Macrofossil Evidence for the Vegetation and Climate History of Southeastern New York State from the Late Glacial to Early Holocene

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Abstract

The earth's climate results from complex interactions between the ocean, the atmosphere, and the earth's astronomical configuration around the sun. For as far back as paleoclimate records show, the earth has oscillated between glacial and interglacial periods. The transitions between these two phases, however, have not necessarily been characterized by a gradual change in temperature until a new state has been reached. At the end of the Last Glacial Maximum, following an initial temperature rise after the retreat of the Laurentide Ice Sheet, an abrupt return to colder temperatures known as the Younger Dryas (YD) took place. The YD had varying effects around the globe, thus regional studies to determine the extent of that and other climate changes are beneficial to help our understanding of the ocean-atmosphere system. This, in turn will help predict how the earth could respond to future climate changes. In this study, macrofossil and LOI analysis on a sediment core retrieved from Tamarack Pond in Black Rock Forest, NY was performed, and a vegetational and climate history of the region focusing on the time period from the retreat of the Laurentide Ice Sheet to the beginning of the Holocene was constructed. It is shown that a boreal to temperate forest was first developed following a cold tundra ecosystem, but a drop in temperature caused an increase in boreal species before an increase in temperature caused their complete disappearance and a switch to temperate forest species. There are clear macrofossil assemblages within the core that outline these warmer to colder temperature oscillations, and the comparison to other records suggests that the transitions between periods were not always gradual. This climate history will be informative for projecting how the region might respond to warming temperatures or a drastic cold event, two possible scenarios for the future.

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Introduction

Glacial Cycles

Paleoclimate records show that the earth's climate has oscillated between times of cold temperatures and extreme ice coverage, known as glacials, and times of little ice coverage and warm temperatures, known as interglacials. According to records such as those from Antarctic ice cores, this has occurred eight times in 100,000-year cycles over the last 800,000 years (Broecker, 1989). One explanatory theory, first introduced by Milutin Milankovitch, proposes that cyclical changes in the earth's axial tilt, orientation, and orbit around the sun (known as "Milankovitch cycles") changes the amount of solar insolation at high latitudes, which acts as a pacemaker for the ice ages (Hays et al., 1976). While there is evidence that shows that the earth's climate responds to Milankovitch cycles, feedback mechanisms between the ocean and the atmosphere play a crucial role in governing glacial cycles (Broecker, 1989).

The transition into glacial periods is a gradual process, partly fueled by the ice-albedo positive feedback loop but terminations of ice ages are rather abrupt and climate can warm drastically over a short period of time. The reason for these abrupt terminations is still a topic of investigation, but ocean-atmosphere interactions are likely a driving force (Broecker, 1989). Ocean-atmosphere interactions contribute to changes in global and regional temperatures, CO_2 levels in the atmosphere, and ice extent (among other things), which are also related through feedback mechanisms. The extent of the effects that the feedback loops and ocean-atmosphere interactions have on the climate is still uncertain. Thus the study of how the earth responded to climate changes in the past is crucial for understanding how the earth might respond to climate changes in the future.

Laurentide Ice Sheet

The Last Glacial Maximum (LGM) was a time when the ice sheets were at their maximum extent during the last glacial period. The Laurentide Ice Sheet was an ice sheet that covered Canada and much of the Northern areas of the United States during LGM. It covered all of New York State eastward to Long Island, which itself was made by moraines that formed by the ice sheet (Fig 1). Although the date of the termination of the ice sheet is still being investigated through different methods, one estimate based on cosmogenic nuclide dating shows the retreat of began as early as 25000 BP (Balco et al., 2009). Another estimate, based on Accelerated Mass Spectrometry (AMS) radiocarbon dating of macrofossils found at the base of lake sediment cores that were once under the ice sheet, suggest the retreat of the southern margin began thousands of years later, around 16000-15000 BP (Peteet et al., 2012).

If the cosmogenic nuclide dates are correct, then this suggests that there was a significant time period (up to 10000 years) where there was an ice-free environment, yet no lithologic or biological deposition in lakes. This would imply extreme Arctic conditions in the region and pose more questions about the pacing at which vegetation colonized the newly exposed land and our understanding of the coupled ocean-atmosphere system (Peteet et al., 2012).

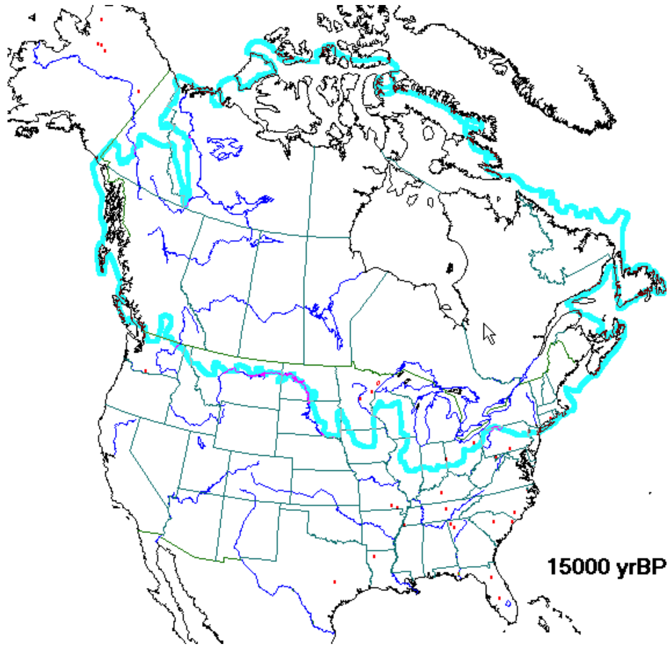

Figure 1: The extent of the Laurentide Ice Sheet at the end of the Last Glacial Maximum, before its retreat, 15,000 BP (NOAA, 2003).

Younger Dryas

When the Laurentide Ice Sheet retreated, climate and weather patterns of North America changed. Temperatures got warmer as the earth entered a period known as the Bolling-Allerod interstadial. Between 15000 and 9000 BP, the orbital conditions of the earth were moving in a way to favor maximum summer insolation (Berger, 1978; COHMAP, 1988). This supports the theory of how the Milankovitch cycles can act as a pacemaker for the ice ages, for maximum summer insolation in the northern hemisphere would promote the retreat of ice sheets and warmer temperatures. However, temperatures did not gradually increase to the climate that we see today. There are many paleoclimate proxies that reveal unexpected short timescale anomalies, such as the Greenland ice cores that display an abrupt cold climate event, the Younger Dryas (Dansgaard, et al, 1982) (Fig. 2). The Younger Dryas, around 12800 BP, was an approximately 1300 year-long time in which isotopic shifts in Greenland cores reveal temperatures dropped 15°C in Greenland, back to glacial conditions (Severinghaus, 1997). However, in other areas of the Northern hemisphere, records indicate a return to colder conditions, but not back to glacial conditions.

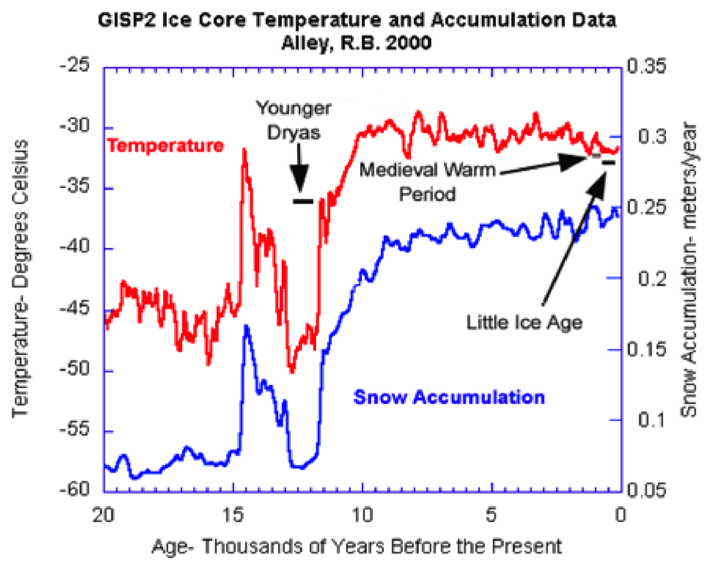

Figure 2: Temperatures from Greenland ice cores show abrupt climate changes since the LGM, such as the Younger Dryas (NOAA, 2004)

One proposed mechanism that could account for the abrupt initiation and termination of this cold period is related to deep water production in the North Atlantic (Broecker et al, 1988). Warm, salty water in the Gulf Stream flows northward from the tropics to the North Atlantic, where the colder temperatures cause the high salinity water to become denser than the surrounding waters and sink to the deep ocean. This initiates the flow of the "Great Ocean Conveyor," the path in which water travels around the globe (Broecker, 1987). Along this path, the ocean transports heat from the tropics to the poles. If the formation of deep water in the North Atlantic were to stop and the conveyor shutdown, heat would not be transferred to the Northern latitudes, and there would be drastic consequences to the climate. When the Laurentide Ice Sheet melted, the meltwater could have flowed into the North Atlantic and covered it with a "freshwater cap" that shut down the ocean conveyor, and caused the cold reversal in the Northern Hemisphere (Broecker at al, 1988).

Southern New York State Climate and Vegetation History

There are many paleoclimate records that show a very distinct Younger Dryas signal, especially in high latitude areas such as Greenland. In North America, there are additional records that show significant lithological changes in Northern areas such as eastern maritime Canada and Maine, but the change is not as obvious in lithological records from Southern New York State (Miller and Griggs, 2012). However, the palynological and macrofossil shifts in the records indicate a cooling of about 3-4°C (Peteet et al., 1990; 1993). New York climate and vegetation from the Last Glacial Maximum to the beginning of the Holocene has been studied through lake sediment analysis, and these studies are central to understanding the timing of the deglaciation of the Laurentide Ice Sheet and the regional effects of the Younger Dryas (Peteet et al., 1990; 1993; Maenza-Gmelch, 1996). In the vicinity of Spruce Pond, NY, Maenza-Gmelch (1996) found that after the deglaciation, the landscape was one of open vegetation dominated by herbs and shrubs. This was followed by a period where thermophilous trees, such as *Quercus,* became dominant. The cold climate of the Younger Dryas was marked with increases in boreal plant species, such as *Picea*, *Larix*, *Betula*, and *Abies*, just as in sites such as Alpine, NY, Allamuchy Pond, NJ, and Linsley Pond, Conn. (Peteet et al, 1990; 1993; Miller and Griggs, 2012). The end of the Younger Dryas and beginning of the Holocene is marked by the decline of boreal species and the return of *Quercus*, *Pinus strobus,* and *Tsuga canadensis* (Peteet et al., 1993; Menking, et al., 2012). This shows that the region underwent periods of colder and warmer temperatures as well as varying amounts of precipitation.

Pollen and Macrofossil Analysis

While these records from in and around the Southern New York region (Peteet et al., 1993; Menking et al., 2012; Maenza-Gmelch, 1996) have a similar trend in the shifts of tree presence and abundances, there are slight differences in the timings of the arrival of plants. Additionally, some sites had macrofossils not found in other cores, such as the *Dryas integrifolia* that was found in Allamuchy Pond, NJ (Peteet et al., 1993), but not in other lakes in Black Rock Forest, NY (Maenza-Gmelch, 1996; 1997a; 1997b). Therefore, additional macrofossil analysis is instrumental in adding to and better understanding these records. These studies were mainly pollen analyses, and while some macrofossil analyses were included, they were not a prominent focus of the studies.

Macrofossils are very important to support pollen analyses. Pollen has the limitation of being airborne long distances, and is often unidentifiable to the species level (Lowe and Walker, 1984). Since pollen can blow in from far places, it does not necessarily represent the regional vegetation. For instance, in arctic and open ecosystems, pollen data can be misinterpreted because the wind is stronger and there are fewer trees as obstacles, thus there is more windborne pollen and less regional pollen (Birks and Birks, 2000). Birks (1993) gives an example of how pollen analysis estimated summer temperatures in Norway during the Allerod that were 2-6°C warmer than what was determined through macrofossil analysis. Macrofosssils are autochthonous, thus representing the vegetation of the area at the time of deposition. It is also possible to identify some macrofossils to the species level, thus a clearer picture of the climate can be inferred since species of plants in the same family can be adapted to different climate conditions.

Certain species of plants are better adapted for living in different temperatures and levels of precipitation. Therefore, climate shifts will result in vegetation changes, and looking at the past vegetation of a region is one way to determine past climate variability. When the Laurentide Ice Sheet retreated, it exposed land for plants to migrate to, and new topographical features formed by the advance and retreat of the ice sheet, such as lakebeds that were devoid of any organic sediment at their bases. Water filled them in and lakes formed that then began to accumulate sediment. The sediment at the base of the lakes contain little organic matter, since it would have taken time for the recently ice-covered land to grow substantial amounts of vegetation. Consequently, the base of the sediment cores are usually glacial clay, and when the sediment switches to more organic based material, it signifies that the land had more stable vegetation growth and/or more in situ production. Some organic matter in lake sediments is comprised of algal and aquatic components, which are generally more abundant in warmer climates.

Study and modern implications

In this study, a sediment core from Tamarack Pond, NY was analyzed for macrofossils and organic carbon content. While the area has been moderately affected by humans, it first developed with the retreat of the Laurentide Ice Sheet (Black Rock Forest, 2012), and its location near the southern margin of the LIS makes it an ideal location to analyze the effects of the retreat. During a time where temperatures are increasing and ice caps are melting, there is a real threat that the deep water formation currently keeping the ocean conveyor belt moving will once again shut down from an influx of cold fresh water to the North Atlantic. While the current climate of the region is much warmer than the climate was before the onset of the Younger Dryas, studying the transitions into and out of the Younger Dryas in different regions is very relevant to understanding how the earth might respond to this kind of event in the future. The macrofossils found in this core will provide a history of the vegetational shifts and climate changes in the region. Used in conjunction with already existing palynological and macrofossil data, this will strengthen our understanding about the timing of the retreat of the LIS and how ocean-atmosphere interactions can affect climate change. Additionally, it will give further evidence about the extent of the regional affects caused by the Younger Dryas, and how vegetational patterns changed in response to the event.

Methods

Study Site: Tamarack Pond

Tamarack Pond (41.39500°N 74.02505°W) is located at an elevation of 1305 ft, within the variable topography (Fig. 3) of Black Rock Forest, a 3830-acre oak (*Quercus)* dominated forest located in the Hudson Highlands Physiographic Province in southeastern New York State (Fig. 4). The forest lies in an ecotonal area between *Quercus* forests to the south and *Tsuga – Pinus strobus* forests to the north (Kuchler, 1964). The mean annual precipitation is 1060 mm, and air temperatures range from a January mean temperature of -2.7°C to a July mean temperature of 23.4°C (Ross, 1958).

The forest is currently used for field-based research and education, and has had a history of land use changes since the arrival of European settlers around 1690 (Black Rock Forest, 2012).

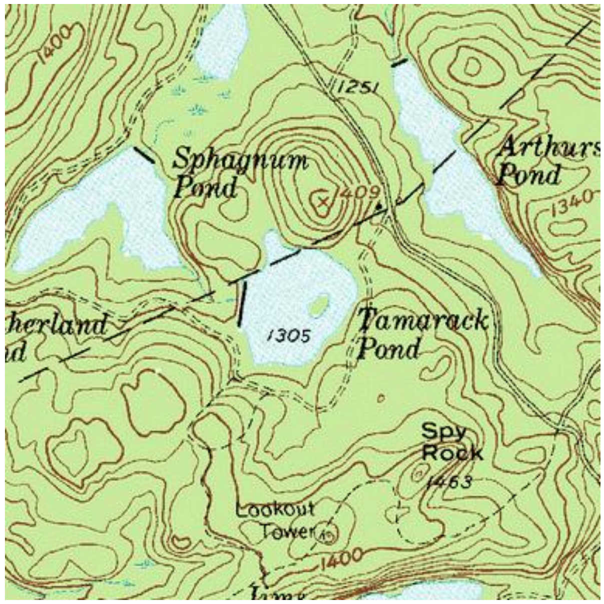

Figure 3: Topography of the region (in feet) surrounding Tamarack Pond, in Black Rock Forest, NY (Topoquest, 2012).

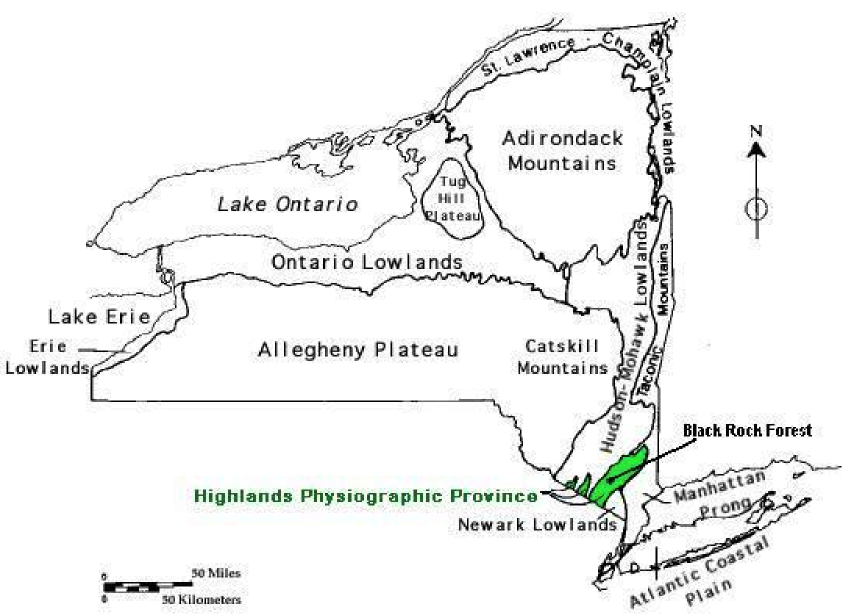

Figure 4: Location of Black Rock Forest in southeastern NY. Shaded in area is the Hudson Highlands Physiographic Province (Black Rock Forest, 2012)

Core Extraction

In October 2012, a 7.22-m long sediment core was retrieved from below 4 m of water in Tamarack Pond, NY. A wooden platform with a hole in the center was attached to two inflatable rafts that were secured to a small peat island in the middle of Tamarack Pond. Through the hole, the sediment core was extracted in 1-meter increments, using a modified Livingstone piston corer (Wright et al., 1984). Sediment retrieval stopped when the corer could not penetrate through anymore, implying that the underlying bedrock or rocky till had been reached. When brought to the surface, the sediment was extruded from the corer and wrapped in plastic and tinfoil. The cores were then stored in plastic tubes in a Lamont-Doherty Earth Observatory (LDEO) refrigerator to prevent decay until they were analyzed.

Laboratory

The bottom 2.22 m of the core (at depths from 11.22-9.00 m) was cut in half longitudinally, and visually analyzed for sediment lithology and evidence of contamination. One half of the core was used for macrofossil and Loss on Ignition (LOI) analysis, and the other will be kept in an LDEO refrigerator for reference and future studies. From 11.19-10.30 m, contiguous 2-cm segments were cut for analysis. Because of timing restraints, from 10.00-9.50 m, the 2-cm segments were sampled at 10-cm intervals, and one more 2-cm sample was taken at 9.02 m.

Organic Carbon Content and loss-on-ignition (LOI) Analysis

The organic carbon content of sediment and how it varies can be an indicator of climate variability. Low organic carbon content suggests that the climate is not conducive for growing vegetation and indicates a time of drought or colder temperatures. High organic carbon content on the other hand, would signify a climate that promotes vegetation growth, thus indicates a wetter or warmer environment with preservation and not too much decomposition. Loss-on-ignition (LOI) is a method that is used to determine the amount of organic carbon in the sediment.

One cm^3 of sediment from every 2-cm segment was analyzed for organic carbon content by the loss-on-ignition method. The samples were placed in a porcelain crucible of known mass and weighed. They were then placed in a furnace at 100ºC for 24 hours to remove any moisture. This weight minus the crucible weight equals the dry weight. They were then placed in a furnace at 550ºC for two hours. The combusted sample minus crucible weight equals the final weight. The difference between the dry weight and the final weight represents the amount of organic matter lost, and %LOI is calculated by dividing the difference by the dry weight, and multiplying by 100.

(Dry weight - Final weight)/(Dry weight) x 100 = %LOI

Macrofossil Analysis

A total of 51 2-cm sediment samples were analyzed, and each sample was washed through a 500 μm sieve to isolate any macrofossils from the sediment. The materials retained on the sieve were placed in water and analyzed under a microscope up to 60x magnification. Macrofossils were handpicked with tweezers and brushes, placed in vials of water, and refrigerated for later identification and dating. The fossils were identified using modern reference collections at Lamont Doherty Earth Observatory and identification books (Katz, et al, 1965, Martin and Barkley 1961, Berggren, 1981, Montgomery, 1977).

Results

Core

Since the study focuses on the Late Glacial to Holocene transition, only the bottom 2.22 m of the core was analyzed. The stratigraphy of this portion consisted of clay at the base and gyttja at shallower depths. The transition from clay to gyttja occurs at 10.78 m (Fig. 5). There appeared to be contamination at the very base of the core (11.22 m-11.19 m) and at the top of the 11 m section (11.00-11.03 m). The contaminated portions were discarded, but any anomalous results from near these areas were examined with this in mind and mostly discarded because of uncertainties.

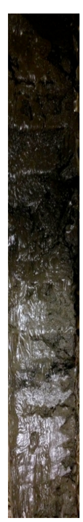

Figure 5: Section of the core retrieved from Tamarack Pond, NY, from a depth of 10.68 m to 10.94 m. The distinct transition from glacial clay to organic gyttja occurs at a depth of 10.78 m.

Loss on Ignition

The LOI values ranged between 4% and 5% through the clay sediment, and drastically rose to 24% at 10.78 m, where the sediment became organic gyttja. Between 10.78-10.56 m, the values stayed between 18% and 23%, and then gradually increased to 42% with decreasing depth until 10.42 m. The LOI values then dropped to 31%, and other than one anomalously low value at 9.8 m, increased gradually from 10.40 to 9.02 m, where it reached the highest value, 49% (Fig. 6).

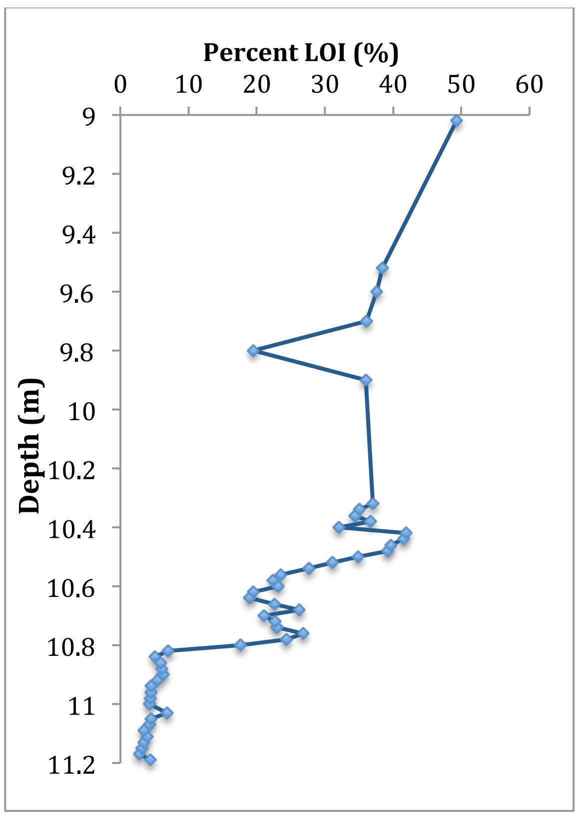

Figure 6: Loss on Ignition diagram from Tamarack Pond, NY. Samples of $1cm^3$ were taken every 2 cm from 11.19-10.30 m, and then every 10 cm from 9.9-9.5 m, with one more taken at 9.0 m.

Macrofossils

A large variety of macrofossils were recovered from throughout the analyzed portion of the core, which allowed the division into four macrofossil assemblage zones (Fig 7). These zones are based on the occurrence of macrofossils that represent different climatic environments. Partial macrofossil remains of the same species were counted as individual macrofossils if they were distinct from the other remains. When there were partial macrofossil remains of the same species that were not distinct individuals, they were counted as one macrofossil. All charcoal pieces were counted individually.

Zone T1: (11.19-10.78 m) *Dryas – Salix*

Zone T1 is mainly marked by the presence of *Dryas integrifolia* leaves (Fig. 9E) throughout the zone, which had a maximal abundance at 10.84 m. *Salix sp*. buds, leaves, (Fig. 9F-G), and capsules were also prominent shrub macrofossils. Two types of moss, *Polytrichum juniperum* (Fig. 9B), and *Sphagnum sp*. appeared in the upper part of this zone, in the same area where a *Rumex orbiculatus* seed (Fig. 8L), *Carex trigonous* seed (Fig. 8I), and two *Carex lenticular* seeds appeared. Of the non-plant macrofossils, *Daphnia* ephippia (egg casings), bryozoan *Cristatella mucedo* statoblasts, and crane fly/beetle remains were found, also increasing at the upper end of the zone. There was a thin layer at 10.84 m that was very enriched in macrofossils.

Zone T2: (10.78-10.46 m) *Picea – Abies*

Zone T2 saw the disappearance of *Dryas integrofilia*, *Salix sp.,* and *Polytrichum junipernum*. Macrofossil abundance was low at the base, but remains of *Picea sp*. (Fig. 9C-D) were discovered, and *Abies balsamea* remains (Fig 9A, Fig. 8K) were found higher in the zone. Additionally, at the top of the zone was the first presence of *Betula glandulosa* (Fig. 8C-D)*,* and *Betula papyrifera* (Fig. 8B). *Sphagnum sp*. declined, but persisted through the zone, and *Carex lenticular* seeds also appeared throughout. Bryozoan statoblasts and crane fly/beetle remains were less abundant, and *Daphnia* ephippia were scarce at the bottom of the zone but increased at the top. Charcoal remains were more dominant in this zone than any other zone.

Zone T3: (10.46-9.8 m) *Picea – Abies – Larix – Betula*

Zone T3 had the most species richness, with the continued presence of *Picea sp*. and *Abies balsamea* remains*,* increase in abundance of *Betula glandulosa* and *Betula papyerifera* seeds*,* and the introduction of *Larix laricina,* and *Alnus sp*. remains (Fig. 9H). *Carex trigonous* seeds, seeds from the *Asteraceae* family (Fig. 8G), *Najas flexilis* seeds (Fig. 8E), and *Isoetes cf. melanopoda* spores (Fig. 8H) were found throughout. One *Impatiens biflora* seed (Fig. 8F), one *Potomageton sp*. seed and one *Chara sp*. oospore (Fig. 8J) were found. There was a large increase in numbers of *Daphnia* ephippia at the start of the zone, whereas bryozoan statoblast numbers remained low. The large gap from 10.30 -10.02 m is because no analysis was done in this section, not because of a lack of macrofossils.

Zone T4: (9.8 – 9.0 m) *Tsuga*

Zone T4 saw the disappearance of almost all prior plant macrofossil species, other than *Sphagnum sp. and Najas flexilis*. *Tsuga canadensis* and *Betula populifolia* appeared in this zone. Of the non-plant macrofossils, bryozoan statoblasts, *Daphnia* ephippia, and crane fly/beetle remains still occurred, but were minimal. The overall abundance of all macrofossils declined.

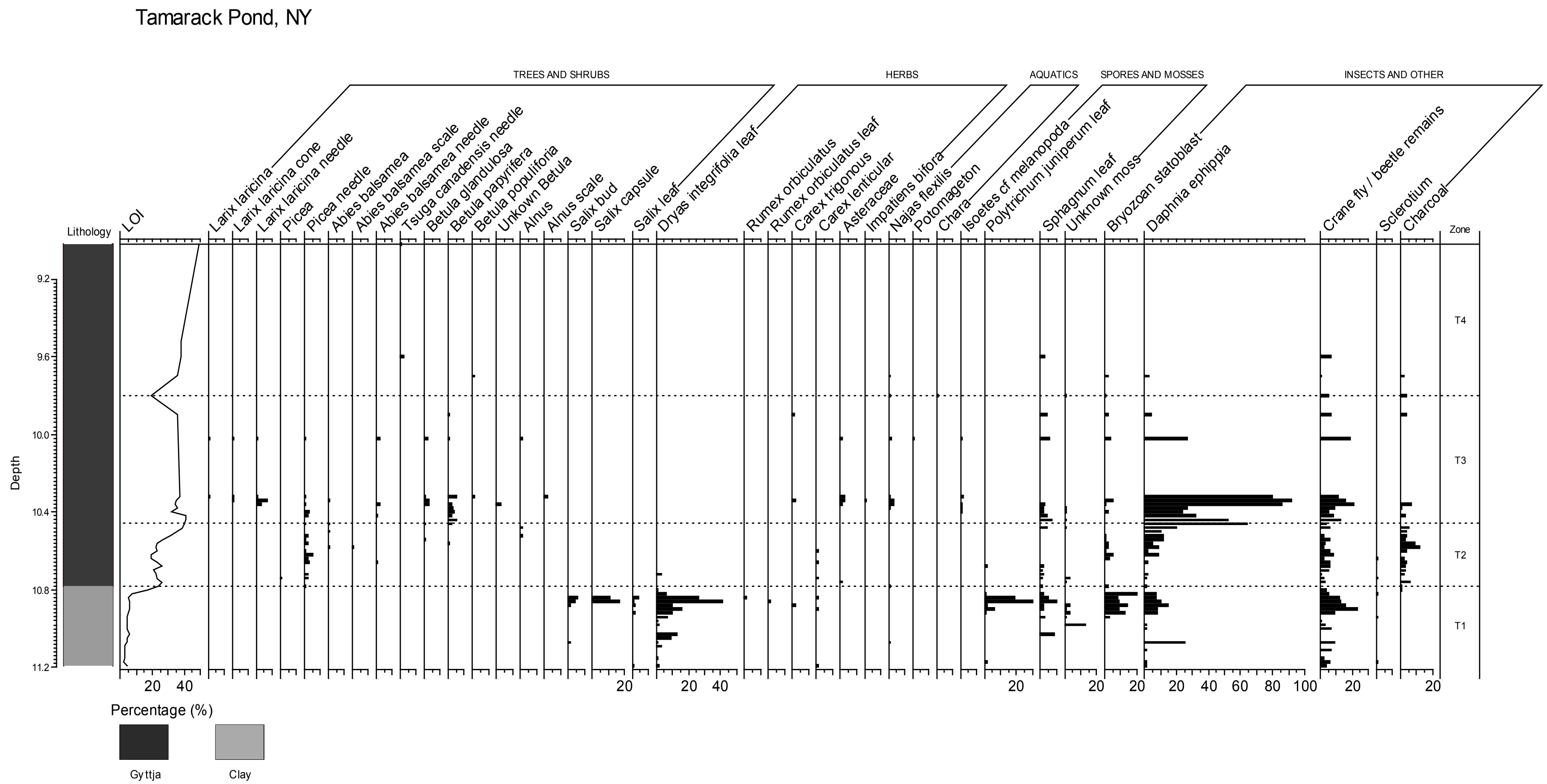

Figure 7: Macrofossil Diagram from 11.19-9.02 m depth, Tamarack Pond, NY. All macrofossils are seeds unless otherwise noted.

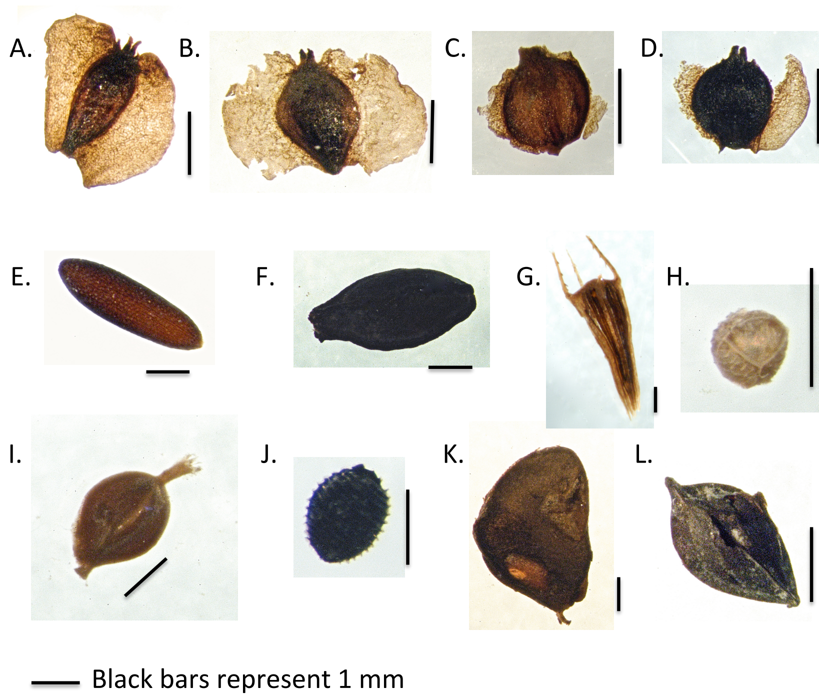

Figure 8A-L: Selected macrofossil seeds and spores retrieved from Tamarack Pond, NY. A) *Betula populiforia* seed, B) *Betula papyrifera* seed, C) *Betula glandulosa* seed D) *Betula glandulosa* seed, E) *Najas flexilis* seed, F) *Impatiens biflora* seed, G) unknown seed from *Asteraceae* family, H) *Isoetes cf. melanopoda* spore, I) *Carex trigonous* seed, J) *Chara sp*. oogonia**,** K) *Abies balsamea* seed, L) *Rumex cf orbiculatus* seed.

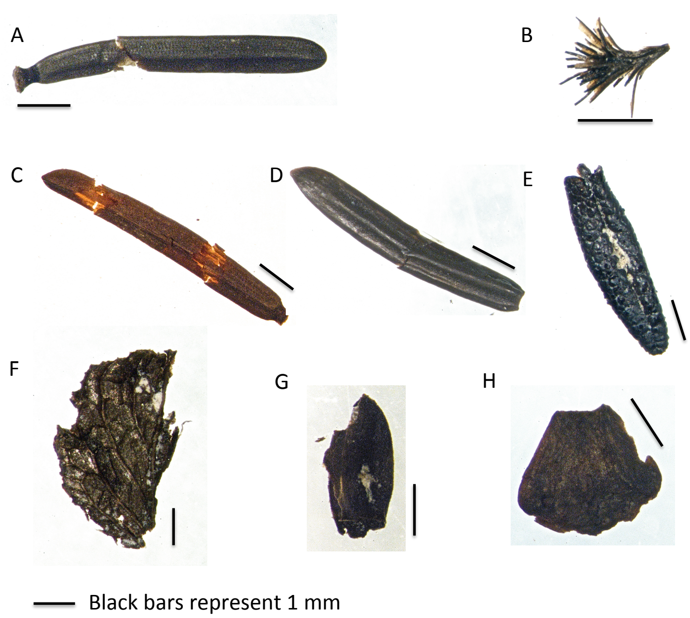

Figure 9: Selected non-seed macrofossil remains retrieved from Tamarack Pond, NY. A) *Abies balsamea* needle, B) *Polytrichum juniperum*, C) *Picea sp*. needle, D) *Picea sp*. needle, E) *Dryas integrifolia* leaf, F) cf. *Salix herbacea* leaf, G) *Salix sp*. bud, H) *Alnus sp*. scale.

Discussion

The sediment core retrieved from Tamarack Pond, NY, contained a variety of macrofossils that revealed a succession from tundra species to boreal species to temperate species. The basal clay in zone T1 indicates that the core goes back to the time of the last deglaciation. The low LOI values and low abundance of macrofossils at the very bottom of the zone indicate the landscape did not consist of much terrestrial life, which is expectant in a region newly exposed from a glacier retreat. The layer of significantly increased macrofossils at 10.86 m, just before the sediment changes from clay to organic material suggests that the landscape comprised of these plant species prior to this time, but either deposition into the lake sediment was minimal, or preservation was poor. No studies on neighboring sites record any sudden change in amount of organic matter production within the basal clay (Peteet et al., 1993; Maenza-Gmelch, 1996; 1997a; 1997b), thus the layer is thought to have been created by weather events that caused massive runoff into the lake.

The most abundant macrofossils in zone T1 are leaves of *Dryas integrifolia*. *Dryas integrifolia* is an arctic shrub that presently grows in colder tundra environments (Fig 10). It is known to be a pioneering species of areas exposed by receding glaciers, and prefers to grow in calcareous areas, such as in areas with limestone (CYSIP, 2012). Its presence in the base of the core indicates that the climate around Tamarack Pond when the sediment was deposited was much colder than the climate in the region today. The sediment at the bottom of the core would have been deposited shortly after the retreat of the Laurentide Ice Sheet, thus it follows that the climate would have been colder. *Dryas integrofilia* was not found at the core bottoms in other studies done in Black Rock

Forest (Sutherland Fen, (Peteet, unpub.); Sutherland Pond (Maenza-Gmelch, 2006)) or other nearby regions, excepting Allamuchy Pond, NJ (Peteet et al., 1993) and Green Pond, Harriman Park, NY (Peteet et al., unpublished). However, pollen from other tundra shrub species, such as *Salix sp.,* which was also found in this zone, were discovered in neighboring sites (Maenza-Gmelch, 1996), which supports the existence of an open tundra environment suggested by the growth of *Dryas integrifolia*. Additionally, Black Rock Forest lies on top of granite bedrock (Black Rock Forest, 2012), thus the presence of calcareous loving *Dryas integrifolia* could also suggest that there was till that consisted of limestone present at the time. If the till was not constant throughout the reagion, this could be one reason for why its presence was not found in other areas.

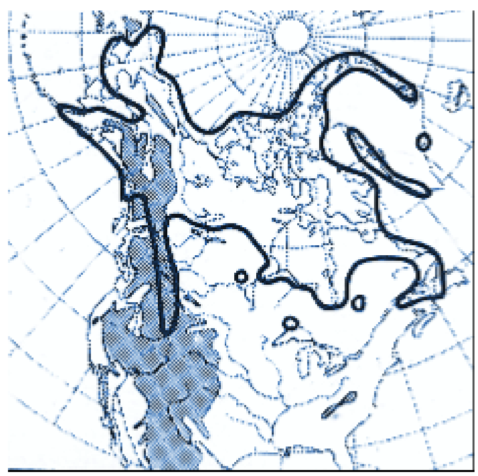

Figure 10: The current range of *Dryas integrifolia,* which is an arctic environment that does not include New York State.

Of the other species found in this zone, the presence of *Polytrichum juniperinum* in zone T1 can be expected, since it also is a common pioneer plant of recently disturbed areas. It is predominantly found on dry, exposed, acidic habitats (Bristish Bryological Society, 2010), thus its presence can indicate that the climate was dry as well as cool.

Carex is found in a wide variety of environments, including arctic tundra, and its presence implies wetlands around the lake.

Zone T1 had the largest amount of *Cristatella mucedo* statoblasts. These bryozoans are temperature sensitive, preferring warmer temperatures, and waters that are more acidic, with medium to high levels of calcium (Okland and Okland, 2000). There presence at the end of the zone could represent warming temperatures, and their preference for acidic and calcareous environments coincides with the fact that they were in the same location in the core as *Polytrichum j.* that is found on acidic habitats, and *Dryas i.* that is found in high calcium areas. This zone can thus be classified as an open tundra environment with still cold temperatures after the glacial retreat that began to warm towards the end of the zone.

One notable difference between the pollen record of nearby Sutherland and Spruce Pond, NY, and this core is the evidence of *Pinus* and *Picea*, which would mean there were scattered trees in the region, classifying the region as park-tundra (Maenza-Gmelch, 1996; 1997a; 1997b). However, since macrofossil evidence of this was not discovered in any of the cores, this can not yet be concluded. There were *Picea* macrofossils discovered in Allamuchy Pond, NJ at the same time as *Dryas integrifolia* (Peteet et al, 1993), but Allamuchy Pond is further inland than Spruce Pond and Tamarack Pond, thus the precipitation and/or temperature could have been different enough to support the growth of trees in that area. Alternatively, because macrofossils were sampled at 10-cm intervals at Allamuchy Pond, as opposed to contiguously in this core, the *Picea* macrofossil at the same level as the *Dryas integrifolia* macrofossil could have come from the end of the tundra environment when conifers started to inhabit the area, as opposed to have been present for the entire interval. The last presence of *Dryas* in this core overlaps with the first presence of *Picea,* thus the landscape could have been an open tundra region, and then transitioned into a park-tundra environment on its way to becoming a boreal forest.

The disappearance of tundra species, increase in LOI values, sediment change to gyttja, and appearance of *Picea sp* in zone T2 mark the end of the open tundra environment, and the beginning of a more boreal forest environment. The *Picea* remains could either be *Picea mariana* or *Picea glauca*, but the identification of *Picea* on a species level is difficult without branches that give away identifying factors, such as small hairs on *Picea mariana* branches. Both species are boreal conifers, although *Picea mariana* prefer wetter environments than *Picea glauca,* and *Picea glauca* have been known to tolerate more extreme climates and slightly warmer temperatures (USDA, 2012). *Picea glauca* is known to repopulate areas after deglaciation events (USDA, 2012).

Pollen evidence from nearby sites show that the period following the open vegetation of arctic shrubs, had boreal species followed by temperate tree species, such as *Quercus sp*. and *Pinus sp.,* as well as *Picea sp*. (Peteet et al, 1990; 1993, Meanza-Gmelch, 1996; 1997a; 1997b). However, macrofossils from these two other species were not discovered in this core or other cores. Macrofossil abundance was rather low at the base of the zone, so it is possible that this is because of a lack of macrofossil preservation, or it was pollen from long distance transport. However, based on comparisons with modern *Quercus* pollen values, it is inferred that they were present in the region at the time (Peteet et al., 1993; Maenza-Gmelch, 1996). While there is no macrofossil evidence of any temperate species in this zone to verify the pollen record, the combination of abrupt changes that happen at the transition between zone T1 and zone T2 signify the region was capable of supporting conifer trees, and thus had a warmer climate than zone T1. A significant amount of charcoal was found in this zone implying warmer temperatures, and also that fire could have had a role in the forest development (Maenza-Gmelch, 1996). The highest amount of charcoal in this zone also correlates with a drop in LOI, which could be interpreted to mean that this specific location of the core represents a drier climate than the rest of the zone, which is not thought to be dry because of the presence of *Abies balsamea*.

Abies balsamea remains appeared in the upper part of zone T2. *Abies balsamea* presently grows best in the northeastern United States and southeastern Canada, where there is a mean temperature of 2°-4°C and ample moisture (USDA, 2012). *Abies* grows better in the eastern part of its range than the western part where it is not as moist (USDA, 2012). Thus with the increasing LOI values in this region, it is implied that the climate of this zone was more productive than the tundra environment preceding it, but was still cold and wet.

Based on the appearance of *Larix laricina, Betula papyrifera, Betula glandulosa, Alnus sp*., it is concluded that zone T3 corresponds with the Younger Dryas cold reversal. *Larix, Abies,* and *Picea* are all boreal conifers, and the introduction of *Larix* in this zone in addition to the increase in *Betula* species indicate a climate cooling that could have been as large as 3-4°C (Peteet et al, 1990; 1993). *Larix laricina* is a conifer that is able to grow under varied conditions, both in regards to temperature and precipitation (USDA, 2012). *Betula papyrifera* is another cold loving species that does not grow in summer temperatures above 21°C, and can tolerate a variety of moisture. *Betula* are shade intolerant species, and their prevalence in areas that correspond to the Younger Dryas has been interpreted to mean an increase in winter storms that ruined the overstory and allowed more sun to penetrate the forest floor (Peteet el al, 1990: Menking et al, 2012).

Macrofossils of the other *Betula* species found in this zone, *Betula glandulosa*, were not discovered in nearby sites during this time period, although they were discovered in a sediment core from Lake Minnewaska, NY (Menking et al, 2012), which is about farther North and slightly more inland than Black Rock Forest. These macrofossils were additionally found in Allamuchy Pond, NJ (Peteet et al, 1993) in an area of the core associated with the colder tundra environment, which shows their prior existence in the area. Since this is a species that can live in arctic environments (Flora of North America, 2012), if this zone does correspond to the Younger Dryas cooling, regional temperatures could have been colder than previously thought.

At the same time as these cold tolerant species, however, seeds of the pondweed *Najas flexilis* were found. This is in contrast to other sites that had a drop of *Najas flexilis* seeds during the Younger Dryas (Peteet et al, 1993). *Najas flexilis* is a thermophilic aquatic plan that requires low lake levels and higher temperatures in order to reproduce (Haas and McAndrews, 2000). This does not necessarily contradict with the findings that imply that this zone corresponds to the cold Younger Dryas period. It suggests that the seasonal contrasts were large, and cold winters were followed by warmer summers. Since Northern summer insolation at this time was high (COHMAP, 1988) the existence of warmer summers during this cold period is feasible. The low lake levels necessary for the presence of *Najas flexilis*, could imply that climate was relatively dry or that the site did not hold that much water.

The drop in LOI values in this zone is in accordance with some New England sites, but not with others that showed in increase in LOI values during the Younger Dryas (Menking et al, 2012). Low LOI values during the Younger Dryas have been attributed to a reduction in aquatic productivity, while higher values could be attributed to increased precipitation rates or the reduced oxidation of organic matter due to snowier conditions (Menking et al, 2012). The presence of *Najas flexilis* and *Potomageton sp*. indicate that Tamarack Pond had an increase in pond productivity, thus the low LOI values are not likely to be because of a reduction in aquatic productivity, but reflect another factor, possibly less precipitation.

Another indicator of cold or dry conditions is found in the abundance of *Daphnia* ephippia, which drastically increased in zone T3. *Daphnia* usually reproduce parthenogentically, but turn to gamogenetic reproduction mainly in response to changes in temperature and length of the photoperiod, as well as in response to other factors such as drought (Sarmaja-Korjonen, 2002). Ephippia are egg casings that are produced to protect the eggs for the duration of the harsh climate (such as during winter seasons), until conditions are favorable. Therefore there could be a link between the abundance of *Daphnia* ephippia found in lake sediment and the severity of the winter season. During harsh conditions, when there are long snow covered winters and the open-water season is reduced, more gamogenetic reproduction would occur and there would be a greater abundance of ephippia collected in the sediment (Sarmaja-Korjonen, 2002). While there are other reasons not related to climate (such as population density and food resources) that alter gamogenetic reproduction and the formation of ephippia, it has been found that ephippia numbers increase in periods that are thought to be extremely cold periods with strong seasonal variability (Sarmaja-Korjonen, 2002), and this is supported by the drastic increase in ephippia at the same location as cold plant species in this core.

The final zone, zone T4, is thought to represent the onset of the Holocene epoch because of the disappearance of all plant species other than *Najas flexilis* and *Sphagnum*, and the appearance of two new species, *Tsuga canadensis*, and *Betula populifolia*. Both of these new species are more temperate species whose current ranges extend down to the Southern United States (USDA, 2012). These two species appear in other sediment cores during the early Holocene interval, concurrent with the decline of the boreal species and an increase in LOI values to the same levels found in Tamarack Pond, 40% (Peteet et al, 1990; 1993, Maenza-Gmech, 1996; 1997a; 1997b). The increase in LOI values could be indicative of increased pond productivity in addition to well-developed upland soil (well-drained soil) that is needed to support *Tsuga canadensis* (Maenza-Gmelch, 1996). The decrease in macrofossil abundance in this zone could also be a signifier of a warmer climate, because warmer temperatures increase the rate of decomposition.

Conclusions

The macrofossil and LOI evidence from the sediment core from Tamarack Pond, NY, show that the region experienced changing environmental conditions from the end of the Last Glacial Maximum through the beginning of the Holocene interval. These changes were not unidirectional towards warming temperatures, but rather alternated between colder and warmer periods. Immediately after the retreat of the Laurentide Ice

Sheet, the region was comprised of an open tundra landscape dominated by herbs and shrubs such as *Salix sp*. and *Dryas integrifolia*. Following this time period was a large increase in organic matter and the appearance of the boreal conifer species *Picea sp*. followed by *Abies balsamea,* indicating an increase in temperatures, but a still cold, wet ecosystem. Next, the appearance of other boreal conifers and cold loving *Betula* species are evidence that temperatures declined, likely in response to the Younger Dryas cooling. Finally, the disappearance of boreal conifers and the appearance of *Tsuga canadensis* and *Betula populifolia* indicate a final reversal in temperatures that allowed the development of a more temperate forest.

These vegetational shifts evidenced by different macrofossil types indicate how the earth can respond to changes in climate. More specifically, they show how the Southeastern New York region responded to abrupt global climate changes, such as the Younger Dryas. While the climate and landscape of Southern New York State was extremely different at the end of the LGM, the shifts in vegetation are suggestive that seemingly small temperature changes could alter regional weather and vegetation patterns. In New York, the temperature is thought to have dropped 3-4°C during the Younger Dryas, which was much smaller than the 15°C drop recorded in Greenland Ice Cores, but still significant enough to change the species composition of the forest. With the current annual mean temperature increase of 1°C over the past few decades, future temperature changes pose a real threat to the vegetation of the region. Knowledge of past climate and vegetation changes will benefit any model for predicting future climate and vegetation changes.

Recommendations

There are notable differences between the macrofossil record in this core and pollen records from other nearby lakes. Two key ones being the lack of macrofossil presence of *Picea* and *Pinus* in the basal sediment during the tundra period, and the other being the lack of macrofossil evidence of deciduous trees preceding the Younger Dryas period. These types of difference demonstrate the importance of the combination of multiple paleoclimate proxies to determine past climate environments. Therefore, this study could benefit from pollen analysis of the core. Additionally, more detailed macrofossil analysis of this core (for example from 10.30-10.02 m), and of lake sediments in nearby sites and throughout New England would be beneficial for corroborating pollen records to get a more precise record of both the timing of the retreat of the Laurentide Ice Sheet and the vegetational migrations through the landscape. Contiguous macrofossil analysis, while time consuming, allows a more precise analysis of the past landscapes. There were many macrofossils that would not have been discovered in this core had the samples been taken at 5 or 10-cm increments, rather than contiguously. It is possible that other sites had the presence of certain macrofossils that were not discovered because of sampling effects.

The dating of the samples would greatly benefit this study, for it would allow better comparison to other records and could give the timings of the vegetation changes. Three macrofossil samples from this core were sent to Keck Labs, Irvine, CA, for accelerateor mass spectrometry (AMS) dating, but have not yet been received at this time. These were samples from: 1) the first presence of macrofossils at the base of the glacial clay, 2) where the sediment transitioned from clay to more organic sediment as determined by LOI values, and 3) right after the disappearance of boreal conifers. When received, these dates will give the timings for the major changes, and give approximate sedimentation rates of the lake. They will confirm if the cold reversal is in fact related to the Younger Dryas cold event, and if it is, what the constraining dates are. The date of the first macrofossil deposition will add to the evidence regarding the timing of the retreat of the Laurentide Ice Sheet. Since the first macrofossil was found at the very base of the core, it indicates that vegetation was present very soon after sediment deposition began. Many other core bottoms did not have macrofossils present at the base, thus dating of first macrofossil did not correspond with a time that was necessarily close to the retreat of the ice sheet. The precise timing of the retreat of the Laurentide Ice Sheet and vegetational shifts will augment the understanding of the ocean-atmosphere system, which is crucial to our understanding of how climate changes occur.

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