LONG-TERM HYDROLOGICAL RECONSTRUCTION FROM A BEAVER MEADOW

An Undergraduate Research Scholars Thesis

by

KATE VON NESS

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ABSTRACT

Long-Term Hydrological Reconstruction from a Beaver Meadow

Kate Von Ness
Department of Geography
Department of English
Texas A&M University

Research Advisor: Dr. Julie Loisel
Department of Geography
Texas A&M University

Beaver ponds contribute 0.8-1.0 million tons of atmospheric methane (CH_4) emissions per year globally (Whitfield et al., 2014; Wik et al., 2016) and are found to be the largest CH_4 emitters among all the wetland types in boreal environments (Roulet et al., 1992). However, the sources and underlying mechanisms of carbon emission in beaver ponds require further elucidation. I have reconstructed the historical development of a beaver meadow located in the Sibbald Research Wetland in the Rocky Mountains of Kananaskis Provincial (Ollennu) Park, Alberta, Canada. I used a combination of testate amoebae, plant macrofossils, and other geochemical proxies to provide high-resolution reconstructions along three peat cores extracted in hydrologically distinct portions of the meadow. To my knowledge, this is the first achievement at reconstructing long-term hydrological conditions in these systems. In addition to providing a unique ecological reconstruction for this site, my project outlines any hydrological changes in the meadow as well as changes in nutrient input, which I tentatively used as proxies for past beaver activity.

ACKNOWLEDGEMENTS

I would first like to thank my faculty advisor Dr. Julie Loisel for supporting me in my endeavors and guiding me through the research process. I would also like to thank her for providing me with the opportunities and resources needed for my success. Her knowledge and advice will always remain with me as I continue in my academic career.

Secondly, I want to acknowledge the inspiration for this research, Daniel Karran, whom without I would not have been led to this educating experience.

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To my best friend Bradley: thank you for always supporting me and reminding me to embrace my potential. Life would not be the same without you.

Lastly, thanks to my mother Diane for being an anchor throughout the more chaotic times. Your constant advice and support will forever hold an invaluable place in my life. Additionally, thanks to my brother Ryan for always encouraging me to pursue the highest of achievements and to my closest friends and family for helping me make every moment count.

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CHAPTER I

INTRODUCTION

The Role of Wetlands in the Global Carbon Cycle

Atmospheric methane (CH_4) concentration has been characterized by large fluctuations since the Last Glacial Maximum. Over the past 2000 years, atmospheric CH_4 concentration has been rising relatively steady until ~1800 AD, after which it increased very rapidly to reach over 1800 ppbv (MacFarling Meure et al., 2006). These fluctuations have led scientists to inquire into the causes and determination of atmospheric CH_4 sources and mechanisms that could explain those said fluctuations. Beaver meadows, a type of wetlands, have proven to release more CH_4 emissions than any single human source (Bousquet et al., 2006). The discovery that wetlands are paramount in the global CH_4 cycle and that they exert a strong control on atmospheric CH_4 concentrations has changed our previous understandings of crucial CH_4 sources, which were thought to be permafrost thawing, volcanism, development of thermokarst lakes, and other connections with CH_4 hydrates and clathrates from continental shelves (Yu et al., 2013; Finkelstein et al., 2011). Boreal peatlands have been particularly important research areas due to their highly-moisturized conditions and high abundance of Cyperaceae, which both allow for large quantities of CH_4 to be emitted to the atmosphere annually (Bubier et al.,1995).

Wetlands as CH_4 sources and carbon dioxide (CO_2) sinks highly impact global C cycling, particularly pertaining to the atmosphere and physical milieu, creating a potential to alter both human and natural environments. Modern-day wetland CH_4 emission fluxes have been analyzed and replicated using inverse models of four key environmental variables: surface vegetation assemblages, water table depths, peat surface elevation (microtopography), and soil temperatures (Bubier et al., 1995). Studies aiming at reconstructing past changes in CH_4 emissions have therefore focused on reconstructing some of these key variables. A proxy that is being more commonly used in water table depth reconstructions is testate amoebae analysis. These micro-organisms leave decay-resistant shells that are distinctly recognizable at the taxa level, and their abundance within a given sample is controlled by the hydrological conditions that were occurring at the peatland's surface when that sample was forming. Testate amoebae therefore provide a detailed insight into past moisture conditions along peat cores (Booth et al., 2010). Another paleoecological indicator, the chemical composition of the vegetation, is also becoming increasingly important as carbon isotopic signatures in plant macrofossils can reinforce or clarify the specific ecological range of peat moisture conditions (Loisel et al., 2009).

Beavers as Biomorphological Agents

Resource management efforts around the world, such as beaver re-introduction programs, have prompted an increase in global beaver populations, resulting in more ponds and consequently higher CH_4 emissions (Whitfield et al., 2014). A recent study suggests that CH_4 emissions from wetland ponds are now 200 times larger than they previously were in 1900 (Whitfield et al., 2014). In addition to altering the global C cycle and strengthening the greenhouse gas effect with higher CH_4 emissions to the atmosphere, beavers have been influencing the physical environment. These ecological engineers have the ability to completely alter the biotic properties and hydrological conditions of an ecosystem through the consequential variance in species diversity, organization of plant communities, and soil composition (Rosell et al., 2005). In riparian landscapes throughout the central Adirondacks in New York, for instance, beaver-modified areas have seen a 33% increase in the number of herbaceous species compared to areas with no evidence of beaver activity (Wright et al., 2002). Beavers make biological modifications by trapping in nutrients and increasing the surface moisture conditions with their dams and ponds, therefore completely altering the ecological and hydrological features of an area which can result in the formation of new ecosystems.

CHAPTER II

METHODOLOGY

Study Area

In 2015, three long peat cores were collected from a beaver meadow in the Sibbald Research Wetland (51.063º N, 114.870º W) which is found at the foothills of the Rocky Mountains in the Kananaskis Provincial Park located in Alberta, Canada. The Sibbald Research Wetland has a size of approximately 1.3km^2 and experiences a mean annual temperature of 3.5ºC and a mean annual precipitation of 661mm (Westbrook et al., 2016). The two major topographic zones in the Sibbald Research Wetland are the mountain zone and foothill zone. Wetlands, and thus beaver habitation, have been found to be more frequent in the foothill zone where there is a flatter slope and an almost constant flow of groundwater from the steeper mountain zones (Morrison et al., 2014). Historical accounting of beaver trapping in this region, as similar to other areas in Canada, dates back to before the 17th century when fur trading started to become extensive (Morrison et al., 2014). Due to the lack of documentation of beaver population rates after the climax of the fur trade, it is hard to know the extent of beaver impact on the geomorphology of the environment since the population has started to increase (Morrison et al., 2014). Based upon stream network density, this study area is considered a high-density beaver ecoregion which generally have an average population density of 0.6 colony per km^2 (Whitfield et al., 2014). Globally, beaver populations are distributed in South America, North America, and Eurasia with a total global population of over 1 million (Whitfield et al., 2014).

The study site is a flow-through fen. This type of wetland is a minerotrophic peatland that is frequently flooded and fed by highly nutritious surface or groundwaters allowing them to support a high diversity of plant and animal species (Drewer et al., 2010). The site drains through Bateman Creek and forms the headwaters of Jumpingpound Creek, a tributary to the Bow River, which is the primary water supply for Calgary and its surroundings (Fig. 1). Peat, in simplistic terms, is waterlogged ground that contains undecomposed organic matter. In other words, peatlands form when dead plant matter accumulates in anaerobic ground that is characterized by a high water level (Xuehui et al., 2009).

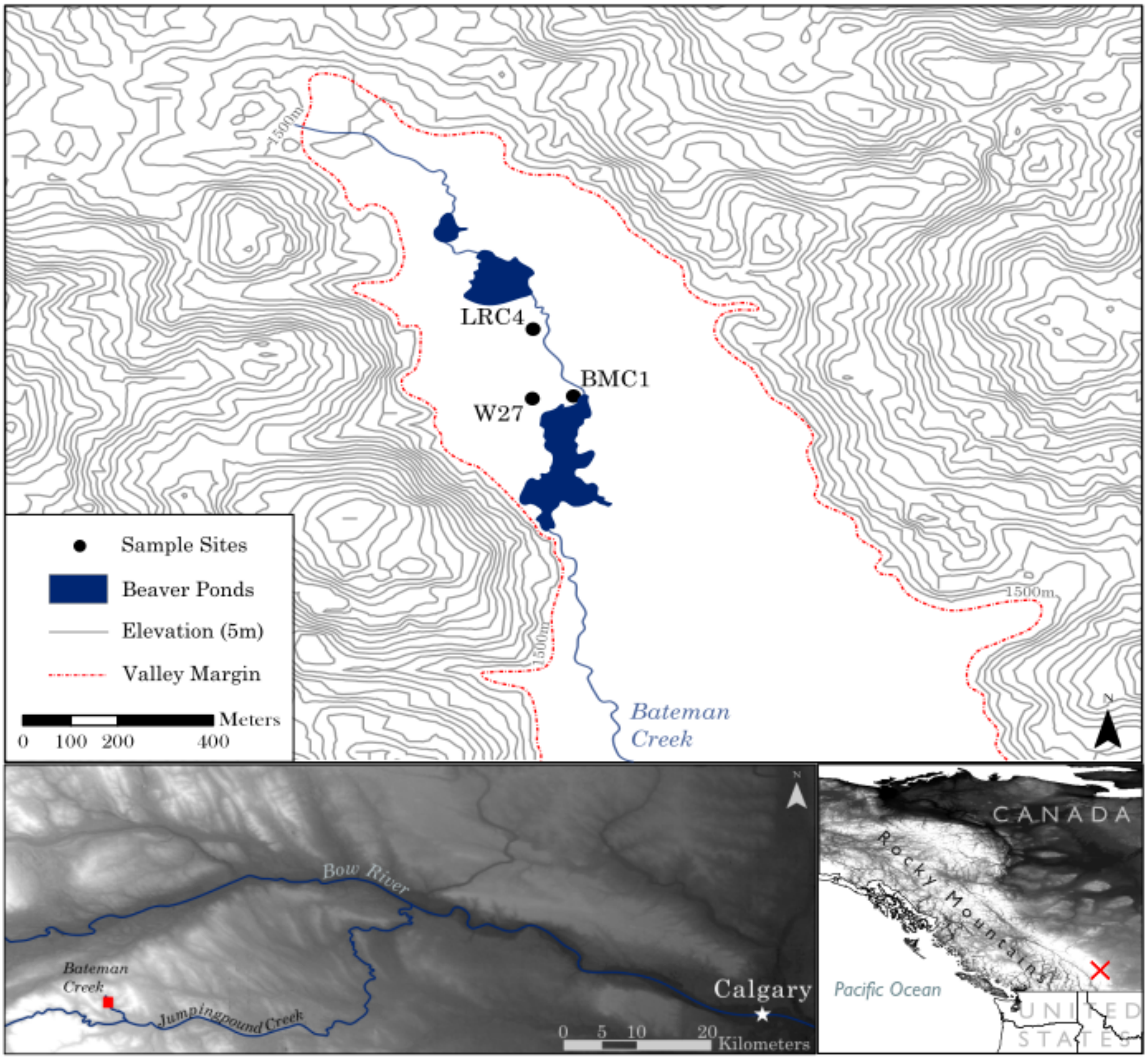

Figure 1: Study area map. The top panel presents a contour map that outlines the valley margin of the study area and shows the sample sites in relation to the area's beaver ponds. The lower left panel shows the study area's location along the Bateman Creek that flows into Jumpingpound Creek which is a tributary to Bow River, Calgary's main source of water. The lower right panel shows the study area's overall position along the foothill zones of the Canadian Rocky Mountains. *Data source: USGS.*

Field Sampling:

Figure 2: Visual of a beaver meadow. Above is a picture of the beaver meadow located at the BMC1 sample site. Notice the forested valley outline that leads into the foothill zones of the Rocky Mountains. *Photo credit: Cherie Westbrook*

Three cores, LRC4, BMC1, and W27 were collected within a few hundred meters from one another. The first core, LRC4 (650cm long), was extracted near a logging road and represents the ‘control’ site, as it has not been affected by beaver activity (Fig. 1). The second core, BMC1 (350cm long), was directly taken from an active beaver meadow (Figs. 1-2). The third core, W27 (250cm long), was collected near a logging well and represents a site that was abandoned by beavers in the past century. The cores were extracted using a Russian corer; W27 was collected on June 16, 2015 while BMC1 and LRC4 were collected on August 4, 2015. Each coring site was chosen based on the assessment of associated beaver activity to identify a range of undeveloped, developing and previously developed ponds. The cores were frozen until analysis and then preserved in a fridge at 4°C.

By looking at each stage in the formation of wetland and pond, we can learn more about the impact of beavers on the environment and the process that mountain valleys undergo when becoming wetlands. Recognizing beaver activity requires that the site has a pond, dam, and lodge; past beaver activity however is identified with broken dams and areas of homogeneous vegetation which differ from the surrounding area (Morrison et al., 2014).

Figure 3: LRC4 core. The LRC4 peat core shows clear stratigraphic changes, from clayey inorganics (gray) to peat (brown), to sandy materials (beige), and back to peat (brown). *Photo credit: Daniel Karran*

Paleoecological Approach

Paleoecology is the science of reconstructing past ecological environments from biological, chemical, and geological indicators. Paleoecological approaches are useful when researching any past phenomena or conditions concerned with an area's ecology and tend to be advantageous in that each approach can reinforce the other. The paleoecological approaches for this study include plant fossils, testate amoebae, bulk density, and carbon and nitrogen isotopes; all of these indicators are well established methods that have been used in other studies. For example, a study focused in the Canadian High Arctic has used plant macrofossils to reconstruct the terrestrial characteristics of this area in the late Early Permian (LePage et al., 2003). Testate amoebae, best for reconstructing hydrology, have been previously used as proxies in a study for average yearly water table depth in North American *Sphagnum* peatlands (Booth et al., 2008). In a study that focused on the reconstruction of estuarine sediments in Botany Bay, bulk density was used to reconstruct sediment porosity proportions as well as the composition of the particles (Macreadie et al., 2012). Isotopic signatures were used in a previous study that conducted a reconstruction and looked into the relationship of *Sphagnum* isotopic signatures with peat surface moisture in two boreal peat bogs in James Bay lowlands, Quebec (Loisel et al., 2009). Paleoecological approaches can overall provide insight into environmental features such as climate conditions, hydrological conditions, soil nutrient and composition, and vegetation diversity.

Plant Fossils

Plant fossils are used to identify the types of vegetation that were specifically growing in a specific environment and at a specific location (Fig. 4). Plant fossil analysis was performed at a resolution of 4cm intervals along each core using a microscope (Mauquoy et al., 2010) and a "plant functional type" classification that consists of ligneous, herbaceous, moss, *Sphagnum*, inorganic material, and unidentifiable organic matter (UOM) types. This proxy is important to understanding the ecological aspects of the environment at certain points in time, as higher percentages of ligneous material may represent a woodier and drier environment with generally denser peat, whereas higher percentages of moss tend to represent a wetter environment. Identifying the types of moss and *Sphagnum* can further specify past moisture and water table levels that used to characterize the environment. Overall, plant fossils function as a preserved record of the physical and biological features of an environment and are used in my study to corroborate the results found by the other proxies.

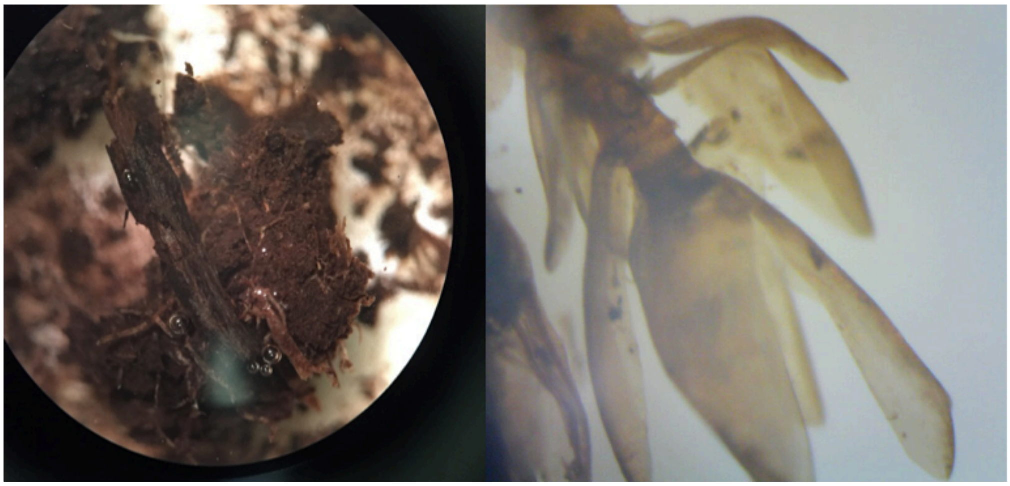

Figure 4: Plant macrofossils. Above are plant macrofossils within the LRC4 core: the left picture features ligneous material, and the right features a moss stem and leaves. *Photo credits: Kate Von Ness and Abbie Mancinelli.*

Testate Amoebae

Testate amoebae (Protozoa: Rhizopoda) are single-celled organisms that inhabit moist substrates and produce a decay-resistant test (Fig. 5). Their shells get preserved within the soil layers and can often be identified at the species level. As each taxon generally occupies a discrete ecological niche related to soil moisture and pH, testate amoebae are good indicators of past and ongoing hydrological change (Booth et al., 2008) Shells are identified at a 4cm resolution using a compound microscope (Booth et al., 2010). At least 50 specimens were identified per sample to reconstruct the general population composition. Preliminary analysis of testate amoebae assemblages downcore suggests that this proxy is suitable to reconstruct hydrological changes in our meadow (and probably in meadows in general), with wetter and drier communities being in good agreement with wetter and drier plant macrofossil assemblages. Overall, testate amoebae are sensitive indicators of the environment's hydrology and surface moisture conditions, and will be compared with the vegetation assemblages and isotopic datasets.

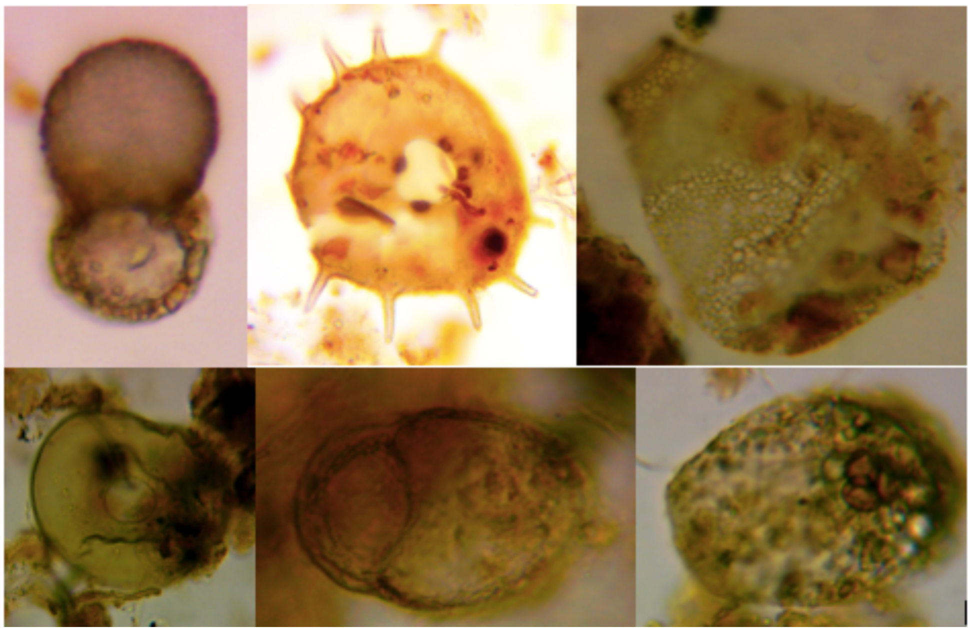

Figure 5: Testate amoebae. Above are a few of the testate amoebae found throughout the cores (moving top left to right, then bottom left to right): *Centropyxis pontigulasiformis, Centropyxis acuelata, Nebela carinata, Arcella artocrea, Centropyxis cassis, Heleopera petricola. Photo credit: Kate Von Ness.*

Bulk Density, and Carbon and Nitrogen Isotopes

Bulk density is a measurement of volume; the sample's dry mass is divided by its original volume (Mauquoy et al., 2002). The bulk density of each sample was taken at 4cm increments. Samples were dried and weighed at 105°C. The bulk density of the samples in part correlates to the vegetation assemblages and to the degree of peat decomposition. Bulk density can be used as a proxy for past peat moisture, with dense peat usually associated with intensified decay, itself potentially caused by either labile vegetation or dry conditions. Bulk density is also used to quantify peat accumulation rates; high bulk density generally corresponds to slower peat accumulation while a low bulk density often corresponds to faster peat accumulation (Mauquoy et al., 2002).

The carbon ($^{13}\delta C$) and nitrogen ($^{15}\delta N$) isotopes are measured on bulk soil samples at 4cm increments and provide independent proxies for changes in soil moisture (carbon) and nutrient status (nitrogen) of the beaver meadow (Loisel et al., 2009). The isotopic signatures could become a proxy for past beaver activity. Carbon and nitrogen isotopes are useful proxies in paleohydrological reconstructions because particular isotopic signatures correlate to well-defined environmental aspects which can reveal changes in climate, hydrological conditions, and reflect the chemistry of the meadow. They will be used to confirm and reinforce our other proxies.

In addition to looking at the carbon and nitrogen isotopes, peat C accumulation rates (CAR) were also calculated. Carbon accumulation rates can tell us how the study area is interacting with the global C cycle. From previous research on C accumulation in the Holocene, temperature has been found to be the main driver of peat carbon accumulation rates (Charman et al., 2015). Soil moisture is a secondary factor controlling CARs, with a more ideal environment for plant growth and increased inhibition of decay generally occurring under wetter conditions (Bubier et al., 2003; Charman et al., 2013). However, there is still much that is unknown about the exact relationship between environmental factors and peat CARs. These rates will be used in conjunction to the other geochemical proxies to better understand the rate at which the peat was storing C and how this may explain or relate to any hydrological conditions, vegetation composition, soil nutrients, and overall climate.

Radiocarbon Dating

Radiocarbon (^{14}C) dates are needed to chronologically constrain the formation and developmental processes of wetlands as well as the timing of beaver impact to a location. Radiocarbon dating is primarily used to construct an age-depth model for each core. For this, the peat samples were prepared at Texas A&M's paleoecology lab and sent to CAMS, at the Lawrence Livermore National Laboratory, California. Radiocarbon dates in conjunction with the other geochemical proxies will allow for a high-resolution paleoecological reconstruction (Mauquoy et al., 2002). All ^{14}C dates were calibrated using the IntCal13 curve (Reimer et al., 2013) and expressed as calendar years before present (1950 CE). Each age-depth model was built using the R package Bacon (Blaauw and Christen, 2011).

Statistical Analysis

In analyzing the differences between the three coring sites, an ordination technique was utilized to examine the environmental factors of each site as well as their data structure (van Bellen et al., 2014). A Detrended Correspondence Analysis (DCA) was used to identify the main gradients controlling the changes in testate amoebae communities. This particular statistical method was used because it is an unconstrained ordination that explores each taxon's assemblage and highlights the variation in each taxon's ecological niche (van Bellen et al., 2014). Testate amoebae percentages from each sample were squared-rooted prior to the DCA analysis.

Cluster analysis was used to identify breaks between the most similar peat samples. Based on testate amoebae and macrofossil assemblages, the dendrograms were constrained and used the Bray-Curtis similarity measure. From these dendrograms we can view the core in transitional terms by looking at what zones the peat samples can be grouped into based on their similarity measurements between plant macrofossils and testate amoebae. Once these zones are identified, we can reconstruct different ecological and climate conditions at specific depths along the cores. Overall, the combined statistical analysis of DCA's and dendrograms will help reveal which plant types and testate amoebae taxa are representative of shallow ponds (active beaver activity), wet wetlands (intermediate/transitional), and dry wetlands (abandoned beaver pond), respectively.

CHAPTER III

RESULTS

Plant Macrofossils:

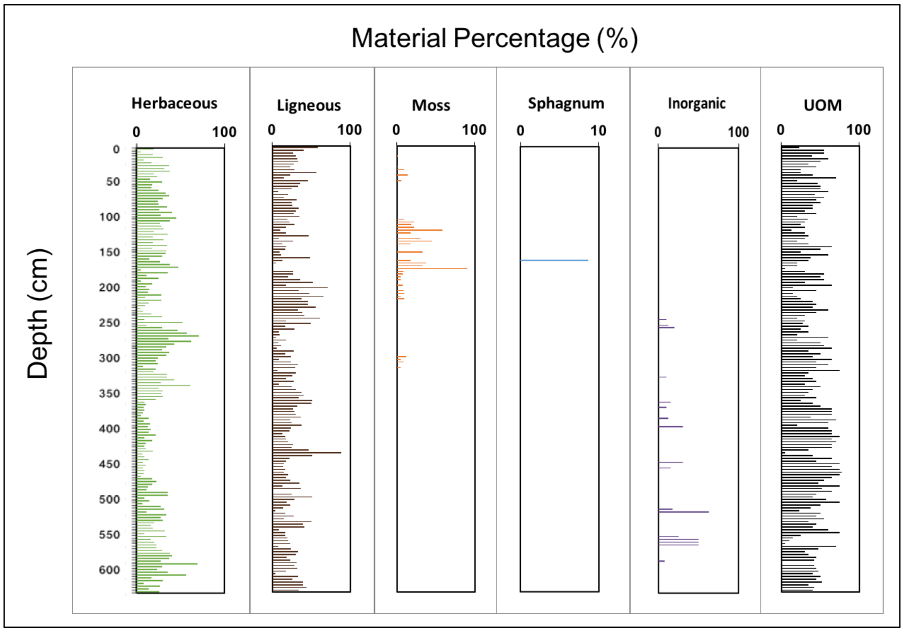

Figure 6a: LRC4 plant macrofossil chart. The above figure shows the distribution of macrofossils throughout the LRC4 core.

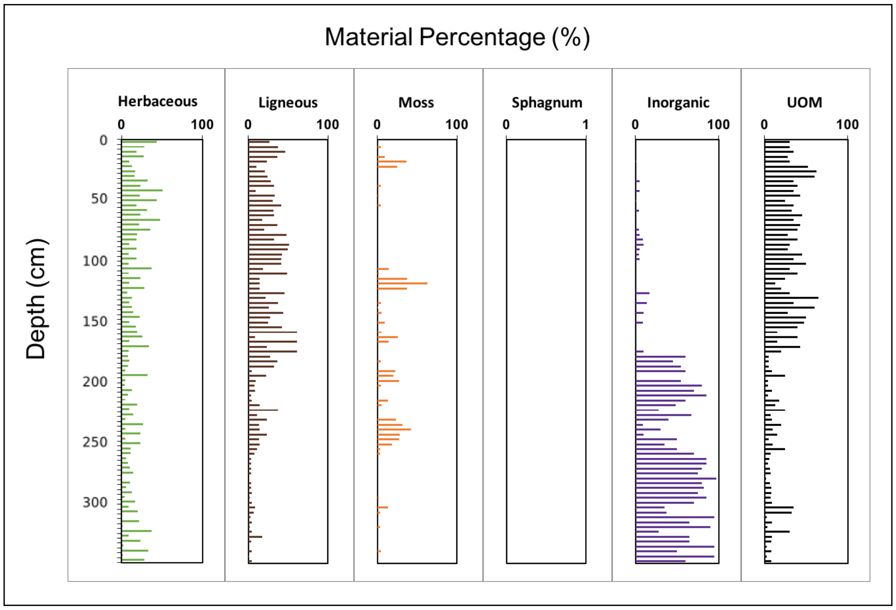

Figure 6b: BMC1 plant macrofossil chart. The above figure shows the distribution of macrofossils throughout the BMC1 core.

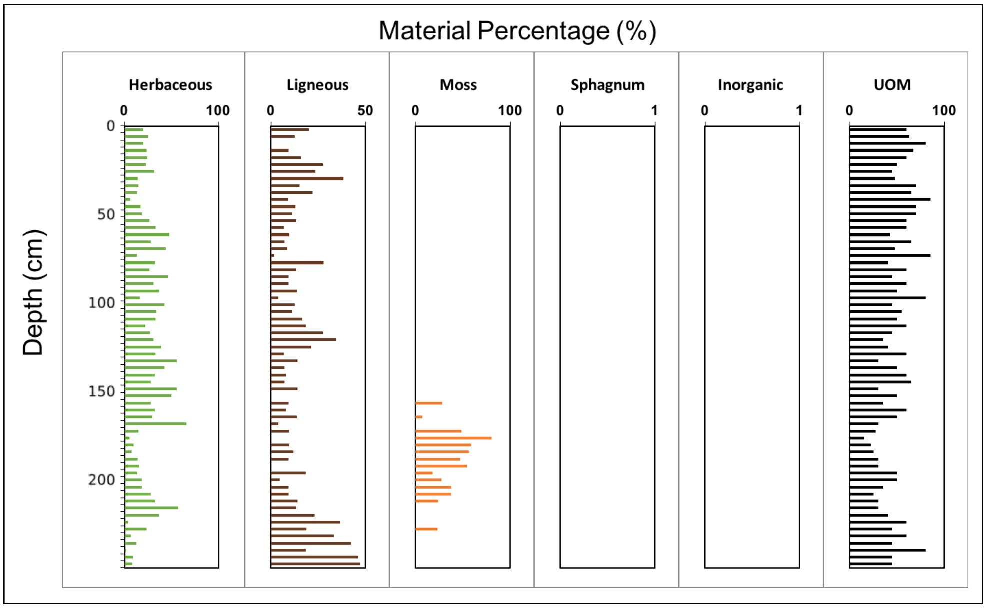

Figure 6c: W27 plant macrofossil chart. The above figure shows the distribution of macrofossils throughout the W27 core.

Dendrograms

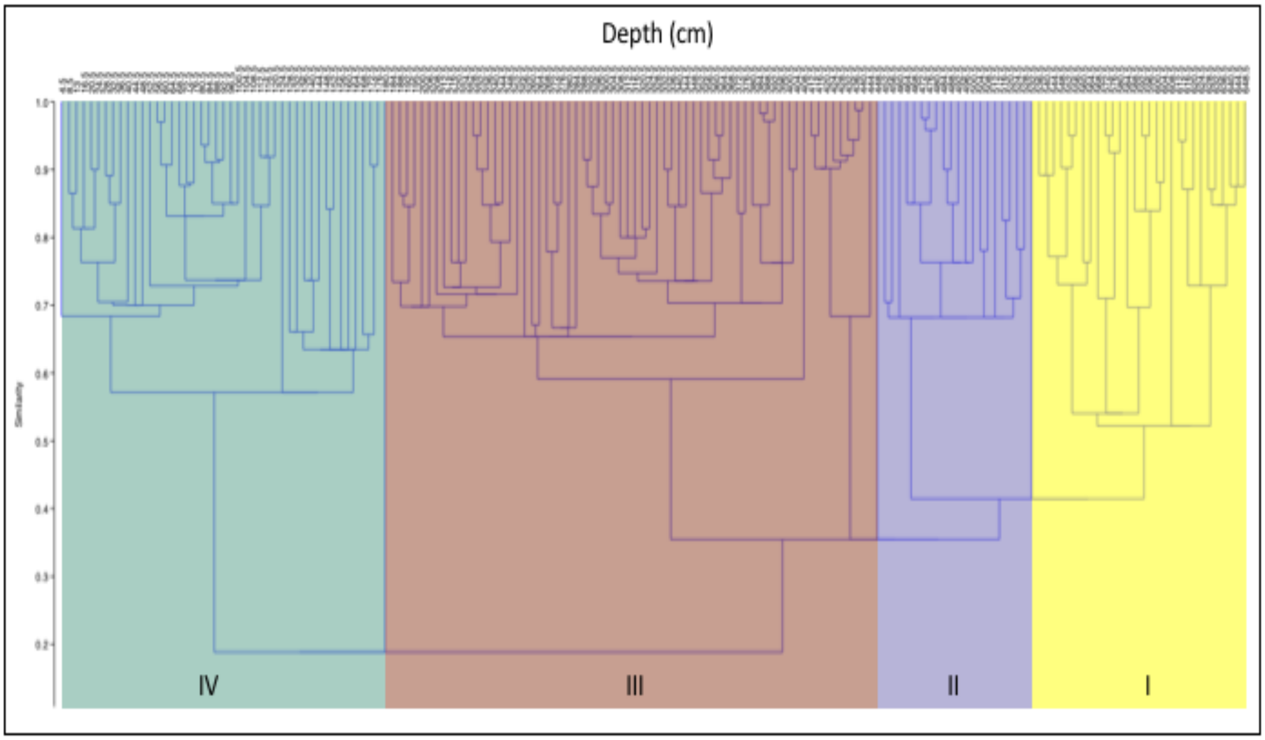

Figure 7a: LRC4 macrofossil dendrogram. This figure shows similarity measurements among LRC4 peat samples based on their corresponding plant macrofossils. Zone 1 starts at the bottom of the core and transitions to new zones with zone 4 being at the top of the core.

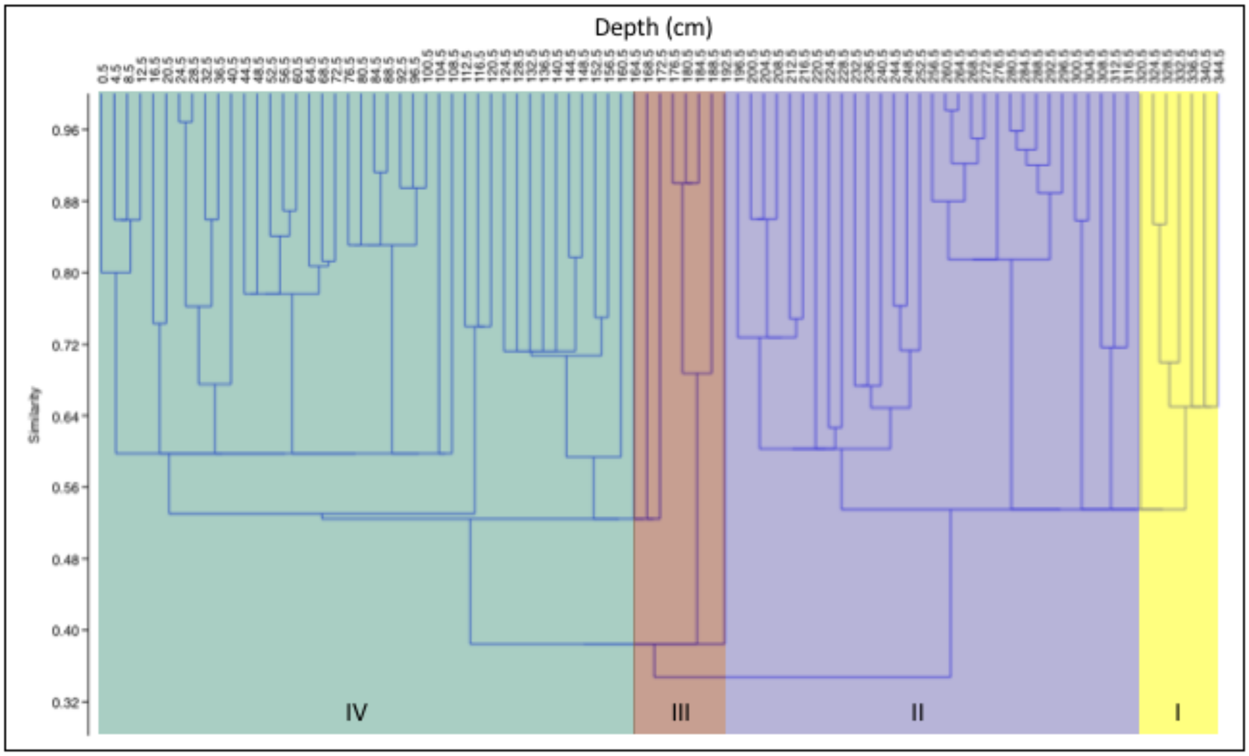

Figure 7b: BMC1 macrofossil dendrogram. This figure shows similarity measurements among BMC1 peat samples based on their corresponding plant macrofossils. Zone 1 starts at the bottom of the core and transitions to new zones with zone 4 being at the top of the core.

In LRC4 (Fig. 6a), from 650cm to 250cm there are relatively high levels of UOM with multiple fluctuations in herbaceous and ligneous material throughout the section; the largest spike in ligneous material occurs around 425cm. Inorganic material mainly appears from 650cm to 350cm with the larger increases being around 600cm to 500cm. 250cm to 100cm is a major moss section with high levels of moss and the only occurrence of *Sphagnum* throughout the entire core. The core returns to previous conditions from 150cm to 0cm. The dendrogram for this core (Fig. 7a) breaks down the plant fossil samples as follows: zone 1 is 650cm to 532cm, zone 2 is 532cm to 448cm, zone 3 is 448cm to 180cm, and zone 4 is 180cm to 0cm.

In BMC1 (Fig. 6b) the bottom of the core, 350cm to 250cm, is rich in inorganic material that has been identified as marl. The section ranging from approximately 250cm to 175cm is a long transitional section of the core with several inorganic layers interspersed with at least 3 major moss layers; ligneous material experiences a large increase. 175cm to 0cm features alternating moss layers around 175cm and near the surface of the core with large percentages of ligneous material and UOM. The dendrogram (Fig. 7b) divides the core as follows: zone 1 is 350cm to 320cm, zone 2 is 320cm to 192cm, zone 3 is 192cm to 164cm, and zone 4 is 164cm to 0cm.

In W27 (Fig. 6c), from 250cm to 225cm, there are high UOM percentages with fluctuating amounts of herbaceous and ligneous material. 225cm to 175 cm is a major moss layer with low herbaceous, low ligneous, and low UOM content. From 175cm to 0cm, the herbaceous, ligneous and UOM material comes back and alternates steadily throughout the rest of the core. Unlike the other 2 cores, there is no inorganic material or *Sphagnum* material.

Testate Amoebae

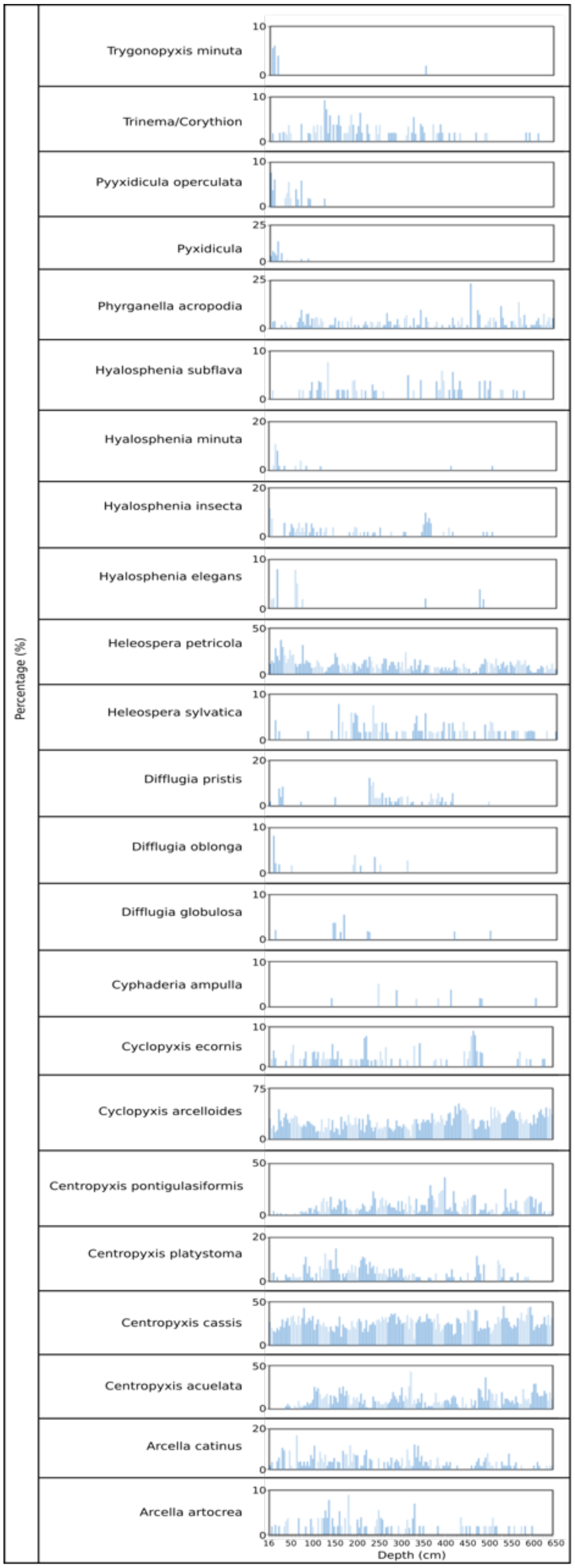

Figure 8a: LRC4 testate amoebae chart. Above are the most common testate amoebae species throughout the LRC4 core.

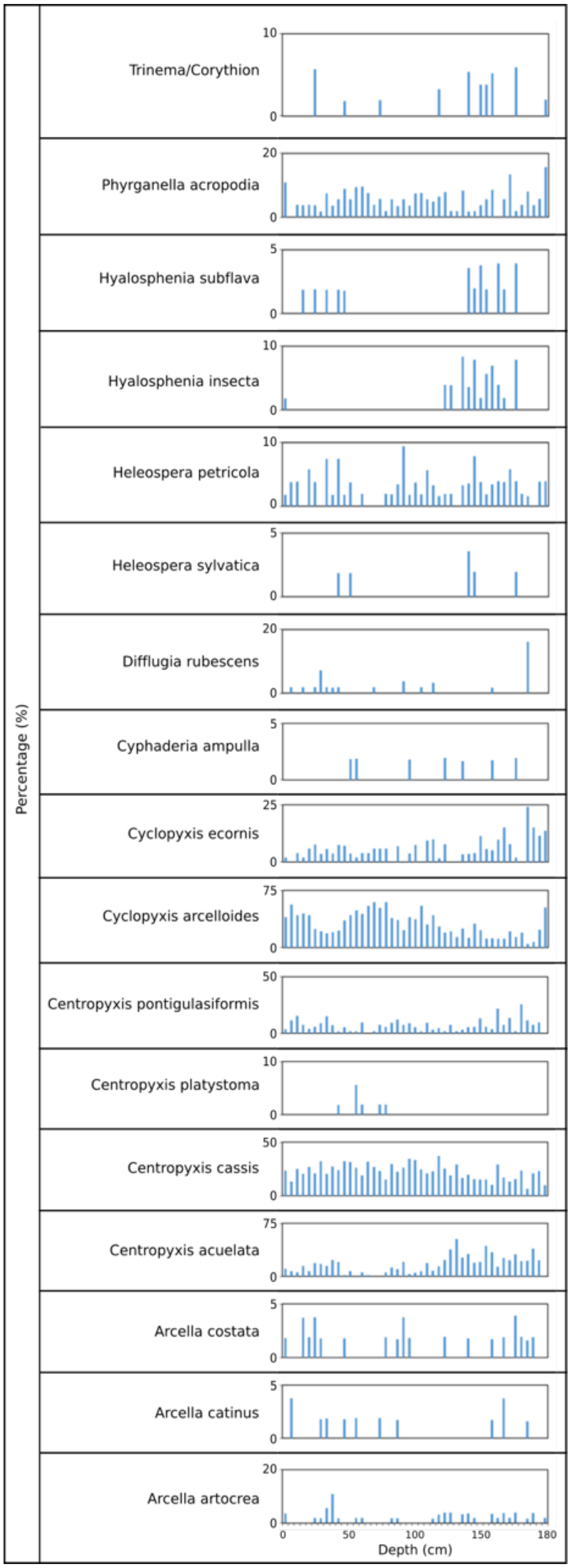

Figure 8b: BMC1 testate amoebae chart. Above are the most common testate amoebae species throughout the BMC1 core.

Dendrograms

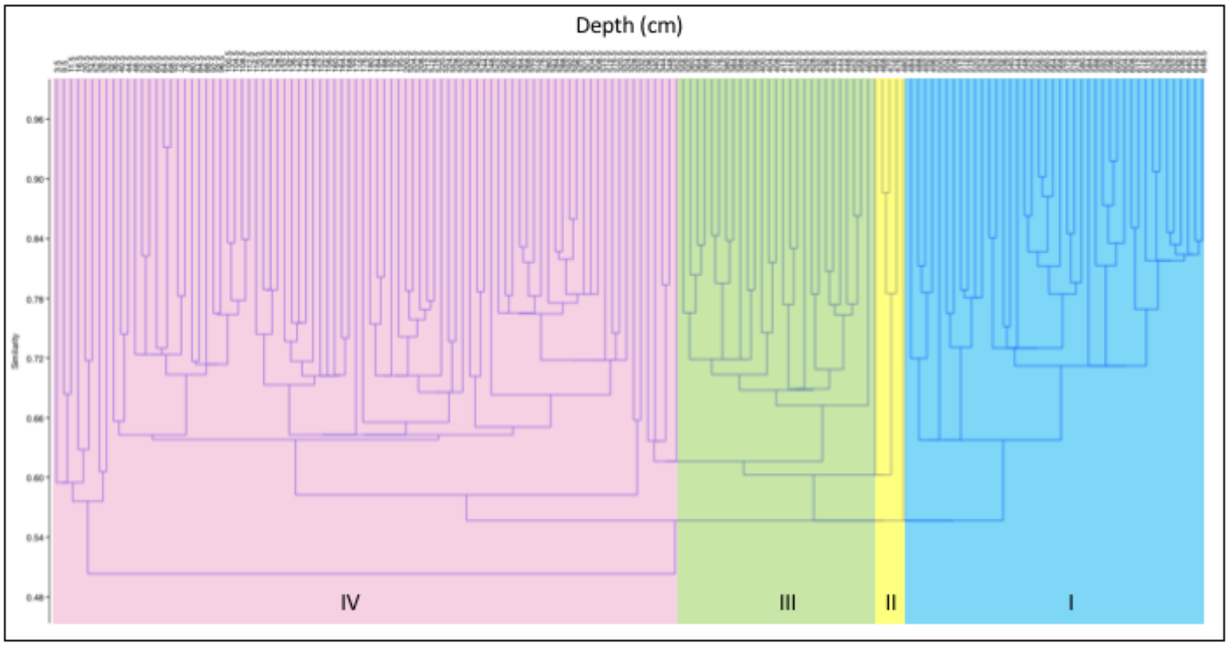

Figure 9a: LRC4 testate amoebae dendrogram. This figure shows similarity measurements among LRC4 peat samples based on their corresponding testate amoebae assemblages. Zone 1 starts at the bottom of the core and transitions to new zones with zone 4 being at the top of the core.

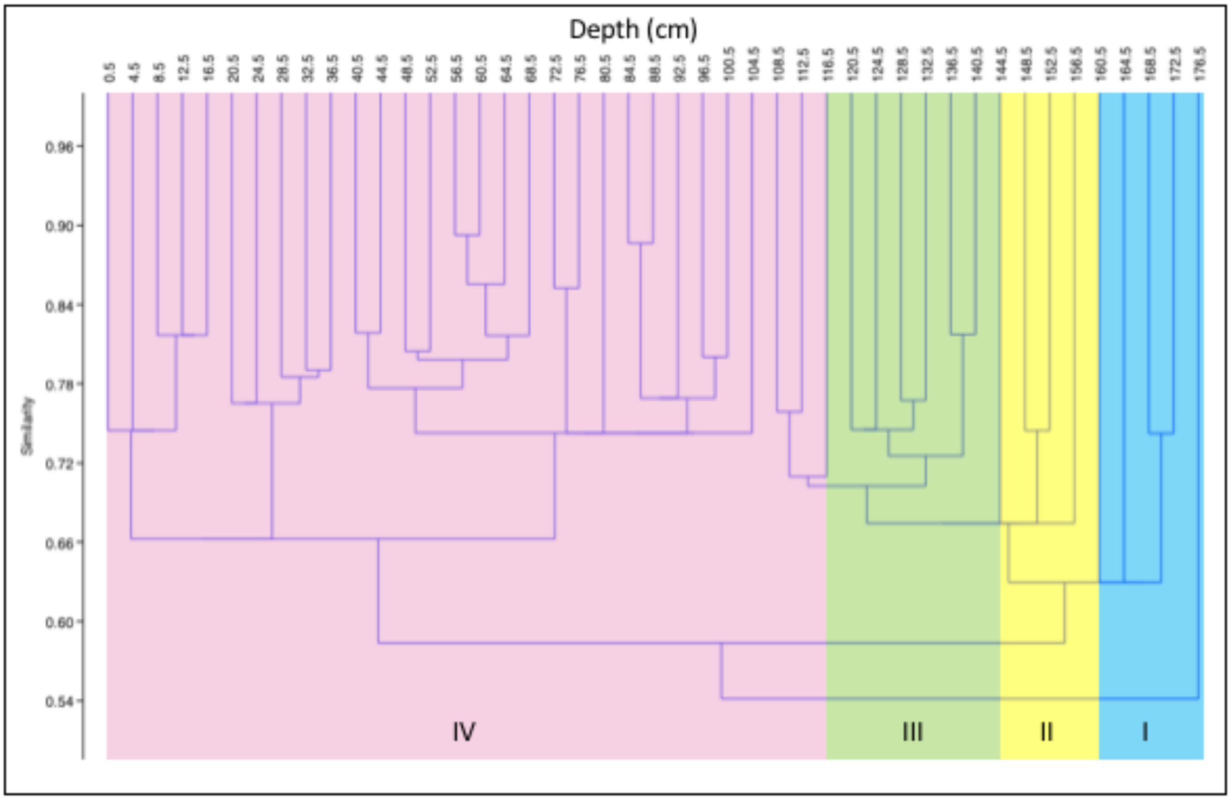

Figure 9b: BMC1 testate amoebae dendrogram. This figure shows similarity measurements among BMC1 peat samples based on their corresponding testate amoebae assemblages. Zone 1 starts at the bottom of the core and transitions to new zones with zone 4 being at the top of the core.

In LRC4 (Fig. 8a) there are high abundances of *Centropyxis cassis, Cyclopyxis arcelloides, Centropyxis acuelata,* and *Heleospera petricola*. This core shows a lot of variation in testate amoebae populations as multiple species alternate in abundance throughout the core. Many species match up in their increases such as *Hyalosphenia elegans* with *Pyxidicula operculata* and *Hyalosphenia insecta*. The *Centropyxis pontigulasiformis* also has a significant abundance with spikes similar to *Centropyxis cassis*. The *Phryganella acropodia* shows a dramatic rise that is in occurrence with a large increase in *Cyclopyxis ecornis.* The dendrogram (Fig. 9a) shows more testate zones in the bottom of the core with the zone 4 encompassing the entire upper half of the core. Zone 1 ranges from 650cm to 480cm, zone 2 is 480cm to 464cm, zone 3 is 464cm to 352cm, and zone 4 is 352cm to 0cm.

In BMC1 (Fig. 8b) there are high abundances of *Centropyxis acuelata, Centropyxis cassis, Centropyxis pontigulasiformis,* and *Cyclopyxis arcelloides*. This core shows variation in testate amoebae but it is less than that of LRC4 as there are not as many different taxa. *Arcella costata, Hyalosphenia insecta, Hyalosphenia subflava,* and *Trinema/Corythion* all have corresponding increases. Also interesting is that *Difflugia rubescens* rises when *Cyclopyxis arcelloides* decreases; *Heleospera petricola* appears to be similarly opposite of *Cyclopyxis arcelloides* as well. The dendrogram (Fig. 9b) shows that there are more testate zones lower downcore as the zones are much smaller from 176cm to 116cm compared to the upper part of the core which is one large zone in itself. Zone 1 is 176cm to 160cm, zone 2 is 160cm to 144cm, zone 3 is 144cm to 116cm, and zone 4 is 116cm to 0cm.

Bulk Density and Carbon and Nitrogen Isotopes

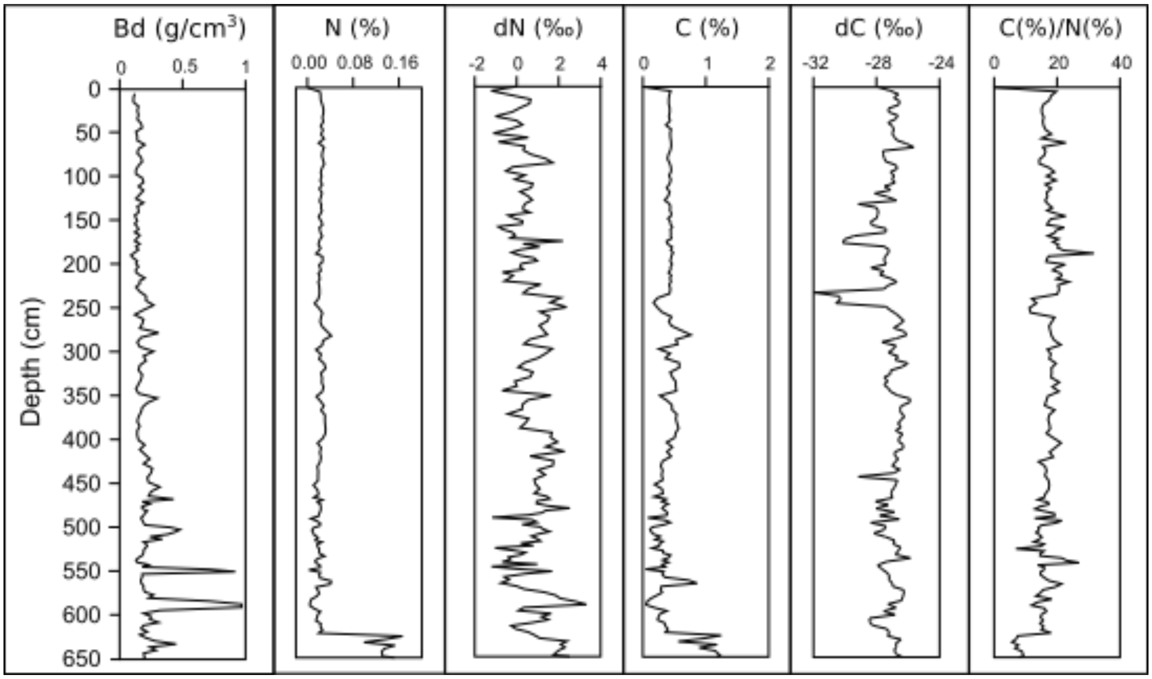

Figure 10a: LRC4 bulk density and carbon and nitrogen isotopes chart. The above figure shows bulk density, nitrogen percent, delta nitrogen, carbon percent, delta carbon, and the ratio of carbon percent to nitrogen percent.

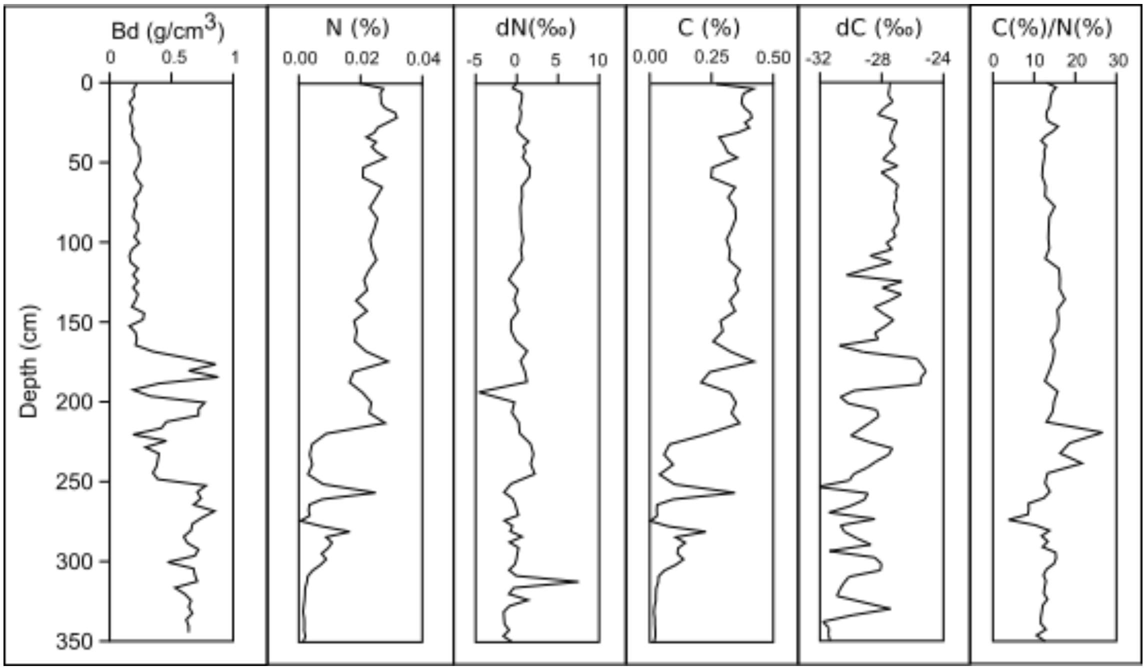

Figure 10b: BMC1 bulk density and carbon and nitrogen isotopes chart. The above figure shows bulk density, nitrogen percent, delta nitrogen, carbon percent, delta carbon, and the ratio of carbon percent to nitrogen percent.

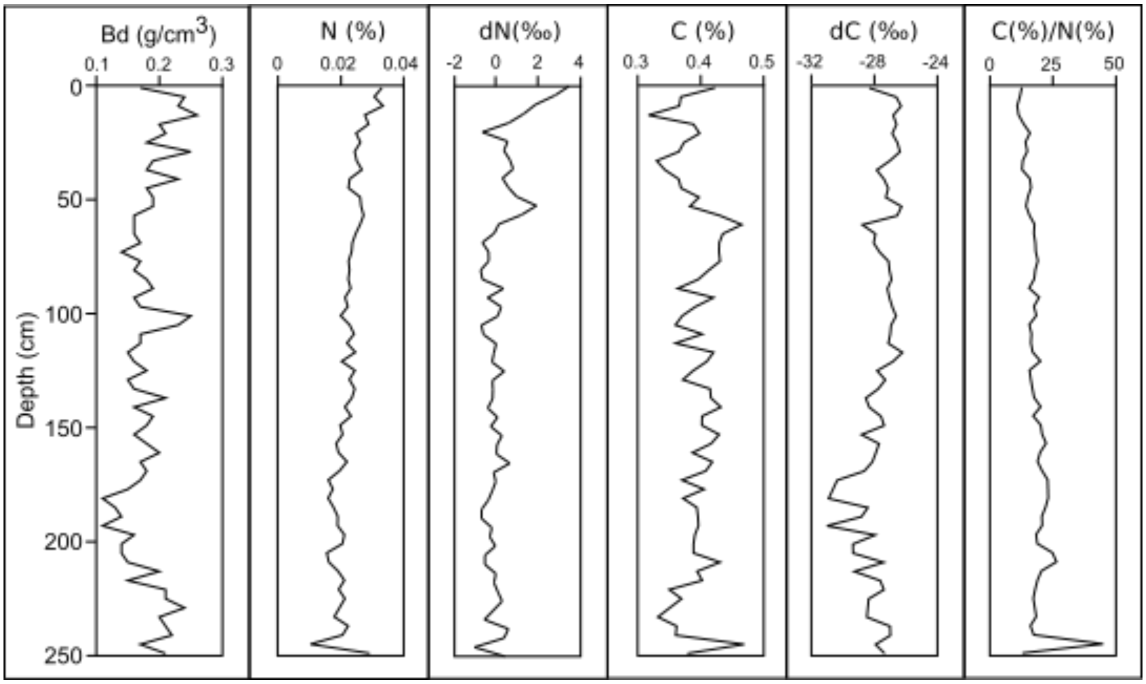

Figure 10c: W27 bulk density and carbon and nitrogen isotopes chart. The above figure shows bulk density, nitrogen percent, delta nitrogen, carbon percent, delta carbon, and the ratio of carbon percent to nitrogen percent.

In LRC4 (Fig. 10a) bulk density is around 0.1 g/cm^3 and becomes increasingly higher as we look downcore, with large spikes around 550cm and 600cm. Nitrogen content is fairly low throughout the core (~2%), except for a large peak at 15% around 625cm. Peat nitrogen isotopic signature fluctuates continuously around 0‰ with the values gradually growing as the core gets deeper, and it reaches a high near 2‰ around 600cm. Carbon content is around 40% throughout most the core with a spike around 625cm; peat carbon isotopic signature fluctuates throughout the core between -26‰ and -30‰, with a major low at -32‰ around 250cm. C/N is fairly linear with small fluctuations, highs around 200cm and 525cm, and lows around 250cm and 625cm.

In BMC1 (Fig. 10b) bulk density has a bimodal distribution, with values around 0.2 g/cm^3 until around 175cm followed by a large increase to a new mean above 0.5 g/cm^3 and the fluctuations remain fairly great throughout the rest of the core with high values. Nitrogen content experiences repeated extreme lows of approximately 0% around 350cm to 225cm and then experiences a steady increase to ~30% in the upper half of the core. Peat nitrogen isotopic signatures are mostly steady with a major low near -5‰ around 200cm and a major high of about 8‰ around 325cm. Carbon content follows practically the same pattern as nitrogen percent with exact fluctuations and lows around the same depths, as it has a low content of approximately 0% in the lower half of the core and then experiences a steady increase up to around 40%. Peat carbon isotopic signatures are fairly stable around -28‰ until around 100cm when fluctuations start increasing and it reaches a high of approximately -25‰ around 175cm; as the core goes deeper, values decrease and fluctuate from -28‰ to -32‰. C/N is approximately stable with major fluctuation activity around 225cm to 275cm as it reaches a high around 225cm and a low around 275cm.

In W27 (Fig. 10c) bulk density experiences fluctuations around 0.2 g/cm^3 throughout the entire core with a major low close to 0.1 g/cm^3 around 175cm to 200cm. Nitrogen content reaches a low of ~1% around 250cm and as the core moves up towards the surface, N% increases steadily to a little above 3% with minor fluctuations throughout. Peat nitrogen isotopic signature experiences some fluctuation from approximately -1‰ to approximately 2‰ around 0cm to about 60cm and is fairly stable at ~0‰ throughout the rest of the core. Carbon percent experiences major fluctuations with lows close to 30% around 0cm to 50cm and 200cm to approximately 250cm; from 200cm to 50cm the values fluctuate but remain fairly steady around 40-50%. Peat carbon isotopic signature experiences some small fluctuations near -28‰ throughout the upper half of the core with a low of approximately -31‰ around 175cm; the values fluctuate back to around -28‰ in the bottom part of the core. C/N is practically linear and gradually increases until there is a drastic increase approximately right before 250cm.

Age Depth Models

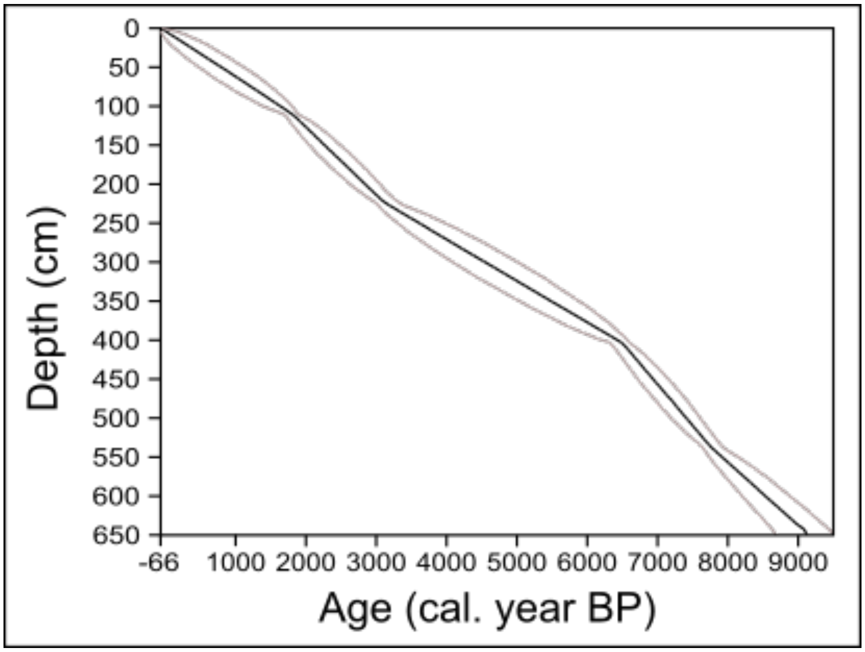

Figure 11a: LRC4 age-depth model. The above figure shows the calculated ages of the sample depths from radiocarbon dates. The black line represents the most likely age; the grey lines show the 95% confidence interval as calculated in Bacon.

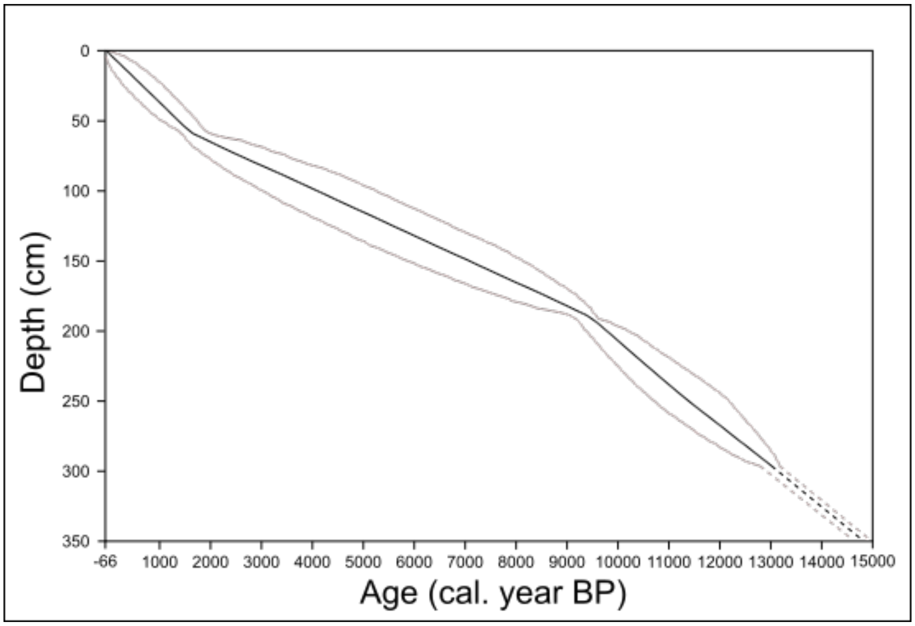

Figure 11b: BMC1 age-depth model. The above figure shows the calculated ages of the sample depths from radiocarbon dates. The black line represents the most likely age; the grey lines show the 95% confidence interval as calculated in Bacon. The dashed lines were extrapolated from the oldest 14C age all the way down to the bottom of the core on the basis of the calculated accumulation rate between the 2 oldest dates.

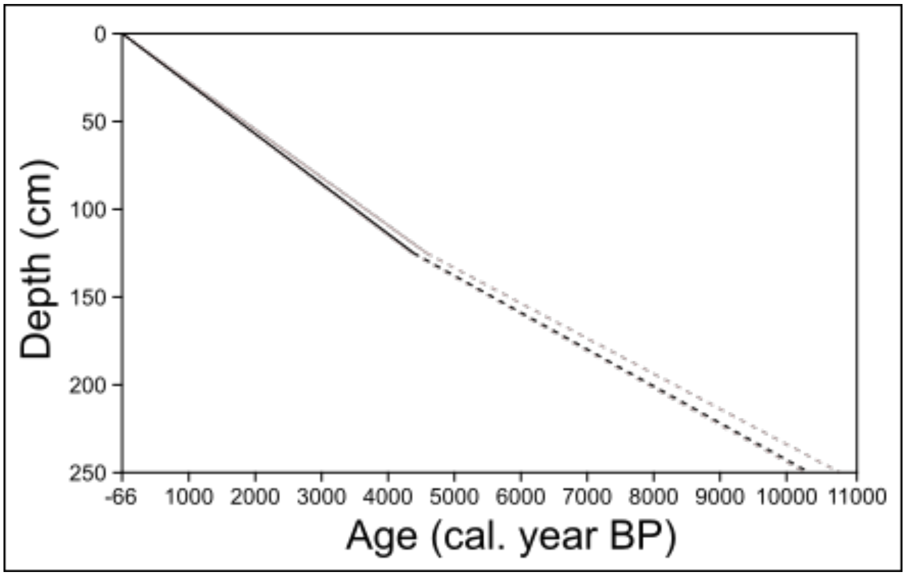

Figure 11c: W27 age-depth model. The above figure shows the calculated ages of the sample depths from radiocarbon dates. The black line represents the most likely age; the grey lines show the 95% confidence interval as calculated in Bacon. The dashed lines were extrapolated from the oldest 14C age all the way down to the bottom of the core on the basis of the calculated accumulation rate between the 2 oldest dates.

LRC4 (Fig. 11a) age is plotted against depth and there are gradual changes in slope as the average line shows LRC4 dating back till around 9,000 cal. BP. BMC1 (Fig. 11b) age is plotted against depth with gradual slope changes as the core dates fairly far back. Radiocarbon dates revealed that around 300cm the core is approximately 13,000 cal. BP; once extrapolated to the bottom of the core at 350cm, I estimate the core's age at 350cm is around 15,000 cal. BP. W27 (Fig. 11c) age is plotted against depth and the slope and the radiocarbon dates reveal the age of the core at 106cm is 4,320 cal. BP. The rest of the core had to be dated by calculating the slope and this led to an approximate estimate of the core dating all the way back to around 10,000 cal. BP.

CHAPTER IV

CONCLUSION

Beaver meadows are seldom studied due to their complex and challenging ecological composition. These areas typically have complex stratigraphies with a combination of inorganic and organic layers. There is heterogeneity within the basin itself, such as between the cores, which is due to dynamic water movement across the valley. Overall, BMC1 appears to have been a shallow pond until approximately 7500 cal. BP when it became a wetland with a couple of drier episodes around 8200 cal. BP and approximately 11000 cal. BP where mosses colonized the site (Fig. 12a). While the LRC4 core doesn't date as far back in time, the stratigraphic changes show about 7 spikes in inorganic material starting around 8200 cal. BP which is about roughly 1 per 1000 years (Fig. 12b). These spikes could indicate sandy layers brought about by fast moving water and/or slumping from adjacent upland that is perhaps due to beaver activity. It should also be noted that some of those layers are synchronous between the 2 cores, with the highest core in the watershed (LRC4) getting "sandy" and the lower one (BMC1) getting "mossy". To analyze these cores further, future studies would need to differentiate between different inorganic material grain size as we can't confirm the sand (LRC4) versus silt-clay (BMC1) content. Sand is coarse and is probably indicative of rapid/episodic deposition by fast moving water; this would explain the peaks in LRC4 (Fig. 12a). Clay sized fine particles would indicate slow moving and deeper water that is usually found in ponds, and this would most likely be the bottom of the BMC1 core (Fig. 12b). Comparing moss percentages in BMC1 with inorganic percentages from LRC4 show that they share some of the same peaks. BMC1 has clearly had a dynamic past between 12000 and 4000 cal. BP, with 4 major moss spikes that indicate shallow flooding or wetland conditions. LRC4's dynamic timeline also seems to stop around 4000 cal. BP, which is interesting. We can see that this site was dynamic since the beginning around 9000 cal. BP as shown by the 7 episodic spikes in inorganic material. The third core, W27, requires further analysis; once this is complete, we can understand the full extent and aftermath of beaver activity as we will have the reconstructed ecological system of a site that beavers abandoned. This, in conjunction to the other two cores, will help us understand more specifically the way the beavers first change an environment, since all that is really known about beaver impact is that they do ecologically re-engineer an ecosystem; we can also make more conclusions on how active beaver meadows are interacting with the global carbon cycle, how an abandoned beaver meadow affected global methane emissions and how the environment changed once it was abandoned by beavers. From a larger standpoint, we can conclude that even though beaver meadows are complex systems, and thus are challenging to analyze and reconstruct, there are still ways to reconstruct their history with a certain level of confidence and coring at multiple locations (our 3 sample sites) can strengthen the reconstruction of what happened.

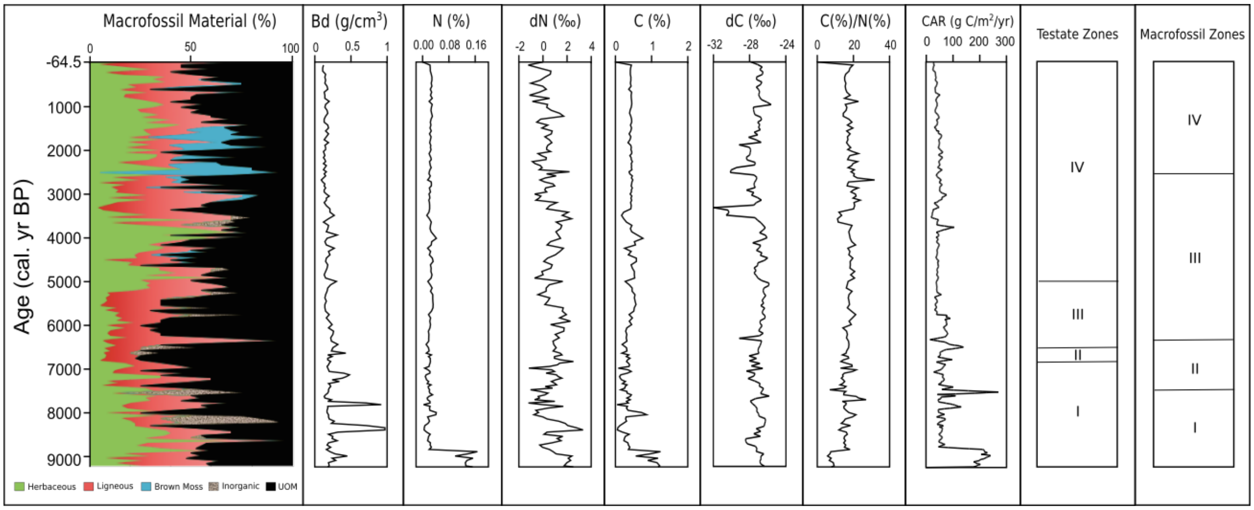

Figure 12a: LRC4 composite chart. The above figure shows plant macrofossils, bulk density and carbon and nitrogen isotope measurements, carbon accumulation rates, and the according testate and plant macrofossil zones.

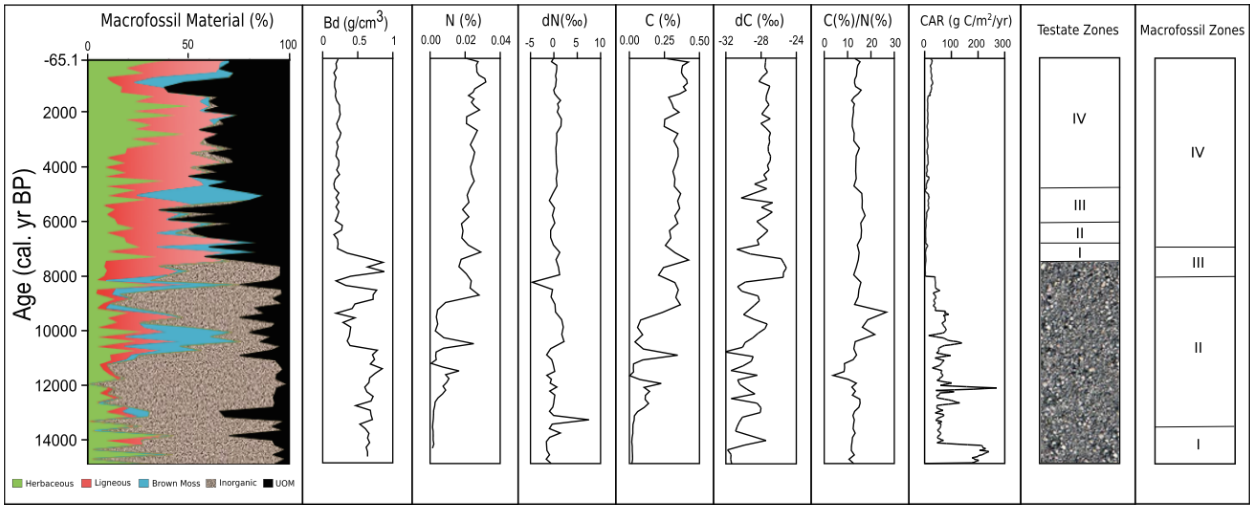

Figure 12b: BMC1 composite chart. The above figure shows plant macrofossils, bulk density and carbon and nitrogen isotope measurements, carbon accumulation rates, and the according testate and plant macrofossil zones.

Employing a multi-proxy analysis allows us to better understand the details of the environment at the corresponding age periods because each proxy can tell us something different about the evolution of the system. For LRC4, the testate zone 1 can approximately correlate to the plant macrofossil zones 1 and 2 (Fig. 12a). The testate zone 2 is right before the approximate transition from the plant macrofossil zone 2 to zone 3. Finally, plant macrofossil zones 3 and 4 could offer detail in the changing vegetation and plant structure in accordance to part of the testate zone 3 and characterize the testate zone 4 as a whole. Looking at the BMC1 core, the plant macrofossil zones 1 and 2 reveal the early peatland history which is mostly inorganic; zone 3 reveals the transition from pond to wetland and thus zone 4 is the current wetland that is an active beaver meadow (Fig. 12b). Comparing these zones to the testate amoebae zones, testate zone 1 correlates to the plant macrofossil zone 3 and the testate amoebae zones 2, 3, and 4 could potentially offer more details to the plant macrofossil zone 4 where BMC1 is currently a wetland (Fig. 12b). The testate amoebae zones reveal the hydrological conditions that are associated with the corresponding plant macrofossil compositions, which provide a more in depth analysis of the core. The other proxies still need to be further analyzed to make more specific conclusions about the overall environment but we currently have a good idea of the differing conditions of the LRC4 and BMC1 cores at certain times.

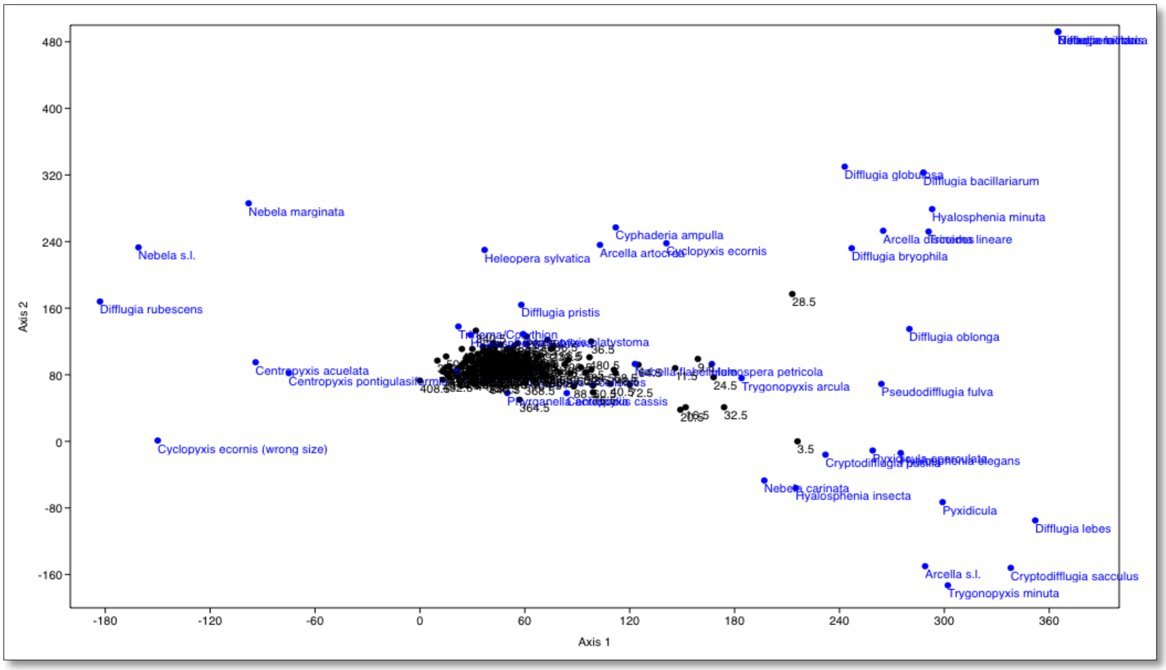

Figure 13a: LRC4 Detrended Correspondence Analysis. The above figure is a DCA ordination of square root transformed testate data from the LRC4 core.

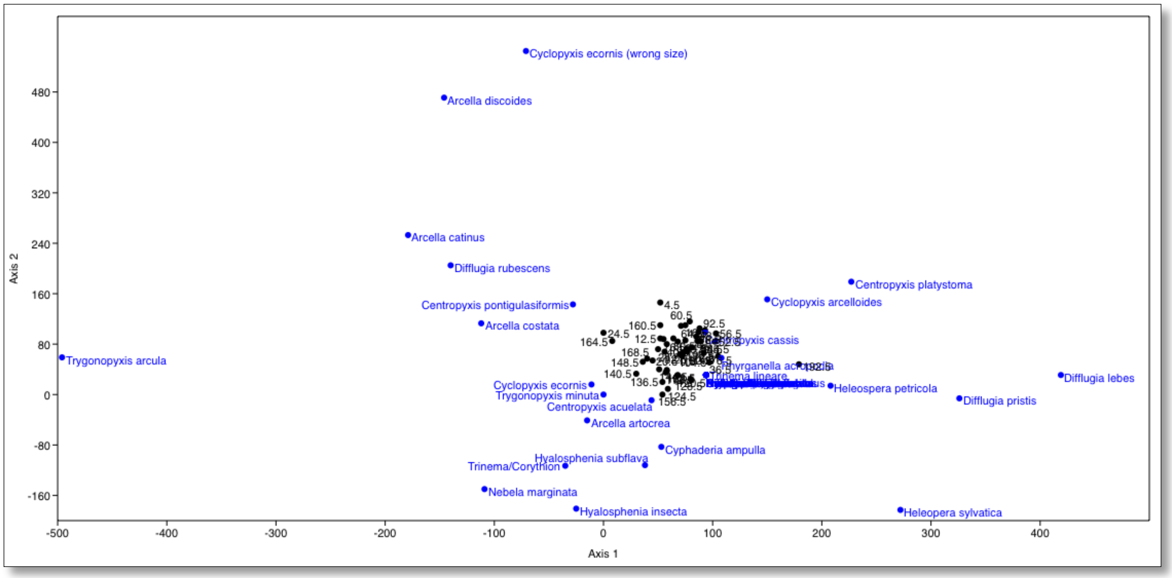

Figure 13b: BMC1 Detrended Correspondence Analysis. The above figure is a DCA ordination of square root transformed testate data from the BMC1 core.

Testate amoebae do show promise as a proxy for hydrological changes based along the profiles and the DCA, and the mentioned examples above with plant macrofossils zones correlating to testate amoebae zones. The above DCAs (Fig. 13a and 13b) are interesting because they reinforce the testate profiles. For example, it's interesting how in BMC1 the *Arcella costata, Hyalosphenia insecta, Hyalosphenia minuta,* and *Trinema corythion* all share the same peaks and decreases in their testate profiles (Fig. 8b). Comparing this to the DCA (Fig. 13b), this data is reinforced by the fact that these species are all placed very closely to each other or are in approximately the same planes along Axis 2. In BMC1, the *Centropyxis acuelata* and *Cyclopyxis arcelloides* oppose each other with one rising as the other decreases; this is also reinforced by the DCA because the species are on opposite sides along Axis 2. Generally, Axis 1 can tell us whether the species is wetter or drier, so the fact that these two species are on opposite sides and occur at opposing times can allow us to conclude that when one species is more abundant, there is a wetter environment compared to the other being abundant and thus bringing about a drier environment. The LRC4 DCA (Fig. 13a) follows the same conditions and shows that for this core, testate taxa such as *Centropyxis acuelata* vary from others such as *Hyalosphenia minuta*. Testate amoebae in the third core, W27, are currently being analyzed and once this analysis concludes, we will be able to make better inferences as to the role testate amoebae might play with beaver activity. To completely analyze the hydrological conditions and changes of the testate amoebae though, we need to quantify the changes in testate amoebae communities. Testate amoebae studies are more prevalent in bogs whereas beaver meadows are a relatively new study site for testates, and thus some of the testates found in our sites do not have any measured or recorded water table depths. To make more accurate hydrological assumptions, future work will need to be conducted where we take surface samples along a hydrological range that would allow us to associate a specific hydrology with the species and then we can reconstruct changes in moisture more specifically.

Carbon accumulation rates (CAR) from the wetland portions of the core are similar to what has been reported for northern peatlands in general (Fig. 12a and Fig. 12b). The highest peat carbon accumulation rates are located in the lowest portions of the core and this is related to the rapid rates of sediment accumulation and their high bulk density. We can also conclude that this would be linked to high inorganic material content which is shown to be prevalent at depths with a higher CAR. High inorganic material is also directly related to sediment accumulation and naturally will have a higher bulk density than macrofossils such as herbaceous material. There is still a lot we do not know about the overall carbon and nitrogen figures in relation to the other proxies throughout the cores. To understand the role of carbon and nitrogen isotopes within these cores, further work will be conducted on the meaning of their isotopic datasets.

To conclude, this study focused on three sample sites chosen in the Sibbald Research Wetland, Alberta, Canada that are related to different levels of beaver activity: none (LRC4), current (BMC1), and abandoned (W27). We have found that, while testate amoebae water table depth reconstruction requires more focus, there are correlations between certain testate species which do show differing or similar hydrological conditions and are thus a reliable proxy for this study. From the plant macrofossils, we can conclude that inorganic material content is a fairly reliable proxy for beaver activity based on its association with sediment accumulation and ponding activity. More work would have to be done to specify inorganic material as a beaver proxy since the inorganic material could be justified by fast moving water or slumping from adjacent upland. We also need to clarify inorganic material grain size to conclude that the inorganic material in the LRC4 and BMC1 cores are the same sort of inorganic material and can be related to the same cause since sand in LRC4 would imply a different environmental situation than silt-clay in BMC1. These conclusions matter because they help us to reconstruct the particular environmental conditions that are associated with beaver activity as well as make conclusions on how beavers can impact global methane emissions with wetland formation and ponding through the way they interact with our selected sample sites throughout their respective times. Our objective was to reconstruct the environments of these three sites to make further assumptions about beaver activity, beaver impacts on methane emissions through wetlands, and overall to create a beaver proxy that can be used in future climate or ecological studies that include beaver meadows. We've addressed this by reconstructing each sample site, with W27 currently incomplete due to still being largely in the lab analysis portion. We are also working to address the carbon and nitrogen isotopes to better understand the carbon accumulation at each site during their ecological transitions, the soil nutrient conditions, and overall the global methane emissions that are brought about by wetlands and their associated ecological changes. To some extent we have also been able to conclude the associated proxies with beaver activity based upon high carbon accumulation rates and inorganic material; we are still addressing the sustained validity of these as a beaver proxy though. We hope to construct a testate key that can be applied to other beaver meadow sites as well as the data from each sample site will add further context to northern peatland ecological features. This research will aid more peatland studies in the area, further beaver meadow studies, and will provide testate amoebae with a new environmental context that has been greatly untested by this proxy.

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