from the peat monolith collected at site C and placed in small plastic vials and refrigerated.

3.2.2 Stratigraphy

Visual inspections of the cores were made both in the field and laboratory to roughly characterize stratigraphic changes in the peat material. Wet mounts of peat were made at 5 cm increments from core C and examined under the light microscope to characterize sediment composition. The frequency of various components were recorded and plotted according to depth. Characteristics included soils and any plant or animal material present. Note that subsamples from 50 to 25 cm depth could not be taken with confidence due to shifting in the peat monolith during storage and are lacking from the more detailed microstructure analysis.

3.2.3 Radiocarbon Dating

Basal samples as well as samples where significant stratigraphic or organic content changes occurred in cores B and C were selected for radiocarbon dating. Each peat sample was examined in the laboratory under the dissecting scope to ensure no contamination such as recent growths of fungal hyphae or roots that could affect the dating process. All samples were dried in an oven, weighed, and placed in whirl-packs for shipment. Peat samples were sent to l'Université Laval for accelerator-mass-spectrometer (AMS) ^{14}C radiocarbon dating. Dates were corrected to calendar years using the CALIB 3.0 calibration program (Stuiver and Reimer, 1993).

3.2.4 Metal Analysis

Samples of peat (2cc volume) were taken between 10 and 15 cm intervals from core B and C, oven dried, and sent to the Lakefield SGS Environmental and Minerals

Services for metal analysis.

3.2.5 Isotope Analysis

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes %C and %N were analyzed from peat core C at 5 cm depth intervals using a mass spectrometer (Delta Plus Continuous Flow Stable Isotope Ratio). Samples were dried, ground into powder using a ball mill, and weighed in the lab before analysis at the University of Waterloo Environmental Isotope Laboratory. The error for clean ball-milled standard material is +/- 0.2‰ for Carbon and +/-0.3‰ for Nitrogen. This error can be expected to increase depending on the homogeneity, type and amount of sample used in analysis.

3.2.6 Organic matter content

Loss on ignition and bulk density determinations were made on cores B and C in the wetlands laboratory. Each sample was dried, weighed, and heated to various temperatures to determine its organic and inorganic content by weight following standard procedures (Dean, 1974). The first reaction involves heating the sample to 500–550 °C until it has oxidized to carbon dioxide and ash. In a second reaction, carbon dioxide is evolved from carbonate at 900–1000 °C, leaving oxide. Weight lost at each interval indicates the organic and then carbonate content of the sample.

3.2.7 Macrofossils

Peat samples from core C were selected at roughly 10 cm intervals for macrofossil analysis. Peat was added to a known volume of water until 20 cm^3 had been displaced, yielding a seed concentration per 20 cm^3. Samples were rinsed with water into a 60 mesh (250 μm) wire filter to remove small particles. Peat was then examined under the dissecting scope and seeds were identified to family and/or genus and counted.

3.2.8 Pollen Analysis

Peat samples (2cc volume) from core C were taken at 5 cm intervals to begin pollen analysis. Pollen from peat was prepared following standard pollen analytical techniques (Faegri and Iversen, 1975). Two cubic centimeters of exotic *Lycopodium clavatum* spores were added as a marker for later calculation of total pollen concentration (Stockmarr, 1971). Peat samples were put through 10% HCl and KOH washes followed by sieving and acetolysis. Silt-rich samples were also put through a finer 5 µm mesh screen to remove excess sediments (Cwynar et.al., 1979). Pollen was stained with safranin-O and dehydrated with tert-butyl alcohol prior to examination. Each pollen sample was smeared with silicone oil onto glass slides, covered with a cover slip and examined at 400x magnification under the light microscope.

The analysis consisted of identifying the pollen and spores present in the sample and recording each taxon's frequency. Identification was completed with the help of reference slides and several reference texts (McAndrews *et al.,* 1973; Faegri and Iverson, 1975). Each grain was simultaneously identified and counted until, depending on the quality and abundance of pollen in each sample, a minimum 300 to 500 grains including spores had been tallied per sample. This information was placed in a pollen diagram and compared with the vegetational data previously recorded from the Maritime region.

A Constrained Incremental Sum of Squares (CONISS) analysis was done on the pollen data to assess changes in overall vegetation makeup in relation to depth (Grimm, 1987). Analysis was stratigraphically constrained, thus only adjacent samples were compared with one another and combined accordingly based on similarity of raw pollen count data.

CHAPTER 4

RESULTS AND INTERPRETATION

4.1 Basin stratigraphy and sediment composition

The Aboushagan swamp basin is about 400 m along its longest north-south axis and reaches 150 m at its widest point on its east-west axis, (figs. 4 and 5). Its deepest point, believed to be near the centre of the basin, was found to be at least 210 cm deep where one of the cores for detailed study was collected. A silty limnic peat with remains of *Carex* sp. sedges lies in the deepest parts of the basin and is overlain with a unit of *Sphagnum* peat marked by *Sphagnum* leaves and stems along with increases in fine and coarse organics (fig. 6). A thin layer of dense highly decomposed peat mixed with some silt overlies the *Sphagnum* peat. The base of the second core, at 82 cm depth, begins in this highly decomposed region of peat. Most of the basin consists of a highly decomposed amorphous wood-rich peat. Finally, the surface 25 cm is the modern herbaceous and moderately decomposed fibrous peat.

4.2 Radiocarbon Dating

A total of seven radiocarbon ages were determined from bulk peat samples in the swamp; six from core C and one basal sample from core B. All values and calibrated dates are summarized in Table 1.

It should be noted that Ca levels were high in varying regions of both cores and suggest the presence of calcareous sediments in the bedrock material that can cause invalid radiocarbon dates through the presence of older material (Mott, 1975a). Ages are thought to be accurate based on similarity with basal ages taken from the surrounding area and correlation of peat material and age between the two cores.

Peat accumulation rate can be estimated from linear interpolation of radiocarbon dates versus depth. A plot of peat accumulation rate shows some dramatic variations in core C (fig. 7). Peat accumulation was most rapid during the early period of basin infilling and then gradually stopped or almost ceased by 8 ka B.P. The interval between 8290 and 4350 years BP represents 15 cm of depth and about 4000 years of time which suggests that minimal peat was produced and survived decomposition so as to contribute to net accumulation during this period. Subsequently, accumulation commenced once again and the rate increased sharply. The most rapid period of peat and sediment accumulation has occurred during the last 790 years.

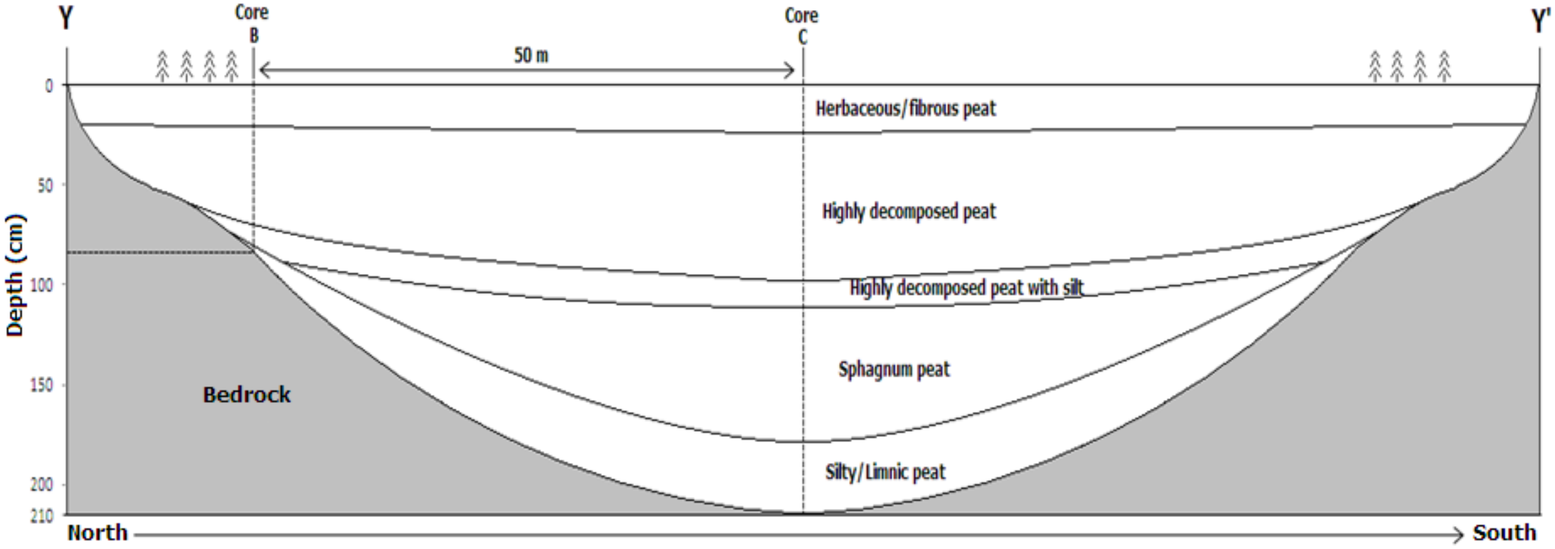


Fig 5: Sketch of north south Aboushagan basin stratigraphy showing positions of cores B and C. Note trees and vegetation cover the entire surface.

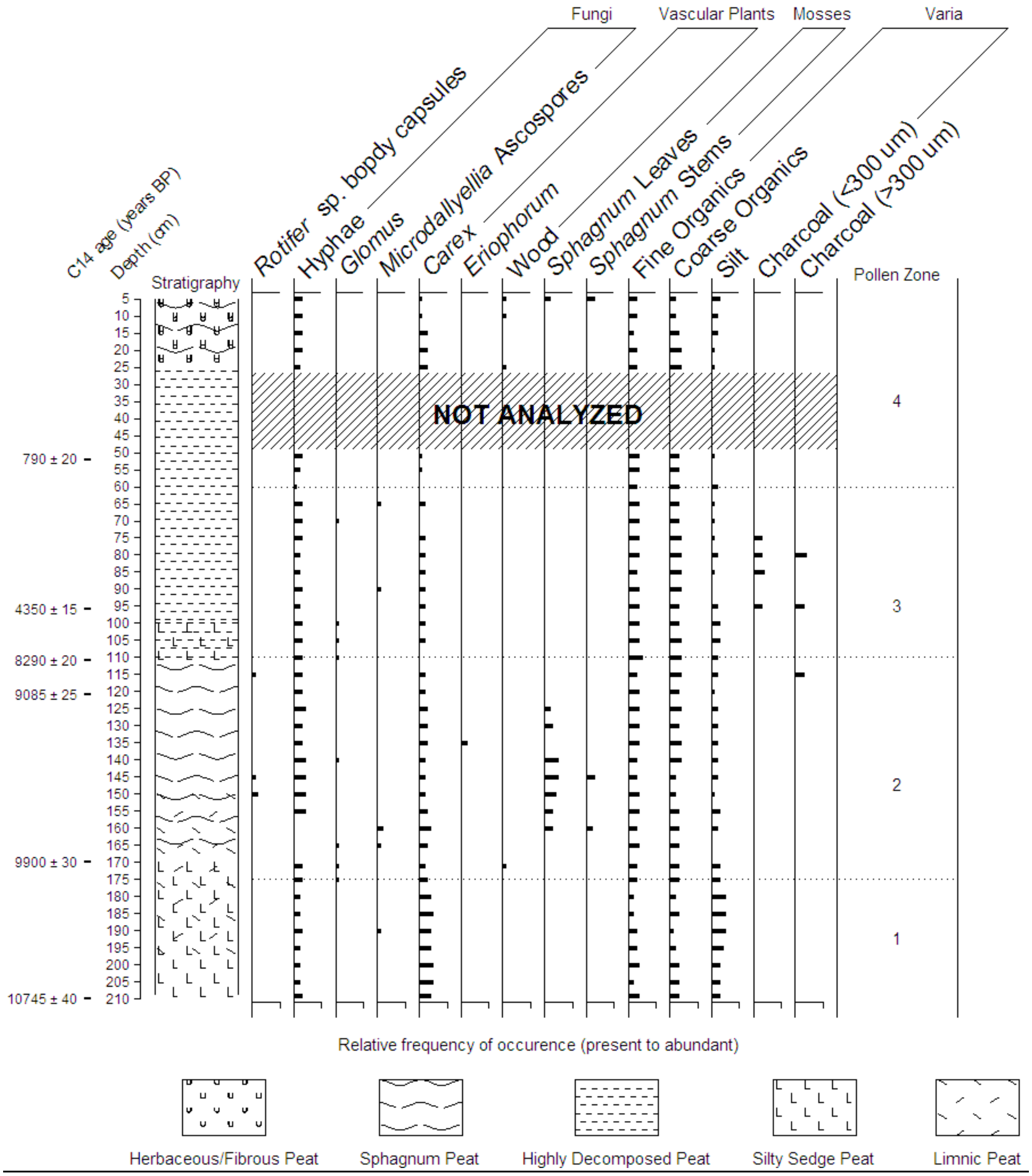


Fig. 6: Peat microstructure analysis and stratigraphy of Aboushagan swamp Core C. Note the lack of data from 50-30cm where subsamples could not be taken due to peat monolith cracking and shifting in storage.

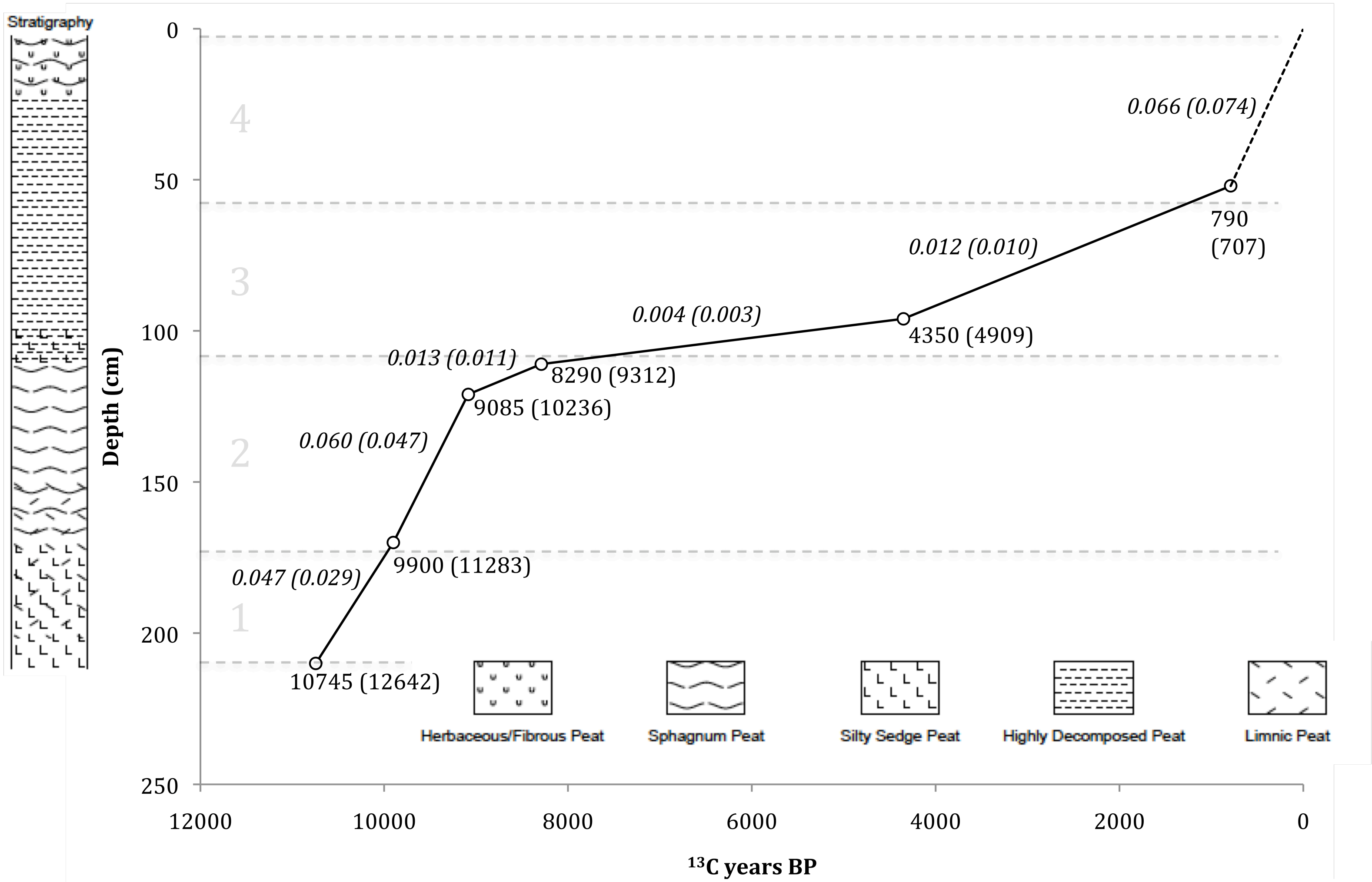


Fig 7: Sediment accumulation rate (cm/year) versus depth of core C is given above the line in italics and calculated by linear interpolation using radiocarbon ^{14}C and calibrated years (in brackets). ^{14}C radiocarbon dates plotted below the line with calibrated dates in brackets. Pollen zones indicated by dotted lines.

Table 1: AMS Radiocarbon ages from core B and C in the Aboushagan Swamp.

Laboratory Designation #	Peat	Name - Depth (cm)	Uncorrected ^{14}C age (years BP)	$\delta^{13}C$ (‰)	Calibrated age BP (2σ range)
ULA-1249	Humic	C-52	790±20	-27.2	707 (680-732)
ULA-1535	Humic	C-96	4350±15	-27.0	4909 (4859-4962)
ULA-1248	Silty humic	C-111	8290±30	-26.8	9312 (9146-9318)
ULA-1536	*Sphagnum*	C-121	9085±25	-27.0	10236 (10203-10254)
ULA-1273	Limnic	C-170	9900±30	-27.4	11283 (11234-11360)
ULA-1247	Silty	C-210	10745±40	-27.2	12642 (12564-12744)
ULA-1250	Humic	B-81	3845±20	-26.7	4255 (4154-4210)

ULA=Université Laval
Ages Corrected for 13C

4.3 Isotopes

$\delta^{13}C$ values are lowest at the bottom of the core between 210 cm and 170 cm depth followed by an increase (fig. 8). From 170 to 10 cm, values oscillate between -26 and -28 and then decrease again until the top of the core. Productivity, organic carbon burial and vegetation type are all functions of $\delta^{13}C$. Plants that use the C_3 Calvin pathway to photosynthesize produce on average a $\delta^{13}C$ isotopic signature of -28 ‰ (Meyers and Lallier-Vergès, 1999). The $\delta^{13}C$ values indicate the presence of terrestrial and marsh C_3 plants throughout the swamp's history (McSween et.al. 2003; Lamb *et al.,* 2007).

$\delta^{15}N$ values hover around 0 at the bottom of the core and have an average of 0.68 ‰ throughout (fig. 8). Values remain relatively unchanged from 200 cm to 115 cm but fluctuate with a net increase between 110 and 70 cm. There is a gradual oscillating decrease between 70 cm and the top of the core with notable low values at 20 and 5 cm depths.

Inorganic nitrogen isotope values between -7 and 6 are indicative of terrestrial C_3 land plants and values between 3 and 5 are C_3 marsh plants (McSween et.al. 2003). Values between 1 and 8 can be indicative of C_4 marsh plants. The fluctuation in $\delta^{14}N$ values from core C fall within the ranges of terrestrial land plants and some marsh plants suggesting that marsh plants were present in conjunction with dominant terrestrial vegetation.

The C/N ratio varies between 16 and 37 with an average of 25 throughout the C core (fig. 8). Ratio values exceeded 30 between 165-145 cm and 80-70 cm. The ratio is 16 at 175 cm, which is much lower than the rest of the data. C/N ratios indicate the origin of organic matter by how small or large the values are (Meyers and Lallier-Vergès, 1999). Values below 10 indicate the presence of organisms such as phytoplankton whereas vascular land plants rich in cellulose have C/N ratios greater than 20. All C/N ratios from the core except for one were greater than 20 and the landscape was likely governed by vascular land plants throughout its history.

4.4 Metal Analysis

A total of 28 metals were analyzed from sediments in core C (see appendix A). The most obvious one of interest in this study is copper, which was present in variable quantities (fig. 9). There was a small copper peak near the bottom of the core from 203-209 cm depth where copper concentration reached 620 µg/g at 207 cm. A second increase is located between 100-90 cm depth and reached a maximum of 4800 µg/g at 65 cm depth. High concentrations of Ca, Al, and Mg amongst other positively charged ions are of note as they generally follow the same trends as the copper.

Copper values for core B were higher than core C with the largest concentration being 25000 µg/g at 35 cm amongst a broader peak copper than in core C (fig. 9). Since peaks in copper are located within the same stratigraphic region and type of peat in both cores, the discrete peak obtained for a single sample at 65 cm depth in core C is likely reliable and not a laboratory error.

While having similar peaks in relation to depth, the difference in concentration of copper between the cores B and C suggests they are or have been exposed to different hydrological conditions throughout their histories, changing the quantity of copper that was deposited at each location.

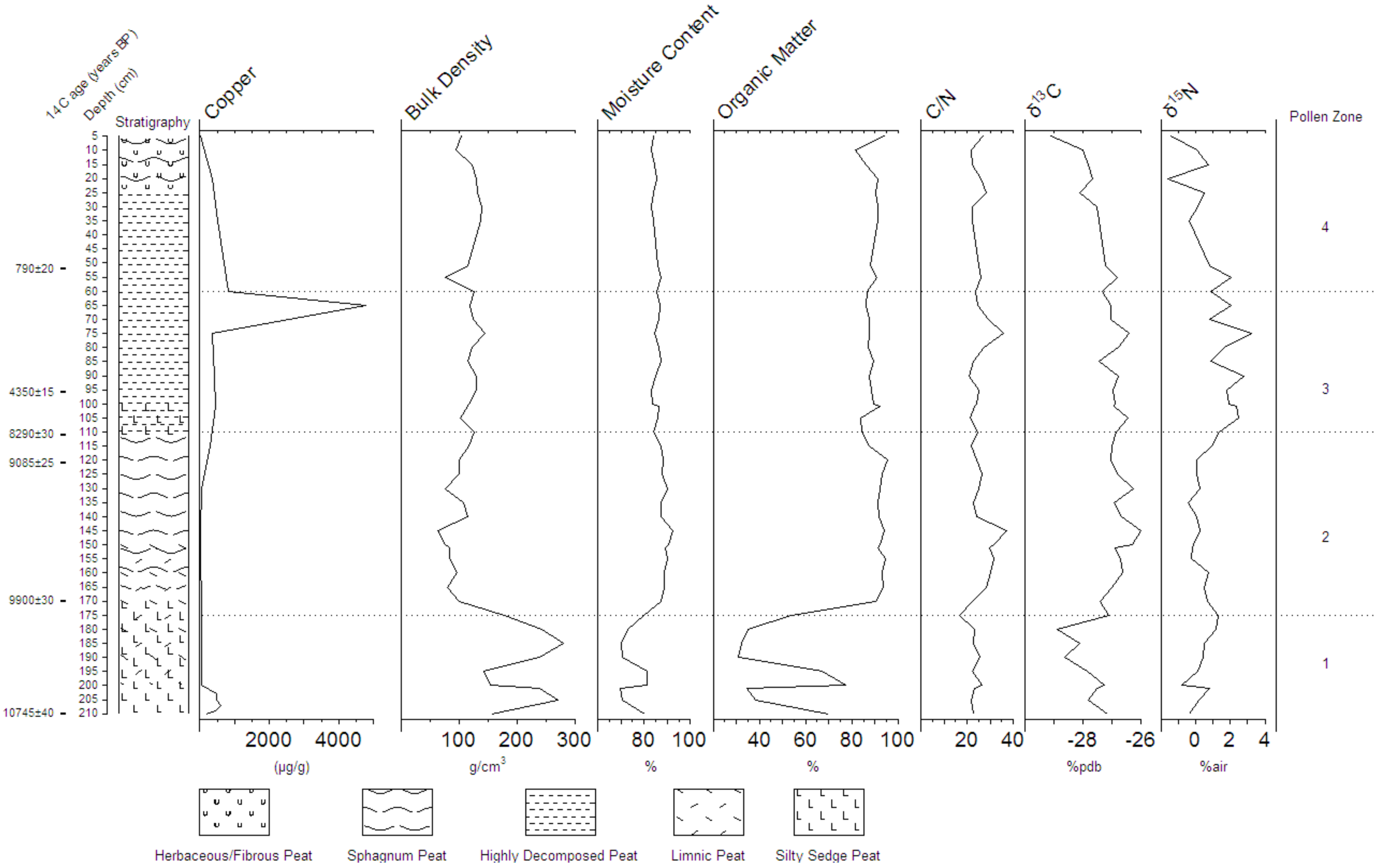


Fig. 8: Copper concentration of Aboushagan swamp core C compared with bulk density, moisture content, organic matter content, carbon to nitrogen ratio (C/N), and ^{13}C and ^{15}N isotopes in relation to depth

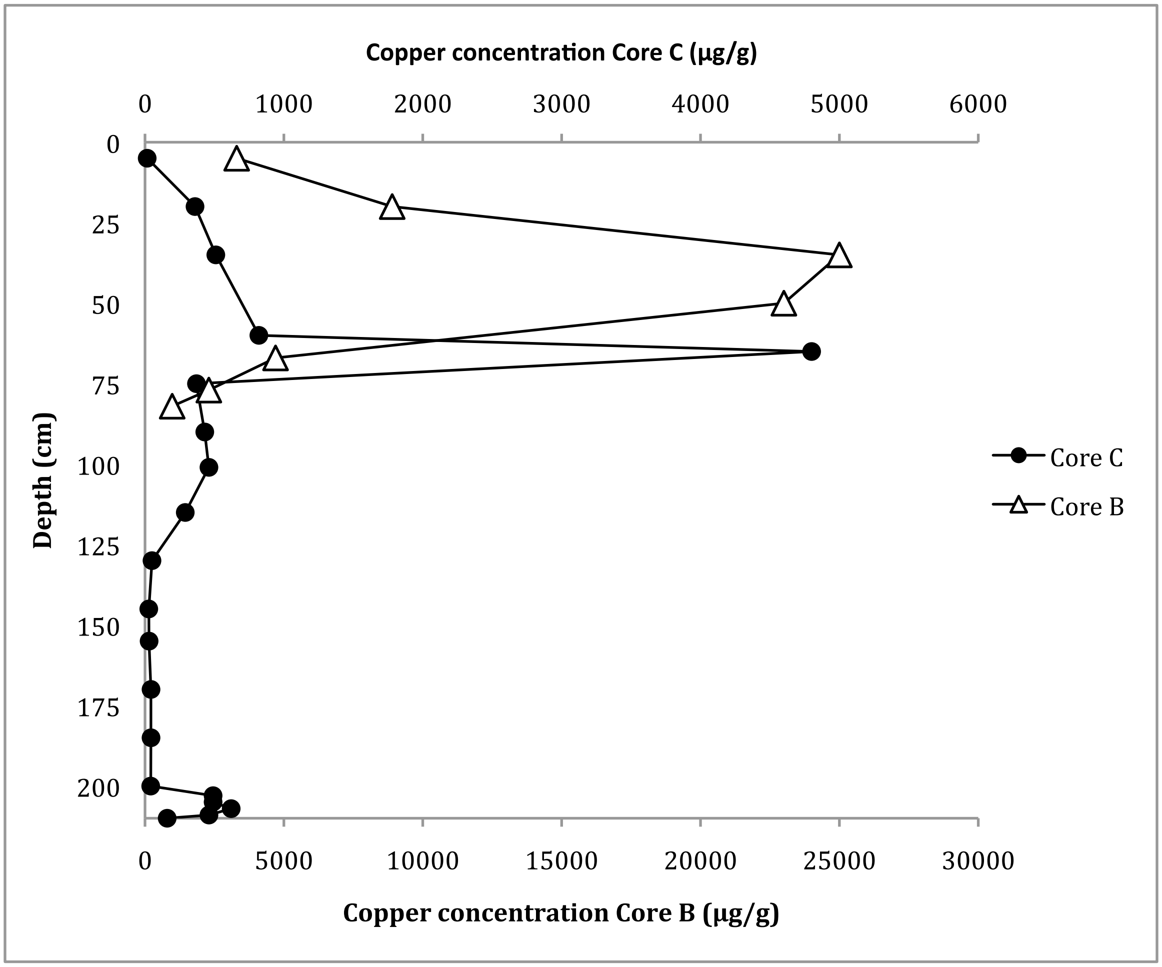


Fig 9: Copper concentrations of cores B and C versus depth. Note that Core B is 82 cm deep while core C is 210 cm deep.

4.5 Pollen, Spore and Plant Macrofossil Analysis:

A pollen diagram from core C reflects the changing vegetation in and around the swamp basin during the last 10745 years BP (fig. 10). Based on CONISS analysis of pollen similarity along with changes in stratigraphy and pollen concentration over time, four pollen zones are recognized for ease of interpretation and discussion.

Zone 1: (210-175 cm, 10745-~9900 ^{14}C years BP, 12642-11283 cal year BP)

This segment of the core is silty, coarse, and characterized by Cyperaceae, which reaches up to 93% pollen abundance at 180 cm depth. *Carex* seeds were abundant throughout the entire zone (fig. 11). There are very few arboreal species in this zone however they are present in small numbers suggesting that species such as *Picea*, *Pinus*, *Abies*, and *Betula* were present in the upper basin. While identification was not confirmed, visual inspection of the peat in this region of the core revealed the presence of brown mosses, often indicative of rich fen wetlands (Kuhry *et al.,* 1993). *Selaginella* megaspores as well as microspores are present in the core suggesting a cooler climate. This is due to the fact that this species' current range is limited to cool, windy places in both New Brunswick and Nova Scotia (figs. 10 and 11) (Zinck, 1998; Hinds, 2000).

Tundra herb and shrub pollen from *Artemisia* and *Salix* are present in the peat and have been found in the Younger Dryas zone in other studies (Anderson, 1980; Mayle and Cwynar, 1995). The area surrounding the wetland basin was likely well vegetated as pollen from many plant species are present at the deepest part of the core.

Zone 2: (175-110 cm, ~9900-8290^{14}C years BP, 11283-9312 cal year BP)

Pollen evidence shows more arboreal and fewer herb and shrub species began to fill the area, marked by Cyperaceae, *Salix*, and *Artemisia* declines. Seed evidence supports this with a sharp decline in *Carex* (fig. 11). This suggests that temperatures were warmer than in the previous zone where mostly herb species are present.

Pollen and microstructure analysis indicate that the vegetation understory shifts to *Sphagnum* dominance. *Sphagnum* along with other plant species likely colonized the growing number of hummocks in the rich fen from the previous zone, eventually helping to fill in the basin and transition the vegetation into a Sphagnum dominated understory. This suggests that the wetland was turning into a poor fen at this time. *Selaginella* appears in the pollen record (up to 13% abundance) with *Sphagnum* suggesting cool and potentially moist soil conditions. *Selaginella* megaspores were also high suggesting that the plant was abundant in the wetland basin and not just in the surrounding area. *Dryopteris* spores and *Viola* seeds are also present in this section suggesting that the canopy was still relatively open. (Bunting *et al.,* 1998)

Picea trees were likely located along the margins of the basin and high percent abundance values in the record are likely a reflection of their overall dominance in the Maritimes between 9500 to 9700 years BP (Anderson, 1985). The time range of *Picea* dominance at the Aboushagan swamp lasts for the entirety of zone 2 (9.9 to 8.0 ka BP) and into zone 3, slightly longer than other documented inland sites. This could be due to local variations in forest succession or perhaps influenced by the swamp's proximity to the eastern coast of New Brunswick (~20 km across, 0-30 m elevation) where cool air off of the Gulf of St. Lawrence kept temperatures cooler as climate warmed inland, allowing *Picea* to remain dominant. As *Picea* declines somewhat at the end of this zone, Cyperaceae abundance increases briefly to 50% suggesting a lack of other arboreal species being abundant or mature enough to take the place of *Picea* during this time. This change could also reflect the present-day eastern coast of New Brunswick becoming more continental in this time period as the Northumberland Strait became a landmass connecting New Brunswick to Prince Edward Island (Shaw *et al.,* 2002).

Pinus becomes mildly more abundant and it is likely that it is present from more than wind blow alone as its presence has been recorded by other studies in New Brunswick (Mott, 1975a). Increases in both *Pinus* and *Betula* near the end of this zone might be initial indicators of a shift to warmer temperatures.

Zone 3: (110-60 cm, 8290- ~1437 ^{14}C years BP, 9312- ~1471 cal year BP)

This zone marks the beginning of vegetation similar to that of present day and the transition from a poor fen to the present day swamp. Tree pollen is dominant, including *Picea*, *Pinus*, *Betula* and *Fraxinus*. Shrubs such as *Alnus* also appear while *Selaginella* disappears early in the zone and species such as *Osmunda* and *Dryopteris* become very abundant suggesting drier soil conditions. Species of *Tubuliflorae* become more abundant as well, suggesting weed species were able to colonize open areas of land in drier climate. *Sphagnum* spores are abundant and it is likely that the moss covered the forest floor beneath the tree canopy. Growing conditions were likely good and plant productivity high based on high total pollen concentrations in comparison with the rest of the record (fig. 12).

Due to the increased dryness and organic decomposition, it is likely that all plant material and pollen from a given year were decomposed in that same year. This in conjunction with any other disturbance that destroyed pollen in the early part of this zone would explain why there does not appear to be a *Tsuga* maximum between 6.5 and 5.4 ka BP ago in conjunction with other pollen records from the area (Anderson, 1985). *Tsuga* does increase but not until the end of this zone, around 2200 years BP, which likely represents the species' gradual comeback following its regional decline 5 ka BP (Anderson 1985). Also lacking is a local *Pinus* dominance, which occurred in the rest of the Maritimes around 7.5k years BP. *Pinus* does peak in this zone but after 4350 years BP, much later than in the other pollen records. Therefore *Tsuga* and *Pinus* pollen maxima were either both lost in the record, never occurred, or for *Pinus* the maxima could have been delayed due to a local extension of warmer temperatures near the coasts from warmth retained in the ocean.

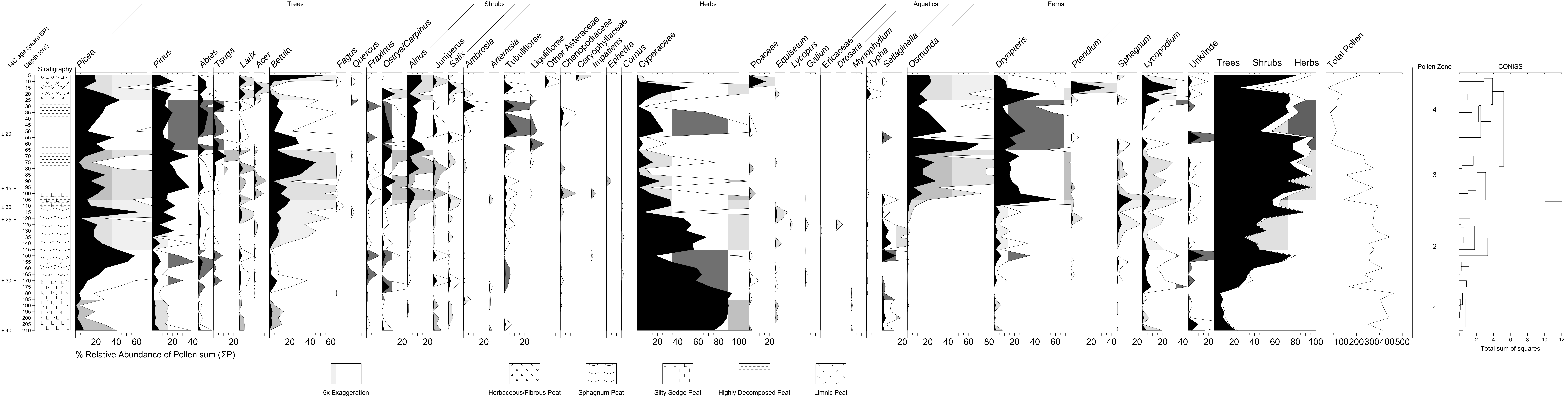
Some pollen samples between 90 and 75 cm were completely dominated by fern spores, which reduced the total amount of pollen counted at these depths (fig. 10). After 4350 years BP (96 cm depth), peat accumulation rate increases. Peat becomes denser, marked by a slight increase in bulk density, and *Sphagnum* disappears in favor of a more closed canopy, as indicated by the large increase in tree pollen. Pioneering species *Betula* and *Alnus* increase and have peaks near the end of this zone as they likely colonized areas affected by disturbance and fire while replacing cooler adapted, later successional species like *Picea* which were abundant in the previous zone (Cwynar, 1978; Tolonen, 1986). *Picea*, *Pinus*, *Abies*, *Acer*, *Fagus*, *Fraxinus*, *Ostrya/Carpinus*, *Salix*, Chenopodaceae, *Impatiens*, and *Ephedra* have their greatest concentrations of the whole record in zone 3.

Zone 4: (60-0 cm, ~1437-0 ^{14}C years BP, ~1471-0 cal year BP)

This zone begins with an increase in *Picea* and *Abies* and a decrease in *Pinus* and deciduous tree species such as *Betula* and *Fraxinus*. The return of *Viola* seeds after their hiatus in zone 3 along with higher proportions of herb pollen suggests a change to cooler temperatures.

The middle of this zone marks the largest peak in *Abies* pollen of the record. Due to *Abies'* affinity for cooler climatic conditions, temperatures may have been cooler in this region. Its presence also suggests a relatively open canopy given that mature individuals are relatively shade intolerant. The soil transitions into coarser peat and the open canopy allowed *Sphagnum* to become present again. Total tree pollen decreases drastically in conjunction with an overall decrease in total pollen and *Osmunda* decreases significantly but quickly rebounds. Tree abundance goes down and *Alnus* increases slightly. High fern abundance and a decrease in overall tree pollen suggest climate was still somewhat dry but not as much as in the previous zone. Tubuliflorae and weeds of Liguliflorae and *Ambrosia*, typically associated with human habitation and agriculture are high in the mid to late area of this zone and potentially indicative of European settlement.

Fig.9: Pollen percent abundance diagram of Aboushagan swamp Core C



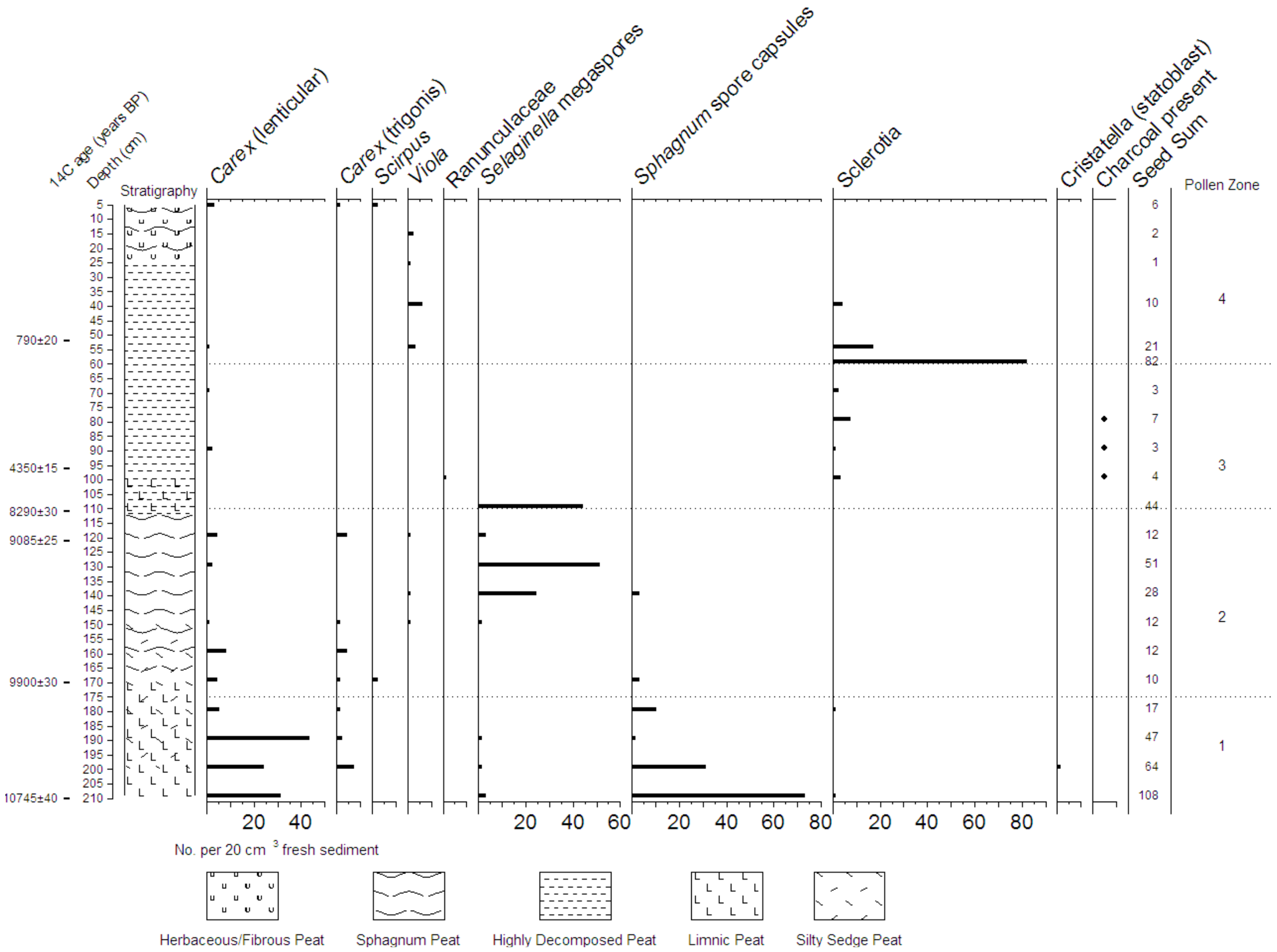


Fig.11: Macrofossil concentration per 20cm^2 in peat in relation to depth.

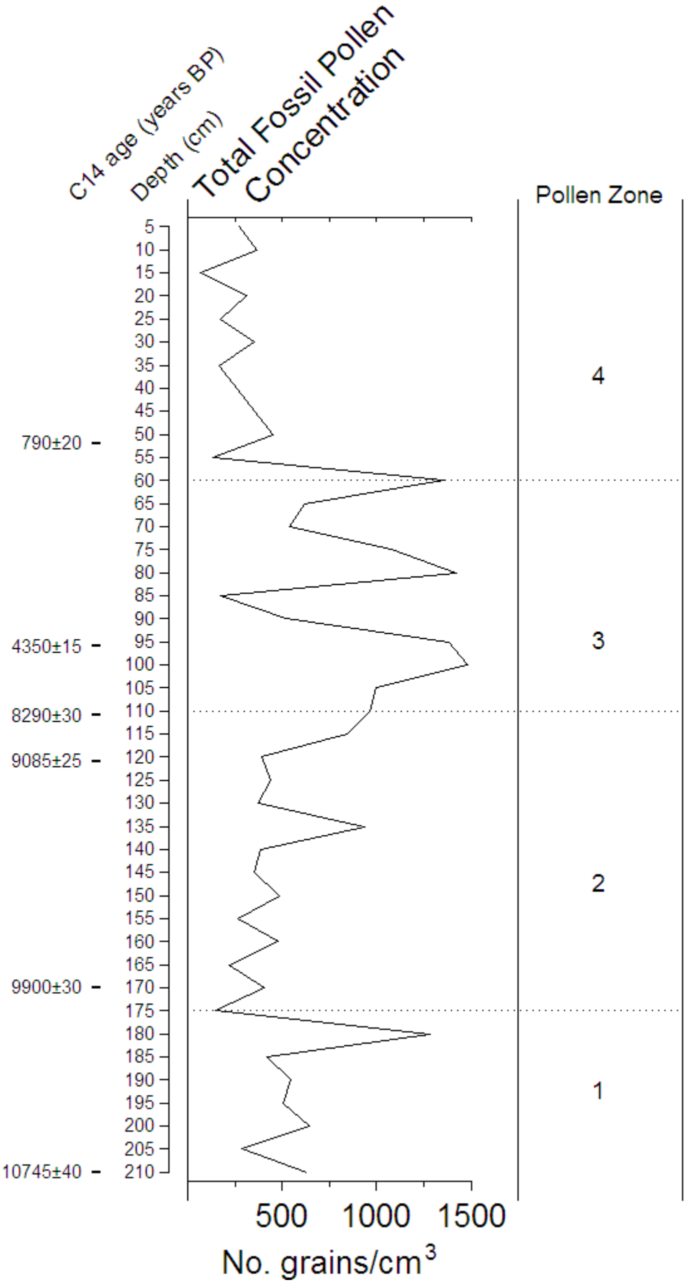


Fig 12: Total fossil pollen concentration per cm^3 versus depth.

CHAPTER 5

DISCUSSION

5.1 Local Swamp Development (Aboushagan swamp basin)

According to pollen evidence, peat accumulation in the present day Aboushagan swamp basin began around 10.7 ka BP. The vegetation was dominated by herbs and sedges, which created a rich minerotrophic fen in the swamp basin. Following 9.9 ka BP, the swamp continued to fill in with organic material, becoming a poor fen still dominated by sedges.

Less than 1000 years later, as the climate warmed more intensely, water levels declined, the canopy partially filled in, and by approximately 8290 ka BP, a mixed coniferous deciduous tree cover along with many fern species dominated the swamp forest. Pine, hemlock and birch likely also occurred in the swamp basin between 8290 and 4350 ka BP but cannot be confirmed due to a lack of peat accumulation and pollen evidence (figs. 7 and 10). Peat accumulation in this area likely stopped due to dry summers and wet winters where high plant productivity, mixed with high microbial activity, and a change in the water table eliminated annual litter formation. Another explanation is that the reduced accumulation is an indicator of the cal 8.2 ka BP cooling event (approximately 7500 years BP). Robichaud and Bégin (2009) saw an interruption in the lateral expansion of peat in the Pointe Escuminac bog in New Brunswick's north-eastern coast between 7500-5500 yr BP. They suggested it was not due to the low amplitude cooling event because they could not find any supporting evidence in their stratigraphic data, however, other studies have found significant evidence for this event in bogs in the Maritimes (Spooner *et al.,* 2002; Kurek, *et al.,* 2004) and Newfoundland (Hughes, *et al.,* 2006) indicated by vegetation changes and decreases in organic matter content. In the Aboushagan swamp, there is a slight drop in organic content around 8290 to 4350 years BP, coinciding with the cal 8.2 ka BP event. There is also a distinct change in the stratigraphy from a *Sphagnum* peat to a silty dense peat and a shift in vegetation beginning at 8.2 ka BP (not calibrated) marking the commencement of pollen zone 3. This suggests possible evidence for a cooling event however other non-climatic factors could be responsible for the stratigraphic change such as natural wetland succession coupled with the aforementioned dry summers possibly responsible for the lack of peat accumulation in this time period.

Following ~1471 ka BP, temperatures cooled again and trees began to share dominance with both shrubs and herbs. The Aboushagan swamp canopy opened up and *Sphagnum* moss in the understory along with spruce and fir trees dominated. In the last approximately 200 years, cold tolerant species such as spruce have decreased in the Aboushagan swamp, replaced by more pine and birch. These changes may indicate a local climate change, vegetative succession without disturbance, or perhaps they provide evidence for a more widespread warming phenomenon.

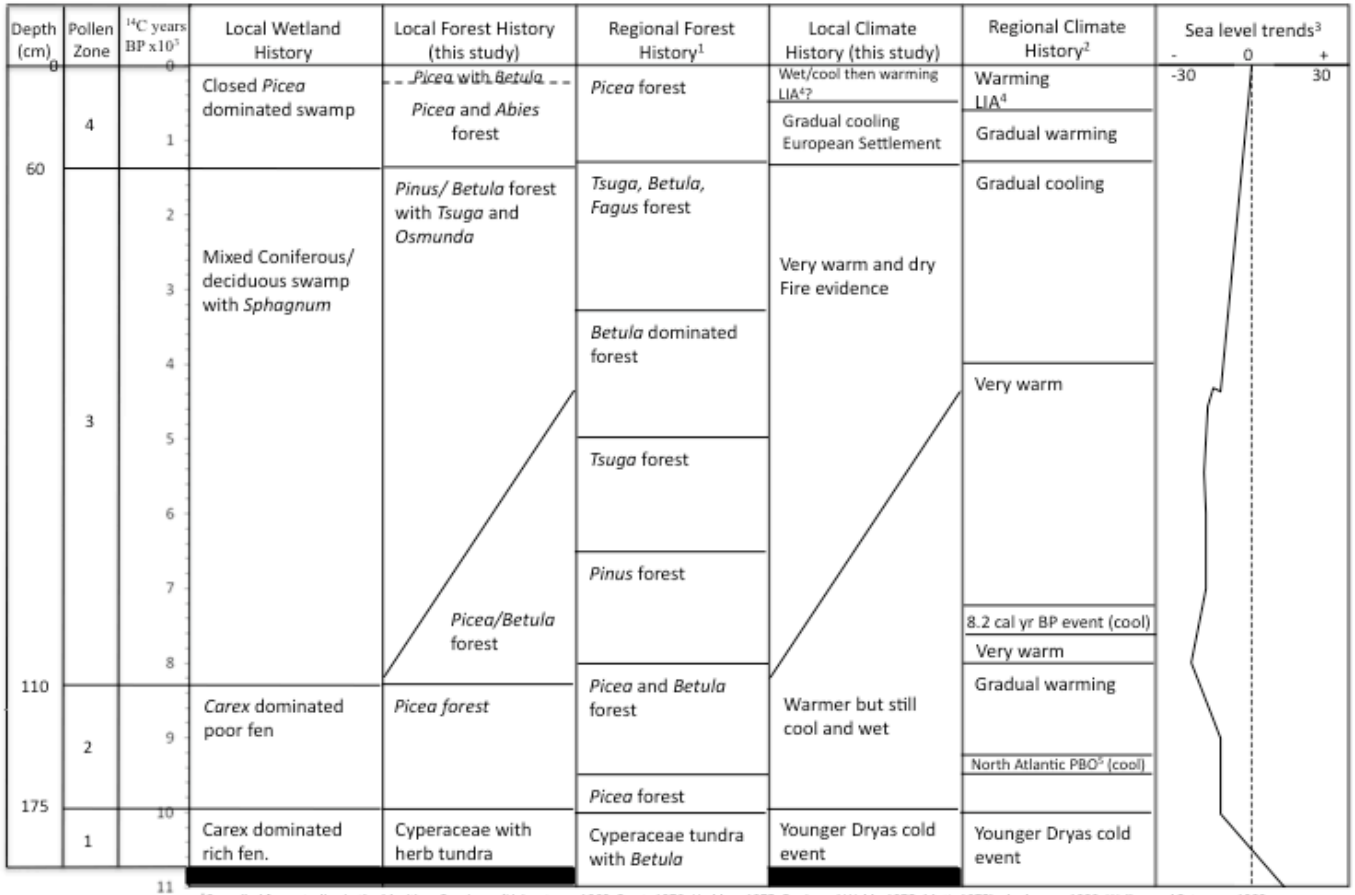
Pollen records of the last 1000 years across North America have variable pollen abundances for the same species with unclear dominant taxa, indicative of many small scale vegetation changes that are difficult to interpret on a regional scale because many of the factors have been local such as human disturbance, succession, or localized climate oscillations. This is amplified in the Atlantic Provinces due to the large variability in climate based on the proximity to the Atlantic Ocean. Given that records are so varied, climatic changes recorded in some regions may not be detected in others.

5.2 Forest Developmental History (Aboushagan swamp upland area)

The surrounding upland area of the Aboushagan swamp was sedge dominated with some shrub birch prior to 9.9 ka BP (fig. 13). As temperatures warmed, spruce forest became dominant in the upper basin. This is consistent with the transition from tundra to spruce and birch forest found regionally (fig. 13). Although slightly later than in the regional area, the forest also began to be dominated by both spruce and birch trees following 8290 ka BP. While regionally the Maritimes began to experience a shift to mixed forest dominated by pine, hemlock and birch, the vegetation in the upland forest of the Aboushagan swamp is unknown due to a lack of peat and pollen accumulation between 8290 and 4350 ka BP. From 4350 to ~1471 ka BP, the forest tree dominance shifts to pine and birch with some hemlock and an abundance of ferns. This is similar to the increase in both hemlock and birch found regionally but there is no correlating increase in pine. This may be due to a local phenomenon allowing the pine to remain present or a false perception of pine abundance based on a lack of data from the previous peat layer.

The forest from ~1471 ka BP to present was primarily dominated by spruce and fir forest correlating almost perfectly with the transition back to spruce forest regionally (fig. 13). In the last approximately 200 years, the forest is still being dominated by spruce with a lower abundance of fir and increase in birch.

Fig. 13: Local (Aboushagan swamp) and regional (New Brunswick, Nova Scotia, and Prince Esward Island) changes in climate and vegetation since deglaciation along with sea level trends in southeastern New Brunswick.



[1] Compiled from studies in the Maritime Provinces (Livingstone, 1968; Prest, 1970; Hadden, 1975; Davis and Webb, 1975; Mott, 1975*b*; Anderson, 1980; Walker and Paterson, 1983; Anderson, 1985; Ritchie, 1987; Warner *et al.*, 1991; Mayle *et al.*, 1993; Cwynar et al., 1994; Mott *et al.*, 2009).

[2] Compiled from studies in the Maritime Provinces (Livingstone, 1968; Railton, 1975; Anderson, 1985; Gajewski, 1988; Mott, 1992; Spooner et al., 2002; Kurek et al., 2004; Anderson et al., 2007; Environment Canada, 2009).

[3] Sea Level represents general trends of the Chignecto isthmus from 11 to 6 ka BP compiled from isobase maps in Shaw et al (2002). Sea level data from 5.8 to 0 ka BP taken from Baie Verte off the Northumberland Strait (Scott et al., 1995)

[4] LIA= Little Ice age

[5] PBO= Pre-boreal Oscillation

5.3 Climatic and Developmental History

Between 10.7 and 9.9 ka BP, the open landscape with some *Picea* trees in the vicinity of the Aboushagan swamp correlates with the Younger Dryas cool climate event known to have occurred between 11 and 10 ka BP. The minimal organic content of sediment at the bottom of core C at the study site is the same as the inorganic-dominated sediment records associated with the Younger Dryas event throughout the rest of eastern Canada (Mayle *et al.,* 1993; Anderson *et al.,* 2007). Conditions were cold and some parts of New Brunswick may even have been covered again by ice as there is evidence of glaciers off the coast of Nova Scotia as late as 10 ka BP (Stea and Mott, 1989).

The fen communities that existed in the Aboushagan basin were dominated by C_3 plants as indicated by low $\delta^{13}C$ values prior to 9.9 ka BP. After this time, values are noticeably higher and distinct from the rest of the core suggesting a significant change in vegetation community occurred at this point. The C/N ratio drops below 20 at around 9.9 ka BP representing the possible presence of both mixed aquatic and terrestrial plants (Lennox *et al.,* 2010). Peat accumulation remained high and higher values of $\delta^{13}C$ as suggest the presence of more terrestrial plants contributing to the litter fall as compared with the previous zone. This positive change in carbon ratio is likely an indicator of a warm climate shift, helping to mark the end of the Younger Dryas period.

From 9.9 to 8.2 ka BP, the C/N ratio is higher than in the previous interval and organic content increases to over 90%, marking an increase in temperatures marking the end of the Younger Dryas. Mayle et al. (1993) found that early high *Picea* abundances in Atlantic Canada reliably indicate the beginning of Holocene sedimentation while high organic content implies that there is more plant material contributing to the litter fall. This time period has one of the highest peat accumulation rates (0.06 cm/year) of the record, likely affected by cooler temperatures where a shorter warm season resulted in plant material being deposited faster than it could be decomposed (Jetté and Mott, 1995). The basin had accumulated some peat material and was likely beginning to fill in resulting in an autogenic wetland transition to a poor fen where the vegetation had less contact with the nutrients in the underlying bedrock, preventing plant enrichment. Shallow pools of water in the peatland at this time likely supported free swimming Rotifers as indicated by microstructure analysis (fig. 6)

Shortly following 8290 years BP, the peat is silty, suggesting the infilling of the basin with sediment as water runs over dryer soils from the upland basin, depositing inorganic materials on the peat (Moore, 1986). $\delta^{15}N$ isotopes increase to their highest levels and C/N ratio jumps up sharply, implying abundant plant life and a transition to more terrestrial species as compared with the previous time frame.

Between 9085 and 4350 years BP, peat accumulation rate drops significantly from the previous zone. From 8290 to 4350 years BP organic content drops and accumulation is only 0.004 cm/year meaning that 15 cm of peat represent nearly 4000 years BP (4400 conventional years). It can be speculated that this is due to a decrease in the rate of peat accumulation or a complete hiatus. Decreased peat accumulation could be caused by a drier phase in climate known to be present in the mid Holocene around 6 ka BP (Lennox et.al., 2010 ; Carcaillet and Richard, 2000; Lavoie and Richard, 2000). This coincides with the re-flooding of the present day Northumberland Strait, potentially making the climate less continental with more coastal influence (Shaw, *et al.,* 2002). High decomposition rates in warm temperatures could decrease or eliminate annual plant litter accumulation. Warm temperatures could cause fires or flooding that can result in sediment erosion and increased decomposition as precipitation washes into the dry basin, removing deposited organic material, and soil aeration increases decomposition rates (Lavoie and Richard, 2000).

Carcaillet and Richard (2000) showed that there was an increase in fire incidence in Eastern Canada after 3 ka BP due to summer droughts but wetter conditions overall due to winter precipitation or less evaporation. Aboushagan swamp microstructure and macrofossil analysis revealed sclerotia fungus and charcoal fragments between 8290 and ~1437 years BP both of which are evidence for regional fires in this zone (Carcaillet *et al.,* 2001) (figs. 6 and 11). Slerotia are an indicator of drier conditions and are often found following fire in paleo records. Since they are part of a mycorrhizal fungus, they establishes themselves beneath the surface and do not necessarily belong to the stratigraphic depth where they are found (Jasinski et. al., 1998; Jasinski and Payette, 2007). Therefore sclerotia's large presence is evidence of fire occurrences or dry periods but not necessarily at the depth they were found.

An increase in copper in core C at 65 cm matched by a copper peak at 35 cm in Core B does not appear to reflect any specific change in vegetation to more copper tolerant species. The vegetation does seem to change at the interval between pollen zone 3 and 4 around 1437 years BP as indicated by CONISS analysis, suggesting that there is a possibility that the high copper may have had an effect on plant community at the time (fig. 10). However, similarities between local vegetation and regional evidence suggest that the vegetation community change was a regional event and that copper accumulation in the sediments is a contemporary phenomenon occurring in previously deposited sediments, potentially influenced by climate (fig. 13).

A fire could have increase copper flow to the surface through evapo-transport if the soil were exposed such as in the case of the northern Aboushagan swamp. Fire can also concentrate Cu and other minerals in the soil as indicated by elevated levels of Ti, Al, and Ca, all of which peak at the same depth as copper in core C. Fire indicators such as *Larix* and fungal sclerotia are also very abundant at the time of the copper peak but no charcoal evidence was found. Despite fossil evidence for an occurrence of fire, as previously mentioned, most of the mineral species assessed peaked at this same depth thus higher copper concentrations are likely not related to fire occurrence.

From 790 years BP to the top of the core, the peat accumulation is the highest of all the record, reaching 0.066 cm/year, likely due to the vegetation maturity of the swamp and the general warming trend occurring in north eastern North America over the past thousand years (Lennox et.al., 2010).

There is potential evidence of the little ice age event between approximately 532 and 228 years BP (1474 to 1814 cal years BP) as indicated by a notable decrease in $\delta^{13}C$ and $\delta^{15}N$ isotopes and a decrease in organic content. Tree pollen abundance suddenly drops below 30% and is replaced by herb species. *Picea* also increases greatly in abundance indicating cooler temperatures. This could be a local event such as increased moisture or flood as indicated by increases in *Lycopodium* mosses, *Typha*, *Selaginella*, Cyperaceae, and the presence of *Debarya* zygospores (VanGeel, 1986). Zygospores can also indicate times of uncertain environmental changes or deterioration of habitat as they wait for optimal climate conditions before germinating (VanGeel, 1986; Head, 1992). Regardless of the cause, these species imply that the swamp had areas of open water at this time. The little ice age is reported to have occurred between 1450 and 1800 cal years

BP, the end of which correlates with approximately 152 years BP in the core. This is consistent with vegetation changes such as increases in *Pinus* and *Betula* suggesting warmer temperatures as well as indicators of European settlement such as Poaceae and Caryophyllaceae. This time frame was determined by dendrochronology, glacier retreat and ice deposits among other geological observations worldwide (Lamb, 1969; Swain, 1978; Gajewski, 1988; Stocker and Mysak, 1992) however the scale varies greatly by region and distinct dates are not clear for all areas (Gajewski, 1993). The little ice age is not often detected in pollen samples and it has been argued that this is because vegetation does not react to climatic change quickly enough to show a change in the pollen record over shorter time scales (Davis *et al.,* 1980; 1986). However, studies have correlated vegetation succession following fire occurrence over short time scales (Bernabo, 1981; Green 1981) and fine resolution pollen records have the ability to detect short events such as the little ice age (Swain, 1978; Gajewski, 1987, 1988, 1993).

While other palynological studies from the Maritimes do not mention the little ice age in the interpretation of their results, an examination of regional pollen diagrams shows decreased total pollen concentrations in the same general time frame as well as increases in herb pollen similar to the Aboushagan swamp (Mott, 1975a; Anderson, 1980; Walker and Paterson, 1983; Anderson, 1985; Jetté and Mott, 1989). However this correlation may simply be due to the land being cleared for farming and development throughout the Maritimes by human intervention.

5.4 Copper

It has long been noted in wetlands that if sulphate is present along with anaerobic conditions, bacteria can reduce it to form sulphide, which produces highly insoluble precipitates with metal species with little influence from pH (Sobolewski, 1996). Organic materials and humic acids can also react with copper and form chelate rings which binds the metal ions to the release of H+ ions (Wei and Tobin, 2004), a process that is highly reliant on constant pH where the optimum pH range for metals capture is typically 3.5-6.5 (Brown *et al.,* 2000). Previous studies confirmed that the copper in the Aboushagan swamp is tightly bound to organic material as copper humates (Smith, 1960; Fraser, 1961a; Kendrick, 1962; Boyle, 1977; Sobolewski, 1999). It is likely that the slightly alkaline pH of the Aboushagan swamp promotes copper's bond to nitrogen and oxygen creating the chelate compounds. This coupled with a manageable copper loading rate and a lack of other metals competing for the same sorption sites could also be a factor. Furthermore, the suggested constant alkaline pH of the water in addition to the low sulfur concentrations (less than 0.2%) recorded by Shotyk (1988) suggest the role, if any, played by sulfur in the sequestration of the copper is minimal. Its influence on copper's ability to enter the swamp in the first place however is substantial as it is likely transported in the form of copper sulphates.

The record of copper content in the peat is moderately low except for a small peak at the base near the contact with underlying mineral sediments and a second peak at about 65 cm depth or ~1467 year BP in the central part of the basin. The peak in copper concentrations occurs preceding a change in the fossil plant record in conjunction with a decrease in arboreal and total pollen (figs. 8 and 10). There is also a decrease in total pollen concentration, indicative of a change in the pollen community (fig. 13). The high peak in copper in both core B and C surrounding similar stratigraphy suggests that the relative peaks in quantities are not anomalous. While the plant community appears to be transitioning due to an increase in copper, vegetation communities on a regional scale all began to change in this interval suggesting the transition was caused by a large-scale allogenic climate change rather than an autogenic wetland process (fig. 13). There was also no indication of a change in organic matter content at the time of the copper peak. Therefore, it seems there is no cause-effect relationship between the copper and the nature of the plants occupying the basin.

This conclusion is supported by previous studies of the Aboushagan swamp which found that the copper in the soils was not directly correlated with how much copper was found in plant matter through uptake (Dykeman and DeSousa, 1966). While some copper is taken up by roots and likely forms plaques due to radial oxygen loss (Ellis *et al.,* 1994), there is no evidence to suggest this is a key process of copper sequestration in the Aboushagan swamp. Thus it is difficult to attempt to correlate the copper found at specific depths in the peat with the pollen that was found at the same depth.

Given that the copper peak in core C was very discrete in relation to depth as opposed to the broad peak in core B, the metal was likely moved and concentrated in specific regions of the cores by hydrologic processes rather than plant uptake or any other biotic factor, explaining the variation between the copper concentration of core B and core C. Other major nutrients such as Ca, Mg, and Na show increases in concentration at the same depth in the core, further suggesting that the metals were moved by hydrologic processes rather than plant uptake or biotic functions. Shifting pathways in groundwater flow would explain the variation and suggests that copper is entering the area via underground seepages and streams that are constrained to certain depths within the peat since copper was not found throughout the entire length of core C. This implies that copper is being sequestered in the previously deposited peat layers as the stream moves through it and not in the time frame represented by that depth. Post depositional sequestration of copper implies that the earliest copper could have entered the swamp is circa 1430 years BP.

Copper flowing solely through an underground stream would also explain why there does not appear to be a strong correlation between copper concentration and organic matter content throughout the entire core as was observed in the swamp by Fraser (1961b). He likely took soil samples from organic material through which copper was actively flowing where one would expect to find higher levels of copper anyway.

Given that the copper appears to be concentrated laterally in the soil, the change that initiated copper's entry into the Aboushagan swamp basin likely occurred outside the basin. A disturbance or autogenic succession in the basin itself is possible however unlikely since vegetation removal by soil destabilization through fire, flood or other autogenic affect could have concentrated copper in upper layers of the peat by upwelling of copper through evaporation, thus making it more bioavailable to plants and the vegetation community would likely not have renewed itself (Glaser et. al., 1996). Disturbances in the upland region however could have initiated lateral downhill groundwater flow from the copper containing Boss Point Formation located west of the swamp, effectively providing mineral transport from the copper deposit to the swamp. Upon arrival, the copper was sequestered in organic complexes and continues to accumulate today in the organic rich peat deposits.

Climatically, there are two such events that could have caused a change in the upland hydrology thus affecting the copper content of the Aboushagan swamp. The first occurs around 1437 years BP where there is a shift from warm and dry temperatures to cool temperatures with increased precipitation. As a result, more runoff from the upland region could have transported copper down and into the basin. The little ice age event between 1450 and the late 1800s could also have caused the copper increase. Winters were long and cold with lots of precipitation in the form of snow. Increased annual snowmelt perhaps in conjunction with freeze thaw effects along the boss point formation, could have made more copper available for transport in water.

It should be noted that human disturbance in the region such as the removal of forests could also have affected the hydrology of the region at any time following European settlement. It is also possible that the copper presence in the swamp is an extremely recent phenomena caused by some other human development such as roads or the opening of a copper mine near Dorchester.

Therefore, the story of the swamp's development begins with vegetation being able to colonize the basin before copper began to seep into the region. Plant development laid down peat material that continued to accumulate as the swamp developed. Some time following a climatic change to cooler conditions around 1.4ka BP, copper began to enter the swamp through underground streams and seepages where it was concentrated in highly organic regions of the peat material ensuring that it did not become bioavailable in high enough quantities to be toxic to the vegetation on the surface. Therefore, as time has passed, copper has accumulated in the peat as it develops and the swamp today continues to store and sequester an abundance of heavy metal.

A drastic change in surface vegetation or hydrology today could potentially release the sequestered copper as was seen in the northern region of the swamp. Warner and Asada (2008) found that copper in the cleared northern region of the swamp was visible at the soil's surface and that the moss *Pohlia nutans* among other copper tolerant vegetation seemed to be related to the high copper content of the sediments. Vascular plants were unable to re-establish themselves and the cleared area continues to expand annually. In this case, the surface vegetation was cleared by fire in 1898 and the copper entering the swamp through seepages was drawn up to the surface layers of soil through increased evaporation. High copper concentration in the barren soil prevented the re-establishment of the forest. Given this, if the surface vegetation were cleared from the southern Aboushagan swamp (this study), it is possible that the soil there would also become toxic to plant life. A strong surface layer of vegetation ensures that the copper does not escape from the wetland through evaporation, and saturated soils allow plant litter accumulation and more organic material for the copper to be sequestered in.

5.5 Peatland records as indicators of palaeoclimate

While paleolimnology may be better equipped to identify allogenic or regional vegetation changes where pollen is windblown from great distances, peatlands are more sensitive to autogenic or local changes as they gather pollen from plants in the wetland itself and the upland forest surrounding it (Janssen, 1973; Aaby, 1986; Jackson, 1990; Bunting *et al.,* 1998). Peatlands also have reduced sediment reworking compared with lakes, which allows more confident conclusions to be drawn from the depth with which a sample is removed as long as peat accumulation rate is known (Green, 1983). This sensitivity makes peatlands important paleoecological indicators as they can be used to infer past vegetation and paleoclimates both locally and regionally through on site pollen and macrofossil analysis compared with regional forest records. In regions such as the

Maritimes and Atlantic provinces where climate and vegetation can vary significantly within a few kilometers (Livingstone, 1968), this level of sensitivity is invaluable in detecting historical ecological transformations.

In the Aboushagan swamp, vegetational and climate histories were similar to the surrounding region but distinct differences allowed specific inferences to be made regarding what occurred in the swamp basin itself as well as the immediate forest region following deglaciation (fig. 13). An example is the large spike of *Picea* in pollen zone 2 in conjunction with a *Sphagnum* dominated peat profile and macrofossil evidence indicating a *Sphagnum* swamp. This suggests that *Picea* was likely present along the wetland margins but also in the upland area in order to account for the large pollen abundance. A noticeable difference between the regional and local forest history of the swamp is the lack of hemlock and pine maxima in the wetland basin, inferring a local change in hydrology that is not widespread throughout the region.

What is more striking is the similarity between the history the local forest with the regional forest (fig. 13). Local and regional trends in dominant species such as Cyperaceae, *Picea*, *Betula*, *Pinus*, and *Tsuga* transition similarly within a few hundred years of one another. Local and regional climate also match up well with each other as well as with the transitions in vegetation. As the Younger Dryas period was ending around 10 ka BP, both the local and regional vegetation shifted from sedge-dominated ecosystem to a *Picea* forest. The early fen in the basin changed to a *Sphagnum* swamp when the open treed landscape became covered by closed *Picea* forest. While the Aboushagan basin remained primarily a *Picea*-dominated ecosystem between 9.9 and 8.2 ka BP, the regional forest had more *Betula* present, creating a mixed *Picea/Betula* forest in the upland. Around 8.2 ka BP the Aboushagan basin also transitioned into a *Picea/Betula* forest just as temperatures were increasing regionally and the Holocene was beginning. The close relationship shows that climate, which is thought to account for some of the changes in forests, seems to have influenced some changes in the wetland. The slower appearance of *Betula* in the Aboushagan basin may be explained by the pattern of tree arrival throughout the Maritimes. Shortly following deglaciation, areas off the coast were exposed as dry land (Prest and Grant 1969) and could have acted as bridges for migrating plant species (Livingstone 1964; 1968; Zinck, 1998; Holland 1981). Green (1986) suggested that species such as *Picea*, *Pinus*, *Betula*, and *Quercus* moved into the area in two waves; the first up the coastal strip via exposed areas on George and Brown Banks and into southwestern Nova Scotia. The second wave through the eastern United States and up into New Brunswick. The two waves eventually merged and sites along the Bay of Fundy and in the Chignecto Isthmus were among the last regions of the Maritimes to be colonized by these species.

Approximately 8000 years BP, the previously dry coastal areas were submerged, cutting off this plant migration route (Grant, 1975). Any species that were not yet in the Maritimes would have had to migrate up through mainland New Brunswick or through seeding along the Bay of Fundy coasts. This coincides with the warming of the Holocene as well as the dominance of *Pinus* in the regional forest of New Brunswick. In the Aboushagan swamp basin, a lack of peat accumulation prevents any direct correlation of local versus regional vegetation, however it does show a distinct change in vegetation community around the same time interval. This speaks to the accuracy with which wetlands record paleoecological information.

Following 4.3 ka BP, the vegetation in the Aboushagan swamp is still similar to the regional area with a mixed coniferous deciduous forest. The swamp basin changes again in conjunction with regional vegetation to a more *Picea*-dominated forest around 1437 years BP, which is around the same time there is a gradual warming in the region.

5.6 Implications for phytoremediation

The Aboushagan copper swamp is an example of a metal removing peatland functioning under natural conditions. Alkaline pH and low or slow copper loading rates coupled with metal species competing for sorption sites in the peat may explain the ability of the swamp to sequester large quantities of copper without affecting the surface vegetation layer. The copper never becomes bioavailable since it enters the swamp below the surface and is sequestered.

Brown et al. (2000) found that the total sorption capacity of peat tended to increase in the presence of competing metal species where one ion may be bound less frequently than another. Given this, the particular makeup and quantity of metals in the Aboushagan swamp may account for the peat’s ability to immobilize copper so efficiently. Brown et al. also found that metals can be recovered from peat using an acid elution process that allows the peat to be re-used with little effect on the peat's sorption capacity. Bulk peat can soak up toxic metals, have the metals eluted, and be returned to the ecosystem for re-sorption. Remediation alternatives for contaminated sites could include re-creating the peat conditions found in the Aboushagan swamp to form a functioning peatland ecosystem or simply involve the use of peat in bulk-form applied to a site where sorption directly from soil and water could occur. Most importantly, having toxins enter peat below the layer of surface vegetation is pivotal in this type of remediation design to ensure that the wetland remains healthy while continuing to accumulate these toxins and helping to keep them sequestered. This should allow effective removal of copper and potentially other heavy metals from these contaminated areas.

5.7 Future Research

This study describes the developmental history of the Aboushagan copper swamp in southeastern New Brunswick in an attempt to better understand the relationship between past vegetation and the copper found there. More paleoecological studies on peatlands from the southeastern area of New Brunswick would be useful in further defining to post glacial history of this area in comparison with the Maritime region as a whole.

A hydrologic study of the area would prove useful to determine exactly where and how the copper is entering the swamp and if patterns of water flow today are similar to those of the past. Determining the locations of the copper seepages and the copper content and distribution in relation to groundwater could explain why the concentrations vary so substantially by area (core B and C) and provide answers as to why the hydrology changed in the recent past and how copper was transported into the basin in the first place. Sulfur could also be quantified and mapped to verify whether Shotyk's (1988) claim that the extent of sulfur was too low to account for much of the copper sequestration is true throughout the entire swamp. While not necessarily involved in the sequestration of copper, sulfur may be responsible for the mobilization and transport of the metal into the swamp.

It seems apparent that further chemical analysis could be done to better understand what conditions are allowing the Aboushagan swamp to sequester copper in the organic material almost exclusively in the form of copper humates and why it is so effective. It was postulated that the high pH of the swamp allows this to occur however copper loading and sorption site competition have not been addressed as possible explanations. It may also be useful to determine where the minerals that keep the water alkaline are coming from and how their high level has been maintained over time. This may help determine if the copper may be re-suspended into the soil if the pH were to become more acidic and determine if the conditions under which the Aboushagan swamp sequesters copper can be implemented in other copper and toxic metal phytoremediation efforts.

Further study may also investigate whether the lack of pine and hemlock maxima and hiatus of peat accumulation detected in the Aboushagan swamp is local or widespread throughout the southeastern region of the province. If it is a local effect, further pollen studies from the region can better describe the vegetation of that time frame and confirm that it matches the rest of the Maritimes.

This investigation is one of few paleoecological studies conducted in southeastern New Brunswick on peatland ecosystems. Given their usefulness as climatic and vegetative indicators of past environments, paleoecological reconstructions might provide the basis for more refinement of postglacial climate history in a region which seems to have experienced a complex history and for which little is known.

REFERENCES

Aaby, B. 1986. Paleoecological studies of Mires. In: Handbook of Holocene Paleoecology and Paleohydrology (Eds. Berglund, B.E.). John Wiley and Sons Ltd. Great Britain pp 145-160.

Adriano, D.C. 1986. Trace elements in the terrestrial environment. Springer Verlag, New York.

Anderson, T.W. 1980. Holocene vegetation and climatic history of Prince Edward Island, Canada. Can. J. Earth Sci., 17: 1152-1165.

Anderson, T.W. 1985. Late-Quaternary pollen records from eastern Ontario, Quebec, and Atlantic Canada. In: Pollen Records of Late-Quaternary North American Sediments (Eds. V.M. Bryant Jr. and R.G. Holloway). The AASP Foundation, Dallas, 426 p.

Anderson, T.W., Levac, E., Lewis, C.F.M. 2007. Cooling in the Gulf of St. Lawrence and estuary region at 9.7 to 7.2 14C ka (11.2–8.0 cal ka): Palynological response to the PBO and 8.2 cal ka cold events, Laurentide Ice Sheet air-mass circulation and enhanced freshwater runoff. Palaeogeography, Paleoclimatology, Palaeoecology, 246: 75-100.

Bendell-Young, L., Chouinard J., Pick, F.R. 1994. Metal Concentrations in Chironomids in Relation to Peatland Geochemistry Arch. Environ. Contam. Toxicol. 27, 186-194.

Beschel, R.E. 1959. The Copper Swamp in the Aboushagan Woods, North Sackville, N.B. Summary for the maritime excursion after the 9th International Botanical Congress in Montreal, Sept. 1959. Mimeographed.

Bernabo, J.C. 1981. Quantitative estimates of temperature changes over the last 2700 years in Michigan based on pollen data. Quat. Res., 15: 143-159.

Boyle, R.W., 1977. Cupriferous bogs in the Sackville area, New Brunswick, Canada. J. Geochem. Explor., 8: 495-527.

Brown, P.A., Gill, S.A., Allen, S.J. 2000. Metal removal from wastewater using peat. Wat.Res., 34(16): 3907-3916.

Bunting, M.J., Warner, B.G., Morgan, C.R. 1998. Interpreting pollen diagrams from wetlands: pollen representation in surface samples from Oil Well Bog, southern Ontario. Can. J. Bot, 76: 1780-1797.

Carcaillet, C. and Richard, P.J.H. 2000. Holocene changes in seasonal precipitation highlighted by fire incidence in eastern Canada. Climate Dynamics, 16: 549-559.

Carcaillet, C., Bouvier, M., Frechette, B., Larouche, A.C., Richard, P.J.H., 2001. Comparison of pollen-slide and sieving methods in lacustrine charcoal analyses for local and regional fire history. Holocene 11: 467-476.

Charman, D.J. 2002. Peatlands and environmental change. John Wiley and Sons, Chichester, England, 312 pp.

Cornfield, A.H. 1977. Effects of addition of 12 metals on CO_2 release during incubation of an acid sandy soil. Geoderma 19:199–203.

Cwynar, L.C. 1978. Recent history of fire and vegetation from laminated sediment of Greenleaf Lake, Algonquin Park, Ontario. Can. J.Bot. 56: 10-21.

Cwynar, L.C., Burden, E., McAndrews, J.C., 1979. An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. Canadian journal of Earth Sciences, 16: 1115-1120.

Cwynar, L. C., Levesque, A. J., Mayle, F. E. and Walker, I. 1994. Wisconsinan Late-glacial environmental change in New Brunswick: a regional synthesis. Journal of Quaternary Science*,* 9: 161-164.

Davis, M.B., Spear, R.W., Shane, L.C.K. 1980. Holocene climate of New England. Quaternary Research, 14: 240-250.

Davis, M.B. 1986. Climatic instability, time lags, and community disequilibrium. In: J. Diamond and T. Case (Editors), Community Ecology. Harper and Row, New York, NY, pp. 269-284.

Davis, R.B. and Webb, T. III. 1975. The contemporary distribution of pollen in eastern North America: a comparison with vegetation. Quaternary Research, 5: 395-434.

Dean, W.E. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. J. Sed. Pet. 44: 242–248.

Drever, J.I., 1982. The Geochemistry of Natural Waters. Prentice-Hall, Englewood Cliffs, N.J., 388 pp.

Dyke, A.S. and Prest, V.K. 1987. Late Wisconsinian and Holocene retreat of the Laurentian Ice Sheet. Geological Survey of Canada, Map 1702A, scale 1:5 000 000.

Dykeman, W.R., and A. S. DeSousa. 1966. Natural mechanisms of copper tolerance in a copper swamp forest. Can. J. Bot. 44: 871-878.

Ellis, J.B., Shutes, R.B., Revitt, D.M., Zhang, T.T. 1994. Use of macrophytes for pollution treatment in urban wetlands. Resources, Conservation and Recycling, 11: 1-12.

Ennis, M.T. 1962. The chemical nature of the copper complexes in peat. Irish. J. Agric. Res., 1: 147-155.

Environment Canada, 2009. National Climate Data and Information Archive: Climate Normals & Averages 1971-2000 for Sackville, New Brunswick. Retrieved from www.climate.weatheroffice.gc.ca.

Faegri, K., and Iversen, J., 1975. Textbook of pollen analysis. 3rd ed. Hafner Press, New York, NY. 295 p.

Flint, R. E. 1953. Probable Wisconsin substages and late-Wisconsin events in north-eastern United States and southeastern Canada. Geol. Soc. America Bull. 64:897-919.

Fraser, D.C., 1961a. A syngenetic copper deposit of recent age. Econ. Geol., 56: 951--962.

Fraser, D.C., 1961b. Organic sequestration of copper. Econ. Geol., 56: 1063--1078.

Fraser, D.C. 1961c. Cupriferous peat: embryonic copper ore? Canadian Institute of Mining and Metallurgy, Bulletin, 54, No. 591, pp. 500-503.

Gajewski, K. 1987. Climatic impacts on the vegetation of eastern North America during the past 2000 years. Vegetation, 68: 179-190.

Gajewski, K. 1988. Late Holocene climate changes in Eastern North America estimated from pollen data. Quaternary Research, 29: 255-262.

Gajewski, K. 1993. The role of paleoecology in the study of global climatic change. Rewview of Paleobotany and Palynology, 79: 141-151.

Gardea-Torresdey, J.L., Tang, L., Salvador, J.M. 1996. Copper adsorption by esterfied and unesterfied fractions of Sphagnum peat moss and its different humic substances. Journal of Hazardous Materials, 48: 191-206.

Gilders, R. and Cheung, L. Agglomeration and bio-leaching of a secondary copper bearing ore. Unpublished report prepared for Falconcrest Resource Inc, Saint john NB. Pp. 1-27.

Glaser, P.H. and Janssens, J.A. 1986. Raised bogs in eastern North America: transitions in landforms and gross stratigraphy. Canadian Journal of Botany, 64: 395-415

Glaser, P.H., Bennett, P.C., Siegel, D.I., Romanowicz, E.A. 1996. Paleo-reversals in groundwater flow and peatland development at Lost River, Minnesota, USA. The Holocene, 6(4): 413-421.

Grant, D.R. 1975. Recent coastal submergence of the Maritime Provinces. In: Enironmental change in the Maritimes. Proc. N.S. Inst. Sci. 27(Suppl. 3): 83 - 102.

Green, D.G. 1976. Nova Scotian forest history: Evidence from statistical analysis of pollen data. Ph. D. dissertation, Dalhousie University, 155p.

Green, D.G. 1981. Time series and postglacial forest ecology. Quat. Res., 15: 265-277.

Green, D.G. 1983. The ecological interpretation of fine resolution pollen records. New Phytol., 94: 459-477.

Green, D.G. 1986. Pollen evidence for the postglacial origin of Nova Scotia's forests. Canadian Journal of Botany 65, 1163–1179.

Grimm, E.C. 1987. CONISS: a fortran 77 program for stratigraphically constrained cluster analysis by method of incremental sum of squares. Computers and Geosciences, 13(1): 13-35.

Gussow, W.C. 1953. Carboniferous stratigraphy and structural geology of New Brunswick, Canada. Am. Assoc. Petrol. Geol. Bull. 37(7):1713-1816.

Hadden, K. A. 1975. A pollen diagram from a postglacial peat bog in Hants Country, Nova Scotia. Canadian Journal of Botany, 53: 39-47.

Head, M.J. 1992. Zygospores of the Zygmataceae (Division Chlorophyta) and other freshwater algal spores from the uppermost Pilocene St. Erth Beds of Cornwall, Southwestern England. Micropaleontology, 38(3): 237-260.

Hinds, H.R. 2000. Flora of New Brunswick 2nd Ed. Primrose Press, Fredericton NB. 699 pp.

Holland, P. G. 1981. Pleistocene refuge areas, and the revegetation of Nova Scotia, Canada. Prog. Phys. Geogr. 5: 535-562.

Hughes, P.D.M., Blundell, A., Charman, D.J., Bartlett, S., Daniell, J.R.G., Wojatsche, A., Chambers, F.M. 2006. An 8500 cal. Year multiproxy climate record from a bog in eastern Newfoundland: contributions of meltwater discharge and solar forcing. Quaternary Science Reviews, 25: 1208-1227.

Jackson, S.T., 1990. Pollen source area and representation in small lakes of northeastern United States. Review of Paleobotany and Palynology, 63: 53-76.

Janssen, C.R. 1973. Local and regional pollen deposition. In: Quaternary Plant Ecology (Eds. H.J.B. Birks and R.G.West), Blackwell. Pp 31-42.

Jasinski, J. P. P., B. G. Warner, A. A. Andreev, R. Aravena, S. E. Gilbert, B. A. Zeeb, J. P. Smol, and A. A. Velichko. 1998. Holocene environmental history of a peatland in the Lena River Valley, Siberia. Canadian Journal of Earth Sciences, 35:637–648.

Jasinski, J.P.P., Payette, S. 2007. Holocene occurrence of *Lophodermium piceae*, a black spruce needle endophyte and possible paleoindicator of boreal forest heath. Quaternary Research, 67: 50-56.

Jetté, H. and Mott, R.J. 1995. Vegetation and climate of maritime Canada 6000 years BP- a synthesis. Géographie physique et quaternaire. 49(1):141-162.

Johnson, S.C. 2008. Carboniferous geology of the Amherst area (NTS 21 H/16 and part of 21 H/09). Westmorland County, New Brunswick. New Brunswick Department of Natural Resources: Minerals, Policy and Planning Division. Plate 2008-24.

Jowsey, P.C. 1966. An improved peat sampler. New Phytologist, 65, 245–248.

Kabata-Pendias, A., and H. Pendias. 1991. Trace elements in soils and plants. 2d ed. CRC Press, Boca Raton, FL.

Kendrick, W.B. 1962. Soil Fungi of a Copper Swamp. Canadian Journal of Microbiology, 8: 639-647.

Korpijaakko, M.L. 1976. On the origin and geobotanical development of Muskeg in New Brunswick Fredericton. PhD dissertation, University of New Brunswick, Fredericton, New Brunswick, Canada, 146 pp.

Kuhry, P., Nicholson, B.J., Vitt, D.H. and Bayley, S.E. 1993. Development of *Sphagnum*-dominated peatlands in boreal continental Canada. Canadian Journal of Earth Sciences, 29: 1070-1090.

Kurek, J., Cwynar, L.C., Spear, R.W. 2004. The 8200 cal yr BP cooling event in eastern North America and the utility of midge analysis for Holocene temperature reconstructions. Quaternary Science Reviews, 23: 627-639.

Lamb, H. H. (1969). Climatic fluctuations. In: World Survey of Climatology, Vol. 2 (Ed. H. Flohn). Elsevier, New York. pp. 173-249.

Lamb, A.L., Vane, C.H., Wilson, G.P., Rees, J.G., Moss-Hayes, V.L. 2007. Assessing δ^{13}C and C/N ratios from organic material in archived cores as Holocene sea level and paleoenvironmental indicators in the Humber Estuary, UK. Marine Geology, 244: 109-128.

Lavoie, M. and Richard, P.J.H. 2000. Postglacial water-level changes of a small lake in southern Quebec, Canada. The Holocene, 10(5): 621-634.

Lennox, B., Spooner, I., Jull, T., Patterson, W.P. 2010. Post-glacial climate change and its effect in a shallow dimictic lake in Nova Scotia, Canada. J. Paleolimnol., 43: 15-27.

Livingstone, D.A. 1964: The pollen flora of submarine sediments from Nantucket Shoals. American Journal of Science 262, 479-8

Livingstone, D.A. 1968. Some interstadial and postglacial pollen diagrams from Eastern Canada. Ecological Monographs, 38: 87-125.

Mayle, F.E., Levesque, A.J., Cwynar, L.C. 1993. Accelerator-Mass-Spectrometer Ages for the Younger Dryas Event in Atlantic Canada. Quaternary Research, 39: 355-360.

Mayle, F.E. and Cwynar, L.C. 1995. Impact of the younger Dryas cooling event upon lowland vegetation of Maritime Canada. Ecological Monographs, 65(2): 129-154.

Mays, P. A. and G. S. Edwards. 2001. Comparison of Heavy Metal Accumulation in a Natural Wetland and Constructed Wetlands Receiving Acid Mine Drainage. Ecological Engineering 16:487-500.

McAndrews, J.H., Berti, A.A., Noris, G. 1973. Key to the Quaternary Pollen and Spores of the Great Lakes Region. Royal Ontario Museum Life Sciences Miscellaneous Publication, The University of Toronto Press: Toronto, Ontario; 64 pp.

McSween, H.Y., Richardson, S.M., Uhle, M. 2003. Geochemistry: Pathways and Processes 2nd Edition. Chapter 13 pp 263- 284.

Meyers, P.A. and Lallier-Vergès, E. 1999. Lacustrine sedimentary organic matter records of Late Quaternary paleoclimates. Journal of Paleolimnology, 21: 345-372.

Moore, P.D. 1986. Hydrological changes in mires. In: Handbook of Holocene Paleoecology and Paleohydrology (Eds. Berglund, B.E.). John Wiley and Sons Ltd. Great Britain pp 91-107.

Mott, R.J. 1975a. Palynological studies of lake sediment profiles from southwestern New Brunswick. Can. J. Earth Sci. 12: 273-288.

Mott, R.J. 1975b. Post glacial history and environments in southwestern New Brunswick. Proc. N.S. Inst. Sci., 27 (Supplement 3): 67-82.

Mott, R.J. 1992. Postglacial climatic history of Nova Scotia from pollen and plant microfossil evidence. In *The Climate of Nova Scotia; Proceedings of a Symposium, November, 1991*. Atmospheric Environment Service, Environment Canada, Dartmouth, N.S.

Mott, R.J., Walker, I.R., Palmer, S.L., Lavoie, M. 2009. A late-glacial-Holocene paleoecological record from Pye Lake on the eastern shore of Nova Scotia, Canada. Canadian Journal of Earth Science, 46: 637-650.

Natural Resources Canada. 1957. Atlas of Canada. Retrieved from http://atlas.nrcan.gc.ca/site/english/maps/archives/3rdedition

Natural Resources Canada. 2006. Atlas of Canada: Land Cover. Retrieved from http://atlas.nrcan.gc.ca/site/index.html.

Natural Resources Canada. 2010. Atlas of Canada: Topographic maps. Retrieved from http://atlas.nrcan.gc.ca/tmp/ntdb_mspaserv461ref128526140410879.png

New Brunswick Department of Natural Resources. 1999. Mineral Occurrence Database: Dorchester Mine. Retrieved from http://dnre-mrne.gnb.ca/MineralOccurrence/default.aspx?componentID=5&URN=87.

Osvald, H. 1970. Vegetation and stratigraphy of peatlands in North America. Acta Universitatus Upsaliensis, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Uppsala, 96p.

Patterson W.A. III, and J.J. Olson. 1982. Effects of heavy metals on radicle growth of selected woody species germinated on filter paper, mineral and organic soil substrates. Can. J. For. Res. 13:233–238.

Payette, S. and Rochefort, L.(eds.). 2001. Écologie des tourbières du Québec-Labrador (Peatland Ecology of Quebec-Labrador). Presses de l'Université Laval, Québec, Canada, 621 pp

Pinto, A.P., Motab, A.M., de Varennesc, A., Pinto, F.C. 2004. Influence of organic matter on the uptake of cadmium, zinc, copper and iron by sorghum plants. Science of the Total Environment. 326: 239–247.

Prest, V.K., Grant, D.R. 1969. Retreat of the last ice sheet from the Maritime Provinces-Gulf of St. Lawrence region. Geol. Surv. Can. Pap. 69-33: 1 - 15.

Prest, V.K. 1970. Quaternary geology of Canada. *In: Douglas, R.J.W. ed., Geology and economic minerals of Canada*. Geological Survey of Canada Economic Geology report 1, part b, p. 657-764.

Railton, J.B. 1975. Post-glacial history of Nova Scotia. Proc. N.S. Inst. Sci., 27 (Supplement 3): 37-42.

Rampton, V. N., Gauthier, R. C, Thibault, J. and Seaman, A. A. 1984. Quaternary geology of New Brunswick. Geological Survey of Canada Memoir, 416, 77pp.

Ritchie, J.C. 1987. "Eastern Canada-fossil record and reconstruction" *in* Post glacial vegetation history of Canada. Cambridge University Press. 178pp.

Robichaud, A. and Bégin, Y. 2009. Development of a raised bog over 9000 years in Atlantic Canada. Mires and Peat, 5: 1-19.

Rowe, J.S. 1959 and 1972. Forest regions of Canada. Department of the Environment, Canadian Forestry Service Publication No. 1300, 172.

Scott, D.B., Brown, K., Medioli, F.S., 1995. A new sea-level curve from Nova Scotia: evidence for a rapid acceleration of sea-level rise in the late mid-Holocene. Canadian Journal of Earth Sciences, 32: 2071-2081.

Scott D.B. and Greenberg, D.A. 1983. Relative sea-level rise and tidal development in the Fundy tidal system. Canadian Journal of Earth Sciences, 20: 1554-1564.

Shaw, J., Gareau, P., Courtney, R.C. 2002. Palaeogeography of Atlantic Canada 13-0 kyr. Quaternary Science Reviews, 21: 1861-1878.

Sheoran A.S. and Sheoran, V. 2006. Heavy metal removal of acid mine drainage in wetlands: A critical review. Minerals Engineering, 19:105-116.

Shotyk, W. 1988. Review of the inorganic geochemistry of peats and peatland waters. Earth-Sci. Rev. 25, 95-176.

Siegel, D.I., Glaser PH. 2006. The hydrology of peatlands. In: Boreal Peatland Ecosystems. (Eds. Weider K, Vitt DH). Springer-Verlag: Heidelberg. p 289-311.

Smith, A.Y. 1960. Heavy metal (Zn, Pb, Cu) content of stream sediments of part of Westmorland County, New Brunswick. Geol. Surv. Can., Paper, 59-12.

Spooner, I., Douglas, M.S.V., Terrusi, l> 2002. Multiproxy evidence of an early Holocene (8.2 kyr) climate oscillation in central Nova Scotia, Canada. Journal of Quaternary Science, 17: 639-645.

Sobolewski, A. 1996. Metal speacies indicate the potential of constructed wetlands for long-term treatment of mine drainage. Journal of Ecological Engineering, 6: 259-271

Sobolewski, A. 1999. A review of processes responsible for metal removal in wetlands treating contaminated mine drainage. International Journal of Phytoremediation, 1(1): 19-51.

Stea, R.R. and Mott, R.J. 1989. Deglaciation environments and evidence for glaciers of Younger Dryas age in Nova Scotia, Canada. Boreas, 18: 169-187.

Stocker, T. and Mysak, L. 1992. Climatic fluctuations at the century timescale: a review of high-resolution proxy data and possible models. Climatic Change, 20: 227-250.

Stockmarr, J., 1971. Tablets with Spores used in Absolute Pollen Analysis. Pollen et Spores 13:615-621.

Stone, E.L. and Timmer, V.R. 1975. On the copper content of some northern conifers. Can. J. Bot. 53: 1453-1456.

Stuiver, M. and Reimer, P.J. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. Radiocarbon, 35(1):215-230.

Swain, A. 1978. Environmental changes during the past 2000 years in north-central Wisconsin: analysis of pollen, charcoal and seeds from varved lake sediments. Quat. Res., 10: 55-68.

Tolonen, K. 1986. Charred Particle Analysis. In: Handbook of Holocene Paleoecology and Paleohydrology (Eds. Berglund, B.E.). John Wiley and Sons Ltd. Great Britain pp 485-496.

VanGeel, 1986. Application of fungal and algal remains and other microfossils in palynological analyses. In: Handbook of Holocene Paleoecology and Paleohydrology (Eds. Berglund, B.E.).John Wiley and Sons Ltd. Great Britain pp 497-505.

Walker, I.R. and Paterson, C.G. 1983. Post-glacial Chironomid succession in two small, humic lakes in the New Brunswick – Nova Scotia (Canada) border area. Freshwat. Invertebr. Biol. 2: 61-73.

Warner, B.G. 1989. Methods in Quaternary Ecology #10. Other fossils. Geoscience Canada, 16: 231-242.

Warner, B.G., Tolonen, K., Tolonen, M. 1991. A postglacial history of vegetation and bog formation at Point Escuminac, New Brunswick. Canadian Journal of Earth Science, 28: 1572-1582.

Warner, B.G. and Asada, T. 2008. Plants and testate amoebae as environmental indicators in cupriferous peatlands, New Brunswick, Canada. Ecological Indicators. 9: 129-137.

Wei, Ma and Tobin, J.M. 2004. Determination and modeling of effects of pH on peat biosorption of chromium, copper and cadmium. Biochemical Engineering Journal, 18: 33-40.

Weis, J.S. and Weis, P. 2004. Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration. Environmental International, 30: 685-700.

Wieder, R.K., Vitt, D.H., Benscoter, B.W. 2006. Peatlands and the Boreal Forest. In: Boreal Peatland Ecosystems (Eds. Wieder, R.K. and Vitt, D.H. Springer-Verlag Berlin Heidelberg, pp 1-8.

Zinck, M. 1998. Roland's Flora of Nova Scotia 3rd Ed Part 1. Nimbus Publishing & Museum of Nova Scotia, Halifax NS. 638 pp.

APPENDIX A: METAL CONCENTRATIONS (RAW DATA) IN RELATION TO DEPTH IN PEAT FROM CORE C

Depth (cm)	5	20	35	60	65	75	90	101	115	130	145	155	170	200	203	205	207	209	210
Silver [µg/g]	0.02	0.03	0.02	0.02	N/A	0.03	0.32	0.22	0.11	0.02	0.01	0.01	0.05	0.04	N/A	N/A	N/A	N/A	0.11
Aluminum [µg/g]	48	41	68	180	1100	401	950	1000	730	290	160	220	930	460	4500	4700	5400	5300	2600
Arsenic [µg/g]	< 0.5	< 0.5	< 0.5	< 0.5	1.6	< 0.5	0.7	< 0.5	0.5	< 0.5	< 0.5	< 0.5	0.7	1.8	14	8.9	6	3.7	0.9
Barium [µg/g]	200	510	630	760	4600	560	340	420	290	140	100	74	250	250	1300	1300	800	880	270
Beryllium [µg/g]	< 0.02	< 0.02	< 0.02	0.06	0.41	0.07	0.17	0.18	0.13	0.05	0.03	0.05	0.24	0.13	0.98	1.3	0.66	0.98	0.36
Boron [µg/g]	10	6	6	5	40	4	4	4	4	4	4	6	6	11	12	52	11	13	6
Calcium [µg/g]	2900	5100	5700	6100	36000	4500	3500	4000	3200	2300	1900	2200	3200	4600	16000	16000	13000	10000	3300
Cadmium [µg/g]	0.27	0.23	0.26	0.32	0.95	0.22	0.81	0.54	0.65	0.16	0.1	0.14	0.35	0.15	1.9	3.3	0.89	1.4	0.16
Cobalt [µg/g]	0.19	0.08	0.04	0.01	0.55	0.01	0.03	0.04	0.09	0.04	< 0.01	0.01	0.27	0.26	7	9.4	5.7	5.8	2.4
Chromium [µg/g]	0.7	< 0.5	< 0.5	< 0.5	3.9	1	1.1	1.3	1.8	0.6	< 0.5	0.6	1.5	1.7	10	11	13	14	6.6
Copper [µg/g]	16	360	510	820	4800	370	430	460	290	50	27	29	43	41	490	490	620	460	160
Iron [µg/g]	93	91	270	300	2100	290	640	630	840	510	440	580	1400	7100	22000	16000	22000	21000	7100
Potassium [µg/g]	140	14	13	12	69	21	13	20	18	9	5	7	11	38	260	220	560	540	310
Magnesium [µg/g]	160	140	160	160	890	120	76	81	64	42	36	38	52	102	800	770	1700	1700	1007
Manganese [µg/g]	52	25	7.2	19	180	31	61	94	89	62	56	74	74	55	390	510	300	320	110
Molybdenum [µg/g]	< 0.1	0.1	< 0.1	< 0.1	0.5	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.5	1.9	2.1	1.7	3	0.9
Sodium [µg/g]	37	48	51	55	190	43	29	36	27	20	16	18	24	31	82	140	72	72	34
Nickel [µg/g]	1.7	1.9	2	2.4	13	1.6	3	3.9	3.7	2.2	0.9	0.9	2.2	1.1	16	21	14	15	6.2
Lead [µg/g]	2.6	1.2	0.6	0.4	3.8	1.4	0.41	0.72	0.56	0.39	0.1	0.33	0.32	1.2	5.3	5.4	9.3	8.2	5.2
Phosphorus [µg/g]	130	85	62	61	320	87	290	310	61	30	20	28	72	39	300	320	300	290	110
Selenium [µg/g]	< 0.7	< 0.7	< 0.7	< 0.7	3.2	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7	3.7	3	2.5	1.6	< 0.7
Antimony [µg/g]	< 0.1	< 0.1	< 0.1	< 0.1	0.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.8	1	0.3	0.3	< 0.1
Tin [µg/g]	0.6	< 0.5	< 0.5	< 0.5	<0.5	< 0.5	0.6	0.6	0.6	< 0.5	< 0.5	< 0.5	0.5	< 0.5	0.7	0.5	<0.5	<0.5	0.7
Strontium [µg/g]	8.3	14	16	16	87	12	7.7	8.8	6.1	3.8	3.1	3.1	5.7	5.7	24	26	17	17	5.9
Tellerium [µg/g]	< 0.1	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	N/A	N/A	N/A	N/A	< 0.1
Titantium [µg/g]	12	9.2	8.8	8.6	33	15	16	19	18	11	10	12	18	19	110	100	85	78	48
Vanadium [µg/g]	< 3	< 3	< 3	< 3	5	< 3	< 3	< 3	< 3	< 3	< 3	< 3	5	5	31	31	24	21	7
Zinc [µg/g]	29	17	18	36	160	24	110	68	57	20	2.8	12	35	44	410	590	250	290	70

APPENDIX B: METAL CONCENTRATIONS (RAW DATA) IN RELATION TO DEPTH IN PEAT FROM CORE B

Depth (cm)	5	20	35	50	67	77	82
% Moisture	67.1	57.2	70.8	64.8	56.4	74.1	67.8
Aluminum [µg/g]	410	700	1300	1100	3300	7800	12000
Arsenic [µg/g]	2.3	2.3	4.1	4.7	43	42	66
Barium [µg/g]	2300	3400	4900	4100	3600	3200	3300
Beryllium [µg/g]	0.14	0.5	1.4	1.5	0.71	1.2	1.3
Boron [µg/g]	39	29	25	14	13	17	21
Calcium [µg/g]	22000	22000	27000	29000	20000	29000	22000
Cadmium [µg/g]	0.3	<0.02	1.1	1.6	0.78	7.8	15
Cobalt [µg/g]	1	0.78	0.58	1.1	0.69	1.8	4.1
Chromium [µg/g]	3.2	3	4.1	5.2	17	19	21
Copper [µg/g]	3300	8900	25000	23000	4700	2300	980
Iron [µg/g]	1100	6200	9900	10000	6200	7300	6100
Potassium [µg/g]	390	150	54	50	190	180	410
Magnesium [µg/g]	910	600	620	690	550	800	1100
Manganese [µg/g]	140	190	160	470	620	430	810
Molybdenum [µg/g]	0.6	0.5	0.3	0.5	0.7	1.1	3.9
Sodium [µg/g]	190	130	130	120	100	100	130
Nickel [µg/g]	4.9	5	7	11	10	24	25
Lead [µg/g]	11	6.5	3	1.8	5.3	5.9	10
Phosphorus [µg/g]	530	1100	450	420	780	1700	3200
Selenium [µg/g]	< 0.7	2.7	3.8	4.3	2.7	8.4	5.9
Antimony [µg/g]	0.7	0.4	0.4	0.3	0.2	0.3	0.6
Tin [µg/g]	0.6	0.5	< 0.5	< 0.5	<0.5	0.5	0.8
Strontium [µg/g]	53	54	68	70	49	49	42
Thallium [µg/g]	0.03	0.12	0.04	0.03	0.11	0.21	0.48
Titantium [µg/g]	35	34	37	29	62	110	160
Vanadium [µg/g]	5	4	9	11	14	36	35
Zinc [µg/g]	75	99	230	230	100	350	1300