# High-Resolution Pollen and Charcoal Records from Fish Lake, New Brunswick, Canada

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**Master of Science (Geography, Urban and Environmental Studies)**

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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# Abstract

High-Resolution Forest Dynamics and Paleo-fire Records from Fish Lake, New Brunswick, Canada from the Past Millennium

Ryan Collins

The Acadian forest is a mixed-wood forest covering the Canadian provinces of New Brunswick and Nova Scotia. *Picea rubens* (red spruce) is its signature species which has been prominent for circa 2,000 years. To our knowledge, no high-resolution pollen analysis has been done in New Brunswick, and no lacustrine charcoal analysis. We extracted a 124 cm surface core from Fish Lake, (46° 8’ 38.32’’N, 66° 53’ 12.64’’ W), near Fredericton, New Brunswick, Canada. A BACON age-depth model, based upon 4 $^{14}C$ and 15 $^{210}Pb$ dates, showed that the bottom of the core dated to AD 890. We performed a high-resolution pollen analysis on this core at a ~10 year resolution, with 125 samples in all. Over the last millennium, there were declines in *Betula* (birch), *Tsuga canadensis* (eastern hemlock) and *Fagus grandifolia* (American beech), together with increases in *Pinus* sp. (pine), *Abies balsamea* (fir) and *Picea sp.* (spruce), including *P. rubens*. CONISS showed that the Medieval Climate Anomaly (MCA – AD 900-1400), Little Ice Age (LIA – AD 1400 –1850), and the European settlement period were clearly demarcated in the pollen record. A rise in *Ambrosia* (ragweed) marked early Acadian French agriculture at ~AD 1680. The last 300 years of the European period showed increases in Poaceae (grasses), *Ambrosia*, and other herbs, and declines in *Pinus* sec. haploxylon (eastern white pine). Charcoal analysis showed that natural forest fires had a continuous presence over the past millennium. The paleo-fire record showed higher fire frequency during the MCA than in the LIA. WA-PLS was used to reconstruct spring temperatures. The reconstruction showed that the MWP had an average spring temperature of 3.2 °C, and the LIA had an average spring temperature of 2.2 °C.

**Key words**: Acadian forest dynamics, charcoal, high-resolution, Nouvelle France, paleo-fires, pollen

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This delightfully implausible adventure would never have happened without the support and endurance of Jeannine and Les, my co-supervisors. Learning how to draw an even tube of lake-bed, process said lake-bed into pollen slides, interpret the slides, and then performing the mathematics needed to bring you this paper is one thing; learning that dill pickles freeze, that it's tough to be a vegan doing fieldwork in Siberia, and that nobody had common names for trees in the 1700s is a gift I will treasure forever.

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# Contributions of Authors

As the first author, I was responsible for the design of this manuscript, including data analysis and writing. Kelly Kyle co-authored this manuscript and analyzed the core's charcoal record. Dr. Jeannine-Marie St. Jacques and Dr. Les Cwynar provided advice for experiment design, statistical analysis, and revisions to the manuscript and figures.

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# Introduction

The Acadian forest has undergone substantial compositional shifts through its entire existence. As a mixed-wood forest, the proportion of coniferous to deciduous trees within the forest likely changed as a result of global climatic shifts like the Medieval Climate Anomaly and the Little Ice Age. Composition changes to the Acadian forest as a result of logging and land clearance have also transpired, especially as the forest was among the first North American forests to be exposed to European logging practices and timber markets. Early French colonists made note of the appearance of burnt trees in their exploration of New Brunswick, suggesting that the forest is also impacted by forest fires before extant written records. Despite these records, De Lafontaine and Payette (2012) have theorized that the Acadian forest was too wet for fire to play an important role in its constitution. The arrival of the iconic *Picea rubens* (red spruce) to the Acadian forest has been hypothesized by Mott (1975) to have occurred between 1-2,000 years ago, however thus far no palynological study in New Brunswick has differentiated between the varieties of spruce in the province. However, a lack of high-resolution paleoclimatic information in New Brunswick obscures this history.

Our sediment core from Fish Lake, New Brunswick, a location approximately thirty kilometers northwest of Fredericton resulted in a 1,100-year pollen and charcoal record. This record thus contains sediments from the entire MCA and LIA, as well as the entire European colonial history. Access to a high-resolution fire record permits the evaluation of the local fire history, which has not been undertaken in New Brunswick since 1987. The resolution of this analysis includes a high degree of speciation between pollen samples, a particularly important feature given the importance of the red spruce and the questions surrounding its arrival inland from coastal refugia. Providing these observations will offer further insights into the dynamics of the Acadian forest and demonstrate the utility of high-resolution methods applied to lake sediment.

# Literature Review

## 2.1 What is the Acadian forest?

Spanning from Connecticut at its southernmost end through the Canadian Maritimes in the north and east, the New England/Acadian forest is a mixed (i.e., containing both conifers and deciduous hardwoods) forest that is transitional between the boreal forest to the north and deciduous forest to the south (Figure 1). It is distinct from other mixed forests in having red spruce (*Picea rubens*) as an integral species. This species began appearing in the region 2,000 years ago (Mott, 1975). Along with red spruce, Mosseler, Lynds and Major (2003) add long-lived species like sugar maple (*Acer saccharum*), eastern hemlock (*Tsuga canadensis*), and American beech (*Fagus grandifolia*), as well as eastern white pine (*Pinus strobus*) and yellow birch (*Betula alleghaniensis*), to the list of the late-successional trees of the Acadian forest. Hardy, shade-tolerant, and representative of a mixture of boreal and deciduous forests, the composition of the Acadian forest is characterized by these particular tree species.

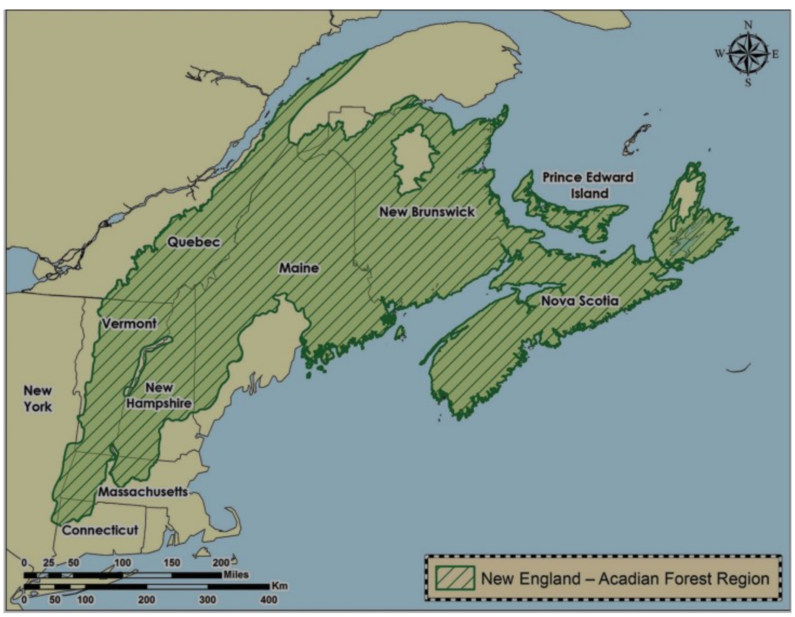


***Figure 1.*** *Map of the New England/Acadian forest (according to Noseworthy and Beckley, 2020).*

There is a species gradient between the northern and southern parts of the New England/Acadian forest. Charles Canham (2021) identifies a general but complex gradient between the northern and southern portions of the New England/Acadian forest, stating that the northern portions of the forest include a greater abundance of balsam fir (*Abies balsamea*) and red spruce, while the southern portion has a greater abundance of oaks (*Quercus sp.*) and beech. Canham also observes the ubiquity of many species in both halves of the forest. At a location in the Acadian forest, a cooler period might be expected to cause an increase in the numbers of trees from cold-tolerant genera, such as spruces; whereas a warmer period might be expected to result in an increase in the numbers of trees from warm-tolerant genera, such as beech. My expectation that forest composition will change in response to disturbances, as well as in response to changes in regional temperature and moisture, means that any interpretation of a pollen record extracted from any lake sediment core from the Acadian forest region requires an understanding of the local context in which it was taken.

## 2.2 Setting the stage: Soil, topography, and climate conditions of New Brunswick

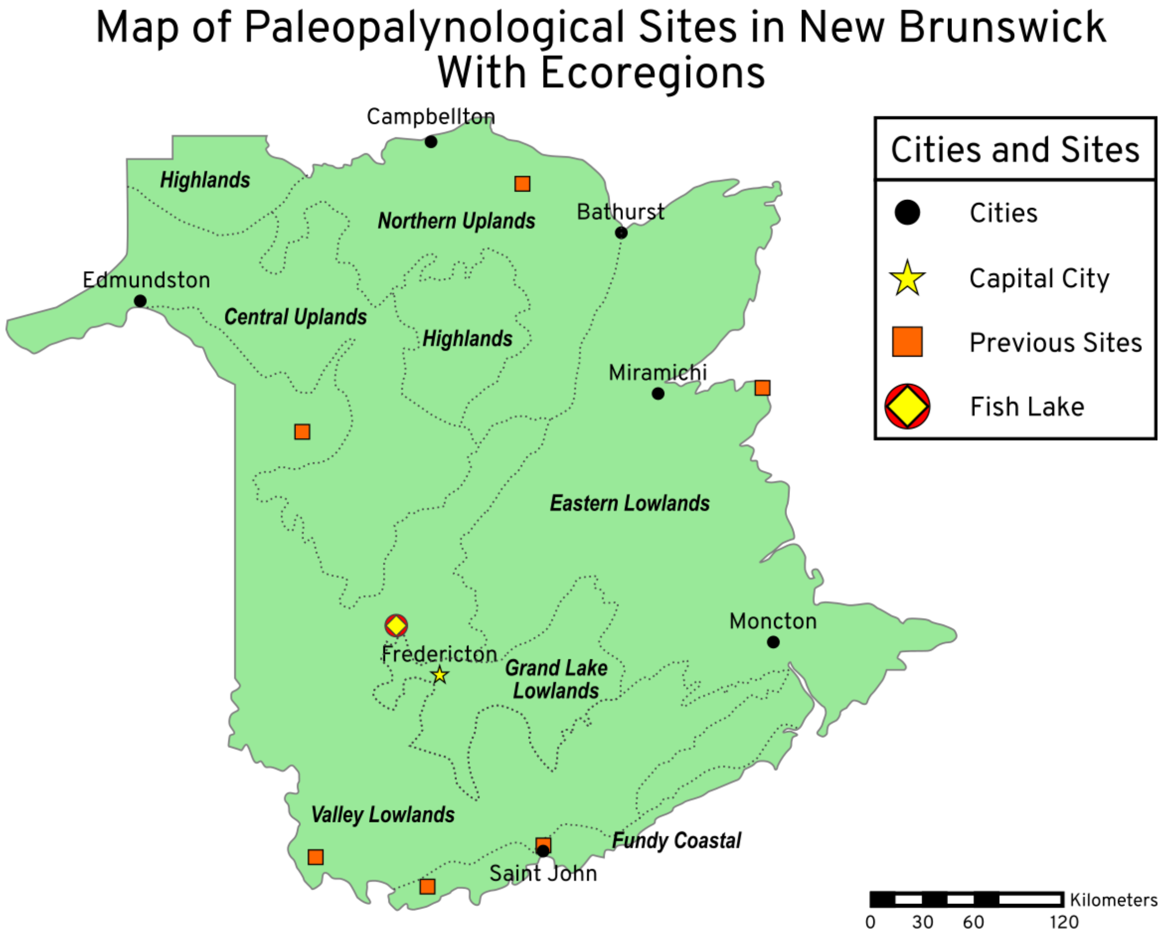


***Figure 2.*** *Map of New Brunswick showing locations of ecoregions (adapted from Aubé, 2008, and Neotoma).*

Topography and soil conditions provide important context for local New Brunswick forest composition. Both of these contexts affect the history of the New Brunswick forest that emerged after glaciation. Topographically, the province of New Brunswick broadly slopes downwards from north and west to south and east. (Figure 2). The geology of the entire province, particularly its surface geology, was heavily impacted by the movement of the Laurentide Ice Sheet (Borns, Jr. and Maasch, 2015), though the southwestern corner of the province was more impacted than the rest of the province (Wicklund and Langmaid, 1953). In fact, the Laurentian Ice Sheet covered the entire New England/Acadian forest, with glaciation in the northern portion continuing well after glacial retreat in the southern portion.

This glaciation has also had a significant impact on the soil composition of New Brunswick. Notably, the soils of the region are relatively infertile and strongly acidic with little variation (Wicklund and Langmaid, 1953). The bedrock of the New Brunswick Highlands is igneous in origin and its soil is more acidic than the sedimentary rock-derived soils of the New Brunswick Lowlands (Colpitts et al., 1995). Hence, both the topography and soil of the Acadian forest in New Brunswick have been greatly influenced by the glaciation events that serve as a prelude to its post-glacial paleoclimate records.

The modern state of the climate of New Brunswick needs mention. For this, the Köppen-Geiger Classification System provides a quantitative 'thumbnail sketch' in the form of a three-letter code that corresponds to a location's broad climate patterns, precipitation levels, and temperatures, respectively. Kottek et al. (2006) designated much of New Brunswick as Dfb, which corresponds to a snowy, humid climate with warm summers. Indeed, temperatures tend to be lower than expected by latitude throughout Atlantic Canada. Annual precipitation throughout the Maritimes ranges between 1,000-1,600 millimeters, split between snow and rainfall, with orographic uplift increasing precipitation (Clayden, Cameron, and McCarthy, 2011). All these combined features— New Brunswick's complex drainage, acidic soils, cooler temperatures, and semi-frequent precipitation—collectively have had profound impacts on the composition of the Acadian forest and its predecessors.

## 2.3 What were the precursors of the New Brunswick Acadian forest?

### *2.3.1 The origins of the initial post-glacial forest*

The geographical predecessors of the New Brunswick Acadian forest developed after the end of glaciation in the area over 10,000 years ago (Dewolfe, Simard, and Coon, 2005) (Figure 2). The earliest record of the predecessors of the New England/Acadian forest emerges after the "abrupt" end of the Younger Dryas in 11,700 cal year BP (Brooke, 2014), as the ice sheets covering

New Brunswick receded. Most likely, as was the case in nearby Maine, the recession of the ice sheets created a succession of landscapes, from open tundra to a grassy taiga, before emerging as a spruce forest (Barton, 2018). The Younger Dryas event was identified in Atlantic Canada by multiple studies (Mayle and Cwynar, 1995; Mott, Grant, Stea, and Occhietti, 1986). This period coincided with a “transitional” period wherein the impacts of solar insolation become more significant in comparison to the impact of waning ice sheets (Webb et al., 1993). Cores taken from Point Escuminac in northern New Brunswick date the beginning of the forest to 11,000 cal year BP (Webb et al., 1993). In adjacent northern Maine, this process of afforestation “began ~10,600 cal year BP, ~1,000 years after the end of the Younger Dryas, …and was completed by 9,200 cal year BP” (Davis et al., 2021). In the Megantic Hills between Quebec and Maine, Mott (1975) found that the region became a completely closed forest by around 10,000 cal year BP. These dates suggest that the first predecessors of the Acadian forest took shape between 10,000 cal year BP and 9,000 cal year BP. In northern Maine, evidence for the presence of trees associated with the Canadian boreal forest, such as a variety of pines (*Pinus*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), and balsam fir (Wells et al., 2020), was found by Davis et al. (2021) and dated to 9,200 cal years BP.

The composition of this predecessor of the Acadian forest as identified in the pollen record, in keeping with the cooler temperatures of the time, exhibits taxa typical of colder environments. Beginning in 11,300 cal year BP, much of the extant vegetation at this time were shrubs (Mott, 1975). Of the trees whose pollen was archived in a lake core from northern Maine, pines dominated the pollen record (Davis et al., 2021). In their research in the southern portion of the New England/Acadian forest, Oswald et al. (2018) found high abundances of spruce (*Picea*), pine (*Pinus*), and birch (*Betula*) pollen between 14,000 to 12,000 cal year BP, genera which gradually declined to near-irrelevance by 10,000 cal year BP (Oswald et al., 2018). Fir pollen instead appears in records from upland southern New England sites starting from 10,000 cal year BP (Oswald et al., 2018). Mott's (1975) sites in the Megantic Hills were also dominated by either fir or spruce at this time, likely arriving in the region through the valleys to the southeast. In keeping with the early history of the landscape being deeply altered by the retreat of the Wisconsinan ice sheet, this first deglacial precursor of the Acadian forest was a cold-weather forest with a notable dominance of cold-tolerant conifers.

### *2.3.2 The precursors of the Acadian forest throughout the mid-Holocene*

From the immediate post-glacial state, the precursor of the Acadian forest transformed rapidly as a result of shifts in regional climate. A general warming trend from the end of the Younger Dryas stopped suddenly during the 8.2 k BP anomaly, described by Alley and Ágústsdóttir (2005) as a "century-scale cool period in pollen diagrams…in Quebec, Canada [through] increased spruce and fir". Perhaps because of this cooling event, Peros et al. (2016) identified a "shift from a pine–hemlock–birch community to a birch–pine assemblage to a spruce–beech–fir assemblage in the regional forests" on Prince Edward Island. Anderson's (1980) work particularly suggests that the transformation of Prince Edward Island's forest cover from spruce to pine points to a warming period after 8,200 cal year BP. The sharp cold snap of the 8.2 k BP anomaly upset the ongoing transformation of the precursor of the Acadian forest from a boreal to a mixed coniferous-deciduous type, but not so completely as to upend this ongoing transformation.

After the 8.2 k B.P. anomaly, broader warming trends continued to transform the precursors of the Acadian forest. Jetté and Mott (1995) identify an important duality of these forests, arguing that within the context of such mixed coniferous/deciduous forests, the proportional relationship between a colder climate and maples and firs is matched by a corresponding relationship between a warmer climate and an increasing prevalence of hemlock and pines. By 6,000 cal year BP, sites in west-central New Brunswick show a significant increase in pine populations and the emergence of hemlocks (Jetté and Mott, 1995). Two thousand years later, hemlocks would begin a decline throughout Atlantic Canada, and indeed through-out their entire range in the northeast (Davis, 1981; Bennett and Fuller, 2002). In some places, such as around Mirror Lake in New Hampshire, birch then became a successional genus (Davis, 1981). The sudden decline in hemlock trees simultaneously across their range and their subsequent relative suppression may be attributable to disease, insect outbreak, and drought (Davis, 1981; Filion and Quinty, 1993; Bennett, 2002; Marsicek et al., 2013). The post-8.2k BP anomaly period found in the pollen records of the precursors of the Acadian forest highlights gradual warming through this period.

Starting around 6,000-8,000 years ago, the Neo-glacial cooling appeared in the North American eastern mid-latitudes (Shuman and Marsicek, 2016). The neoglacial cooling itself was triggered by orbital changes causing changes in summer insolation. This initiated widespread cooling and increases in effective moisture, which resulted in the coolest, wettest millennia in most regions after 2.1 BP. Although there are small important low-frequency upticks in temperature, the general regional temperature trend over the past 6,000-8,000 years has been a decline until present-day anthropogenic warming.

## 2.4 The Acadian forest proper

### *2.4.1 The appearance of the Acadian forest*

It is during the last two millennia that the Acadian forest took on its characteristic form through the movement of spruces from their coastal preserves into New England and the Maritimes (Lindbladh et al. 2003; Schauffler and Jacobson, 2002; Mott, 1975). In one of the rare studies that split *Picea* into individual species, Lindbladh et al. (2003) found that red spruce (*P. rubens*) made up a substantial portion of total spruce pollen in Maine by 1400 BP. Red spruce's increase was gradual, as Schauffler and Jacobson (2002) found in their regional study that total spruce did not again (after its initial high abundance at Early Deglaciation) become abundant (≥ 6% of total pollen) in most of Maine until 1000 to 500 cal yr B.P.

Two major northern hemisphere climatic shifts occurred during the last half of the Common Era and could have possibly affected the Acadian forest. First, the Medieval Climate Anomaly, a period broadly "associated with warm temperatures in 800-1200 AD" occurred (Neukom et al., 2019). In the northeastern United States, Marlon et al. (2017) write that this timeframe was also likely drier than later periods, noting that evidence of regional temperature increases in the MCA are particularly evident in pollen-based forest reconstructions. This anomalous warm period, while possibly corresponding to global shifts in climate patterns, does not occur as a singular, global event. Rather, the consequences of the MCA appear at slightly different times in different places (Neukom et al., 2019). Despite a variety of proposed mechanisms to produce the MCA, including the North Atlantic Oscillation and the El Niño-Southern Oscillation, Hunt (2006), using global climate models, demonstrated that an external "forcing event" was required for both the MCA and the subsequent LIA. Much research continues about the causes of the MCA; for the purposes of this research, the most relevant aspects are warmer temperatures and drier regional climates.

The warmth of the MCA gave way to a global cooling period, the LIA, which transpired between 1400-1850 AD (Neukom et al., 2019). The result of a complex assemblage of atmospheric and oceanic currents, the LIA brought colder temperatures and drier conditions around the world. Like the MCA, this event did not occur simultaneously around the world (Fagan, 2002). In the northern hemisphere, this period began in the late fourteenth to early fifteenth century and is documented in both Europe and North America by historical and archaeological records (Foster, 2012). In the eastern portion of North America, droughts were reported in multiple places during the sixteenth century, while the deepest cold began in the eastern part of the continent in the nineteenth century (Fagan, 2002). In their review of the northeastern North American paleoclimate record, Marlon et al. (2017) note that while all of the proxies they considered show a period of cooling and an increase in moisture, tree-ring records suggest a temperature minimum in the 1600s, while reconstructions using a broader range of proxies point to the coldest period being in the 1800s. Like the MCA, the LIA is a complex series of events whose most important consequences in this project are cooler, wetter conditions in the Acadian forest.

During the MCA and subsequent LIA, Houle et al. (2012) plot a broad trend of increasing coniferous pollen and decreasing deciduous pollen at Lac Clair, northwest of Quebec City. A study conducted by Aubé (2008), using witness tree data from the time of English settlement, identifies spruce, birch, and fir as the common trees of the New Brunswick forest in the Miramichi region, in east-central New Brunswick, with smaller numbers of maples, cedars, pines, and hemlocks.

### *2.4.2 Indigenous effects on the Acadian forest of New Brunswick*

Aubé (2008) notes that the area around the Miramichi River, in New Brunswick, was inhabited by the Mi'kmaq and Maliseet for at least 2,800 years, though bottle gourd shards found in central Maine and dated to 5,695 cal year BP suggest the possibility of much earlier human habitation (Petersen and Sidell, 1996). Among the eastern Algonquin populations, it is known that maize-based agriculture was at least present in the territory today known as New England (Betts and Hrynick, 2021), although the extent of its adoption in the Maritimes and the subsequent transition to sedentary communities remains hotly debated among archeologists. Political centralization and trade in the Maritimes are evinced by the construction of palisades and reports of copper earrings (sourced in the Great Lakes region) from European witnesses (Betts and Hrynick, 2021). Food appears to have come increasingly, but certainly not entirely, from terrestrial sources, despite proximity to waterways (Betts and Hrynick, 2021). Fire, an occasionally important human tool to shape forest composition, appears to have been ceremonially and socially critical, but in the absence of a known record of crop domestication in what would become New Brunswick, the role of fire in shaping the forest was likely minor (Betts and Hrynick, 2021). A complex collection of villages and communities within the forest fertilized and relied on the forest for sustenance, fuel, and construction, in so doing leaving a small but possibly tangible mark on the forest itself.

### *2.4.3 Effects of European settlement on the Acadian forest of New Brunswick*

Noseworthy and Beckley (2020) argue that the boreal character of parts of the Acadian forest has been amplified by post-European Contact human activities, notably farming and forestry. European settlers, noting the inadequacies of New Brunswick's soil for large-scale farming, began a pattern of intensive timbering that would profoundly change the composition of the local Acadian forest. Early French settlers, like their English and other European counterparts, arrived initially with an intent towards the catching and processing of cod and other fish, as well as the trading of furs (Griffiths, 2005). By the end of the 1680s, the presence of the horse heralded the rise of larger-scale agriculture in the Acadian colony (Griffiths, 2005). The large-scale clearings required for agriculture contrasted to the species-specific nature of early forestry. By 1708, Governor Subercase wrote of the wide availability of different sorts of timber and praised the Acadians for their carpentry skills (Griffiths, 2005). Importantly, these early colonial foresters sought the tall and straight white pines for ship's masts, decreasing the supply of these pines "dramatically" by the 1830s (Dewolfe, Simard, and Coon, 2005). Thus, by the early eighteenth century, the Acadian colonists had already begun the kinds of agricultural and foresting activities that would fundamentally change the Acadian forest.

European settlers left significant records, descriptions, and classifications of particular forest compositions within the New England/Acadian forest. Nicolas Denys, the governor of the French Cape Breton Company, wrote in 1633 recounting the presence of "Oaks…[pines], [firs] of three sorts, [birches], [black birches], [aspens], [maples], [ashes], and [oaks]" on the shores of what is now Annapolis Royal, Nova Scotia (Denys, 1908). Tellingly, in his catalog of tree types at the mouth of what is now known as the Penobscot River in Maine, Denys reports the presence of undifferentiated spruce, the "best of them all" for the production of ship masts.

### *2.4.4 Modern New Brunswick's impact on the Acadian Forest*

Today, in a continuation of the above extractive pattern, over half of the Canadian portion of the Acadian forest, and three-quarters of New England's forested area, are privately owned (Farr, 2003; Perschel, Giffen, and Lowenstein, 2014). The results of contemporary logging in the Acadian forest have raised alarm among conservation groups and other advocates. Noss (2023) notes the common process of reforestation that took place after the abandonment of farms in New Brunswick in the nineteenth and twentieth centuries and the presence of large fires sparked by and within logging waste. Preferential logging of softwoods over 300 years has resulted in a forest composed of leftovers: hardwoods and the less-desirable balsam fir (Dewolfe, Simard, and Coon, 2005). Among the consequences of modern clearcutting is an Acadian forest "composed of younger forest stands that contain shade intolerant species that are fast growing and typically short-lived, such as poplar, white birch, white spruce, and balsam fir" (Dewolfe, Simard, and Coon, 2005). The red spruce, a tree associated with mature forests, has thus proportionally fallen from prominence in favor of the white spruce, a tree which is noteworthy for its ability to successfully invade abandoned farmland (Dewolfe, Simard, and Coon, 2005). Nearly 50% of the Acadian forest in Canada was considered "heavily altered" as of 2005. A long legacy of exploitation by European settlers has transformed and imperiled this forest.

The modern Acadian forest has an integral role in the province of New Brunswick in part because almost all of the province is covered by it. In a report commissioned by the province of New Brunswick, spruce, fir, and jack pine (*Pinus banksiana*) were identified as the predominant merchandisable volume (54%) of the forest, and 60% of the forest was reported as being softwoods (New Brunswick Department of Energy and Resource Development, 2020). The transformation of the old-growth composition of the Acadian forest noted at the beginning of this section into the modern stands of trees intended for commercial sale has had a tremendous impact on New Brunswick well before that name for the region existed.

# Manuscript

**High-Resolution Forest Dynamics and Paleo-fire Records from Fish Lake, New Brunswick, Canada from the Past Millennium**

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## Abstract

The Acadian forest is a mixed-wood forest covering the Canadian provinces of New Brunswick and Nova Scotia. *Picea rubens* (red spruce) is its signature species which has been prominent for circa 2,000 years. To our knowledge, no high-resolution pollen analysis has been done in New Brunswick, and no lacustrine charcoal analysis. We extracted a 124 cm surface core from Fish Lake, (46° 8' 38.32''N, 66° 53' 12.64'' W), near Fredericton, New Brunswick, Canada. A BACON age-depth model, based upon 4 $^{14}C$ and 15 $^{210}Pb$ dates, showed that the bottom of the core dated to AD 890. We performed a high-resolution pollen analysis on this core at a ~10 year resolution, with 125 samples in all. Over the last millennium, there were declines in *Betula* (birch), *Tsuga canadensis* (eastern hemlock) and *Fagus grandifolia* (American beech), together with increases in *Pinus* sp. (pine), *Abies balsamea* (fir) and *Picea sp.* (spruce), including *P. rubens*. CONISS showed that the Medieval Climate Anomaly (MCA – AD 900-1400), Little Ice Age (LIA – AD 1400 –1850), and the European settlement period were clearly demarcated in the pollen record. A rise in *Ambrosia* (ragweed) marked early Acadian French agriculture at ~AD 1680. The last 300 years of the European period showed increases in Poaceae (grasses), *Ambrosia*, and other herbs, and declines in *Pinus* sec. haploxylon (eastern white pine). Charcoal analysis showed that natural forest fires had a continuous presence over the past millennium. The paleo-fire record showed higher fire frequency during the MCA than in the LIA. WA-PLS was used to reconstruct spring temperatures. The reconstruction showed that the MWP had an average spring temperature of 3.2 °C, and the LIA had an average spring temperature of 2.2 °C.

**Key words**: Acadian forest dynamics, charcoal, high-resolution, Nouvelle France, paleo-fires, pollen

## Introduction

The portion of the New England/Acadian forest within New Brunswick, Canada, has received comparatively little attention from high-resolution paleo-environmental studies. Encompassing much of the Canadian Maritimes, the Acadian forest is a 24-million hectare land area that constitutes the northernmost portion of the broader New England/Acadian forest region (Canham, 2022). The existing research has focused on the whole-Holocene or late glacial-Younger Dryas past of this region (Mott, 1977; Warner, Tolonen, and Tolonen, 1991; Mayle, Levesque, and Cwynar, 1992; Jetté and Mott,1995; Mayle and Cwynar, 1995a; Mayle and Cwynar, 1995b); Davis, Norton, Kuhns, and Haltemann, 2021), and to the best of our knowledge, no high-resolution work has been done in the province focusing on recent millennia. The forest is believed to have undergone a process of "borealization" since the arrival of European colonists (Noseworthy and Beckley, 2020); indeed, the forest is among the most disturbed in North America, a consequence of the region's early colonization by Europeans and by the early role of timbering in the economies of the settler communities that emerged from it.

*Picea rubens* Sarg. (red spruce) is the signature species of the Acadian forest. *Picea rubens* is speculated to have expanded from its coastal refugia off of the coast of Maine into the continental portion of the forest 1,000 – 2,000 years ago (Mott, 1975). Long-lived and cold-tolerant, the arrival of *P. rubens* into inland New Brunswick, if pinpointed to a specific range of years, offers hints as to regional climatic shifts during the period in which it emerges. Existing research in Quebec and Maine suggests the appearance of significant numbers of *P. rubens* during the LIA (Schauffler and Jacobson, 2002; Houle et al, 2012; Paquette and Gajewski, 2012), but this has not yet been observed at high resolution in New Brunswick.

Similarly, the role of fire in the Acadian forest appears to have not been evaluated over a longer time-scale. Some researchers have argued that the Acadian forest is too wet for fire to play an important role in the forest's composition (De Lafontaine and Payette, 2012). However, our review of the existing literature has found no recent lake sediment-derived charcoal records from New Brunswick (the most recent being from 1987), creating a gap in our understanding of fire history in the Acadian forest of the most recent millennia. European records both in the early French and later English colonial periods suggest that wildfires did occur in the Acadian forest (Hay,1903), though puzzlingly these observations generally correspond with the Little Ice Age (LIA), a climatic event generally associated with cooler temperatures and an increase in precipitation (Marlon et al, 2007; Wu et al., 2022). Existing scholarship arguing that fires have long-term consequences for the composition for the Acadian forest (Remy et al, 2017) heightens the need for a thorough investigation of fire regimes in the region.

The objective of this study is to perform both pollen and charcoal analyses of a lake sediment core in order to complete the first high-resolution paleoforest study in New Brunswick. The goals of this work are to identify regional vegetation changes in the Acadian forest during the last millennium, so as to provide data that will help clarify our understandings of when red spruce first became a major component in the Acadian forest, the response of the forest to the climate changes over this time period, the role of fire in the Acadian forest, and the possibility that the forest has been borealized since the arrival of European settlers.

## Research Questions

High-resolution pollen analysis from lake sediment cores can provide valuable information for modelling and reconstructing the history of the Acadian forest in New Brunswick. There has not been any high-resolution pollen analysis done in New Brunswick, period, never mind any focusing on the most recent millennia over the time span of the Acadian forest. The goal of my MSc project is to contribute to a better understanding of the dynamics of the Acadian forest during the last ~1,000 years through high-resolution pollen and charcoal analysis of a lake sediment core from the New Brunswick lowlands. Fortunately, existing research from other regions of the New England/Acadian Forest provides an abundance of comparative data against which the findings from the Fish Lake core can be compared.

**The primary research questions that this research seeks to answer include:**

i. Did the MCA and LIA impact the vegetation and fire frequencies of central New Brunswick?
ii. How did vegetation composition and fire impact each other over the last millennium at Fish Lake?
iii. Did Eastern Algonquian Peoples impact the vegetation of central New Brunswick?
iv. What impact did European Colonists have on the vegetation of central New Brunswick?

To answer these research questions, I will do pollen analysis on the sediments of the Fish Lake core. I will also statistically analyze a companion charcoal record from Fish Lake produced by a fellow student, Kelly Kyle.

## Area and Methods

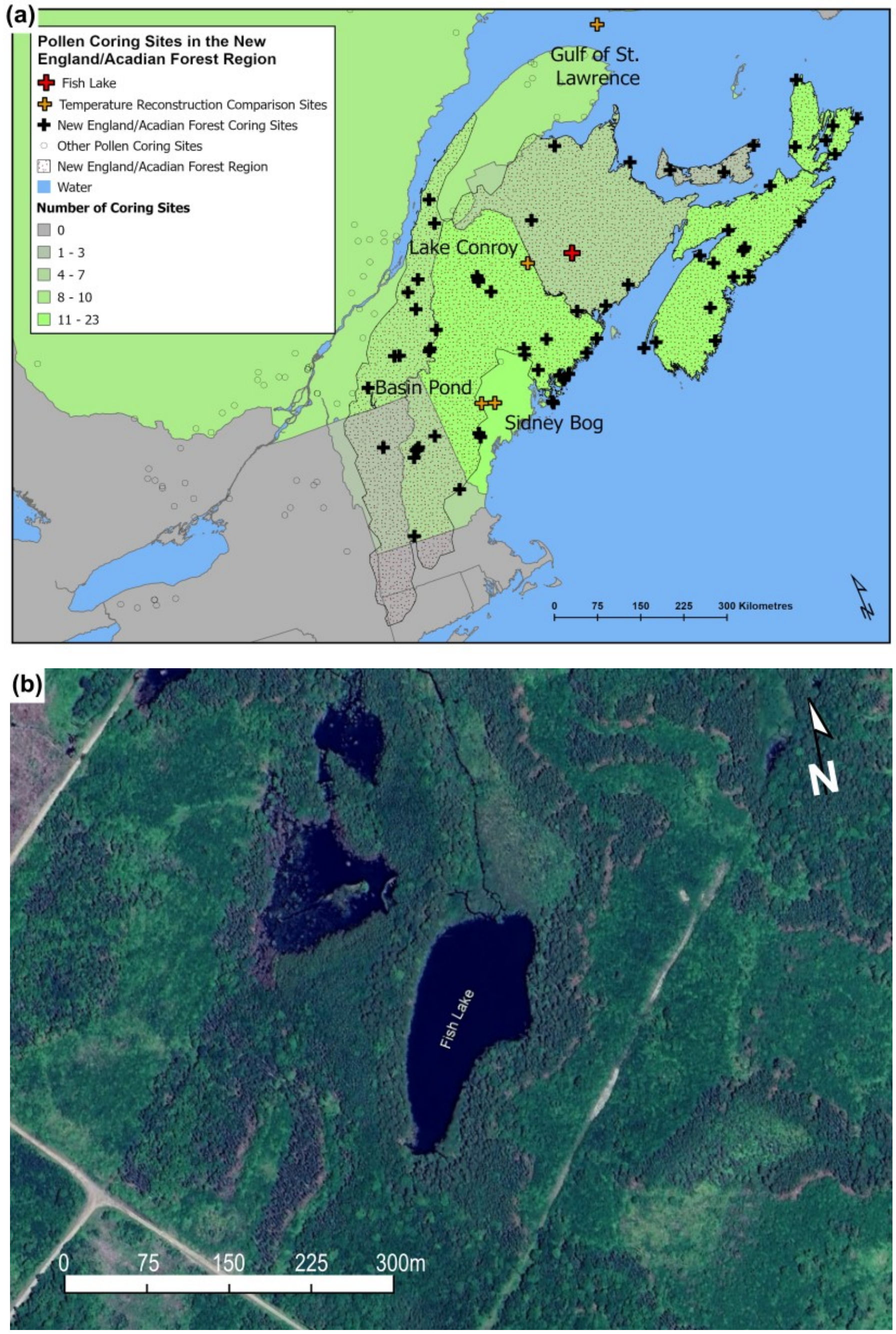



***Figure 3. (a)*** *Map of the New England/Acadian forest region, with coring sites of previous researchers identified by black crosses and our new site with a red cross. Note the paucity of coring sites in New Brunswick relative to neighboring Maine and Nova Scotia.* ***(b)*** *A satellite image of Fish Lake from Google Maps (Adapted from Noseworthy and Beckley (2020), Neotoma, and Google Earth)*

Our coring site was Fish Lake (46° 8’ 38.32’’N, 66° 53’ 12.64’’ W) in Douglas Parish, New Brunswick (Figure 3). Fish Lake is located at the border of two regions defined by the New

Brunswick Department of Mines: the New Brunswick Highlands, and the New Brunswick Lowlands, the latter of whose topography exhibits lower hills and gentler relief than much of the rest of the province (Burrell and Anderson, 1991). Roughly 4.5 meters deep at its center, the lake has a surface area of 1.5 hectares. Fish Lake has a single outflow and a single inflow point at its wider, northern end. It is surrounded by conifers, principally *Pinus strobus* L., on three sides. It is 28 kilometers away from downtown Fredericton, has no human habitations nearby, and is at least 200 meters away from lightly trafficked dirt roads.

# Methods

## Field methods

A surface core was taken in February 2023, using the ice as a coring platform and a 1.5 m long, 7.5 cm wide clear acrylic tube with an accompanying piston. The core was taken in 4.5 m of water as measured by a Secchi disk. The coring location (46° 08' 40.1'' N, 66° 53' 11.7'' W) was determined using a GARMIN ITRAX GPS. Using a Livingston piston corer, a subsequent 4 meters of sediments were taken until the beginning of the grey Younger Dryas silt layer. However, my MSc project was focused on the Acadian forest and only used the surface core; therefore, the piston cores were archived and not mentioned further. The surface core was stored in an upright position with the piston in place in a walk-in fridge at 4°C in the Department of Biology, University of New Brunswick. In June 2023, the surface sediment core was extruded. Above 20 cm, it was subsampled every 0.5 cm into plastic bags. Below 20 cm, the core was subsampled every 0.25 cm into plastic bags.

## Chronology construction method

Terrestrial macro-fossils found while extruding the surface core were extracted, rinsed in weak HCl, dried, weighed and then dated using AMS radiocarbon analysis at Beta Analytics. In total, four macro-fossils were used for $^{14}C$ analysis. Samples from the first 32 cm of surface sediments from the core were dated by $^{210}Pb$ at Flett Labs, Winnipeg, and the constant rate of supply (CRS) model was used to interpret the $^{210}Pb$ depth profiles (Ghaleb, 2009). The resulting data were modeled using Bayesian methods with the *rplum* package in R to create a composite chronology (Aquino-Lopez, Blaauw, Christen, and Sanderson 2018).

## Loss-on-ignition method

Sediment samples of 0.5 cc were analyzed at a 1 cm sampling resolution to determine percent carbon and percent minerals throughout the core. The sediment samples were heated to 100 °C to dry them, and then to 550 °C in accordance with the methodologies of Dean (1974) and Heiri et al. (2001).

## Pollen analysis methods

Pollen samples of 0.5 $cm^3$ were analyzed at a 1 cm sampling resolution along the length of the core, i.e., from every other sample for the top 20 cm and from every fourth sample below 20 cm. Each sample was spiked with one *Lycopodium* tablet to use the exotic marker grain method (Benninghoff, 1962; Bonny, 1972) to calculate pollen accumulation rates throughout the core (Moore et al., 1991). Samples were treated by the standard pollen preparation procedure to remove as much non-pollen debris from the sediment as possible, while conserving the pollen grains (Fægri and Iverson, 1989). The procedure included HCl to remove carbonates, and KOH and acetolysis to remove non-pollen organic matter. An initial 36 samples also received HF treatment to remove possible silicates. Since silicates were not present in any quantity, its use was discontinued. The processed pollen samples were stored in silicone oil before being mounted on slides for microscopic pollen analysis.

High resolution pollen counts were done, during which a minimum of 400 terrestrial pollen grains and spores were identified and counted on each slide. Pollen slides were counted at 400x and 800x using a Leica DM 2500 LED microscope. Regional pollen guides and papers (Richard, 1970; McAndrews et al., 1973; Bassett et al. 1978; Philbrick and Bogel, 1981; Moore, Webb, and Collinson, 1991; Lindbladh et al., 2002) were used as references for pollen taxonomy. Pollen grains were identified to the highest resolution. In order to trace the dynamics of the *Picea* species, their pollen was split into that from *Picea rubens, P. mariana* (Mill.) Britton, Sterns & Poggenburg, and *P. glauca* (Moench) Voss (red, black, and white spruce, respectively) following Richard (1970), and Lindbladh et al. (2002). *Pinus* was split into sections haploxylon and diploxylon following McAndrews et al. (1973). *Alnus* was split into *Alnus crispa* (Ehrh.) K.Koch (green alder) and *Alnus rugosa* Du Roi (speckled alder) following Richard (1970) and McAndrews et al. (1973).

Pollen stratigraphic plots of relative and absolute abundances were made with the R package *rioja*; and CONISS was used to divide them into zones whose significance was assessed by the broken stick test (van Buuren, 2023). To further examine changes in the taxa through time, principal components analysis (PCA) was performed for the relative abundance record using the R package *vegan*. The gradient length was checked using the length of the first axis of DCA to ensure that PCA was appropriate, and the significance of the first three axes was checked with a broken stick test.

## Climate reconstruction methods

To provide evidence that the shifts in vegetation composition were driven by regional climate changes, we converted the high-resolution pollen relative abundance data into temperature and precipitation values and compared the climate signals from this site with those from other sites in the region. We assumed that if the reconstructions were similar, then the vegetation changes were caused by regional climate change. We reconstructed past climate using weighted averaging partial least squares regression and calibration (WA-PLS). For the pollen-climate calibration set, we used version 1.8 of Whitmore et al. (2005). For the calculations, we used the *rioja* package in R (Juggins, 2024), exploring reconstructions of annually and MAM-, JJA-, SON-, DJF-averaged temperatures, and annually and seasonally summed precipitation. The best reconstructions were chosen by maximizing $R^2$, minimizing *RMSE,* and testing the significance of the WA-PLS components using a randomized *t*-test. Given the taxonomic decisions of the earlier researchers whose work forms the pollen-climate training set, we had to merge the *Picea, Alnus, Pinus and Acer* species counts to generic counts. Modern pollen data spanning 74° and 61° W longitude and 43° and 50° N latitude were extracted, resulting in 301 sites in our Maritimes pollen-climate calibration set. We used WA-PLS because it copes well with the irregular spatial distribution of sites in the Whitmore et al. (2005) calibration set and successfully handles minor extrapolation.

We verified that the Maritimes pollen-climate calibration set contained adequate modern analogs for the Fish Lake pollen samples by computing the minimum squared chord distance for each Fish Lake sample to the Maritimes calibration set. Any Fish Lake sample with minimum squared Euclidean distance $\leq$ 15.87 (the 5$^{th}$ closest percentile of comparisons within the Maritimes calibration set) has a close modern analog; any Fish Lake sample with 15.87 < minimum squared chord distance $\leq$ 24.37 has a modern analog; and any Fish Lake pollen sample with a minimum squared chord distance $>$ 24.37 (the 20$^{th}$ closest percentile of comparisons within the Maritimes calibration set) has no modern analog (St-Jacques et al., 2007; Simpson, 2012).

We compared our reconstructions to other high-resolution and well-dated terrestrial and marine sedimentary reconstructions from within a 350 km radius to examine regional past climate patterns (e.g., Gajewski, 1988; Clifford and Booth, 2013; Wu et al., 2022). We defined high-resolution sampling as at least four proxy samples per century, and well-dated to mean varved sediments or at least four $^{14}$C dates per 1000 years. We did not include tree-ring-based climate reconstructions in our local comparison set. Although annually resolved, they do not capture centennial-scale climate variability well in this region because of the aggressive detrending methods dendro-climatologists must use to remove stand dynamics in the closed-canopy northeastern forests (e.g. Tardif et al., 2001; Pace et al., 2025).

## Charcoal analysis methods

Charcoal archived in lake sediment cores is an ideal material from which to derive regional fire frequencies, being both chemically and biologically inert, and thus able to survive long spans of time after charcoalization (Crawford and Belcher, 2014). Samples of 0.5 cc were taken at 0.5 cm increments continuously along the core. Each sample was soaked in 10% KOH for 24 hours, which disaggregated the sediment. Commercial bleach was then added for one hour to whiten dark organic matter, making the charcoal easier to see. Each sample was sieved using a 150 µm sieve, and the residue examined under a Leica M80 microscope. The charcoal pieces were gathered together using a fine paint brush and photographed using a Leica digital color MC170 HD microscope camera. These photographs were used as inputs for the imaging analysis software WinSeedle®, which calculated the aggregated surface area of charcoal for each sample.

Statistical analysis of the charcoal data (the time series consisting of the total surface area of all the samples) was done using the Matlab© version of CharAnalysis (Higuera et al. 2009a, 2009b) to identify peaks in the charcoal record marking local fire events. Charcoal area accumulation rates were interpolated using the age-depth model and proportional interpolation with a fixed time interval bin size of 5 years (the median resolution of the record), producing an interpolated series of samples of equal duration ($\mu m^2 \cdot cm^{-2} \cdot yr^{-1}$) (Higuera et al. 2009b, Molinari et al. 2018). The background charcoal (BCHAR) of non-local and secondary charcoal was calculated using a moving window of 300 years and a moving mode smoother to ensure that the signal-to-noise index (SNI) of the charcoal peaks was above 3.0 as recommended by Kelly et al. (2011). The BCHAR series represents distant fires, long-term shifts in fire regimes and secondary taphonomic processes not related to local fire occurrences (e.g. sediment mixing, intra-lake charcoal transport, slope wash). Then CHAR was calculated as the residual of the interpolated charcoal series minus BCHAR. Peaks in charcoal, interpreted as local fire events, were identified as CHAR values exceeding the 99th percentile of the CHAR noise distribution modelled using Gaussian mixture models with a locally set threshold (Higuera et al. 2009b). The window size and smoother type were also optimized to maximize the goodness-of-fit of the noise component of the Gaussian mixture model as assessed by the Kolmogorov-Smirnov test.

# Results

## Age-depth model construction

The age-depth model derived from the core serves as the backbone of the analysis by providing vital temporal context for the results. Two different radioisotopes, $^{210}Pb$ and $^{14}C$, are modeled here. $^{210}Pb$, a result of decaying $^{238}U$, is commonly used to infer recent (i.e.: up to 200 years) sedimentation rates (Barsanti et al, 2020). Terrestrial macrofossils trapped in lake sediment contain $^{14}C$, which decays at a known rate and permits dating through the entire Holocene (Yeloff et al, 2006). The results of analysis of these two radioisotopes in the core are plotted and checked for validity using the *rplum* package in R.

**Table 1.** $^{210}Pb$ dating results from Flett Labs, Winnipeg, Manitoba, for the 15 samples, showing laboratory IDs, sample IDs, sample depths, $^{210}Pb$ total activities, 1 standard deviation $^{210}P$ counting errors and the ages of the bottoms of the samples as calculated using a CRS model.

| LAB ID | Sample ID | Upper Depth (cm) | Lower Depth (cm) | $^{210}Pb$ Total Activity DPM/g dry wt | $^{210}Pb$ Counting Error ± 1 S.D. DPM/g dry wt | Age at Bottom of Extrapolated Section in Years |
|---|---|---|---|---|---|---|
| 115135 | Fish Lake (0-1 cm) | 0.0 | 1.0 | **25.14** | 0.52 | 2.4 |
| 115139 | Fish Lake (2-3 cm) | 2.0 | 3.0 | **33.18** | 0.64 | 9.7 |
| 115144 | Fish Lake (4.5-5 cm) | 4.5 | 5.0 | **32.97** | 0.66 | 18.5 |
| 115148 | Fish Lake (6.5-7 cm) | 6.5 | 7.0 | **33.14** | 0.65 | 31.5 |
| 115152 | Fish Lake (8.5-9 cm) | 8.5 | 9.0 | **25.06** | 0.57 | 41.6 |
| 115154 | Fish Lake (9.5-10 cm) | 9.5 | 10.0 | **21.67** | 0.50 | 48.1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 115158 | Fish Lake (10.25-11 cm) | 10.3 | 11.0 | **17.27** | 0.49 | 56.0 |
| 115162 | Fish Lake (11.25-12 cm) | 11.3 | 12.0 | **13.06** | 0.40 | 64.8 |
| 115166 | Fish Lake (12.5-13 cm) | 12.5 | 13.0 | **7.89** | 0.32 | 69.0 |
| 115170 | Fish Lake (13 -14 cm) | 13.0 | 14.0 | **5.38** | 0.26 | 74.8 |
| 115174 | Fish Lake (14.5-15 cm) | 14.5 | 15.0 | **3.79** | 0.23 | 79.8 |
| 115184 | Fish Lake (17.0-17.5 cm) | 17.0 | 17.5 | **2.89** | 0.19 | 85.7 |
| 115194 | Fish Lake (19.5-20 cm) | 19.5 | 20.0 | **2.61** | 0.18 | 99.3 |
| 115218 | Fish Lake (25.5-26 cm) | 25.5 | 26.0 | **1.86** | 0.15 | 122.7 |
| 115242 | Fish Lake (31.5-32 cm) | 31.5 | 32.0 | **1.26** | 0.13 | 131.1 |

**Table 2.** Radiocarbon dating results from Fish Lake, New Brunswick, from Beta Analytic, showing laboratory IDs, sample names, materials, depths (cm), uncalibrated $^{14}C$ years, their 1 standard deviation errors and the calibrated dates according to INTCAL20 (Reimer et al, 2020). Note: BP means prior to 1950.

| Lab ID | Sample name | Material | Depth (cm) | $^{14}C$ year BP | Error | Calibrated year AD (BP) ranges and their probabilities |
|---|---|---|---|---|---|---|
| Beta-665649 | Fish 33.25-33.5 | Conifer needle | 33.25-33.50 | 180 | ±30 | 1722-1814 cal. AD (228-136 cal. BP) - 49.9%<br>1656-1698 cal. AD (294-252 cal. BP) - 19.2%<br>1910-Post AD 1950 (40-Post BP 0) - 19%<br>1836-1880 cal. AD (114-70 cal. BP) - 7.3% |
| Beta-665650 | Fish 40.50-40.75 | Conifer needle | 40.50-40.75 | 170 | ±30 | 1720-1815 cal. AD (230-135 cal. BP) - 46.1%<br>1907 - Post AD 1950 (43 - Post BP 0) - 19.5%<br>1660-1700 cal. AD (290-250 cal. BP) - 17.4%<br>1832-1890 cal. AD (118-60 cal. BP) - 12.5% |
| Beta-665651 | Fish 85-85.25 | Conifer needle | 85-85.25 | 660 | ±30 | 1278-1325 cal. AD (672-625 cal. BP) - 48.4%<br>1352-1394 cal. AD (598-556 cal. BP) - 47% |
| Beta-665652 | Fish 100.75-101 | wood | 100.75-101 | 930 | ±30 | 1032-1177 cal. AD (918-773 cal. BP) - 93.2%<br>1192-1202 cal. AD (758-748 cal. BP) - 2.2% |

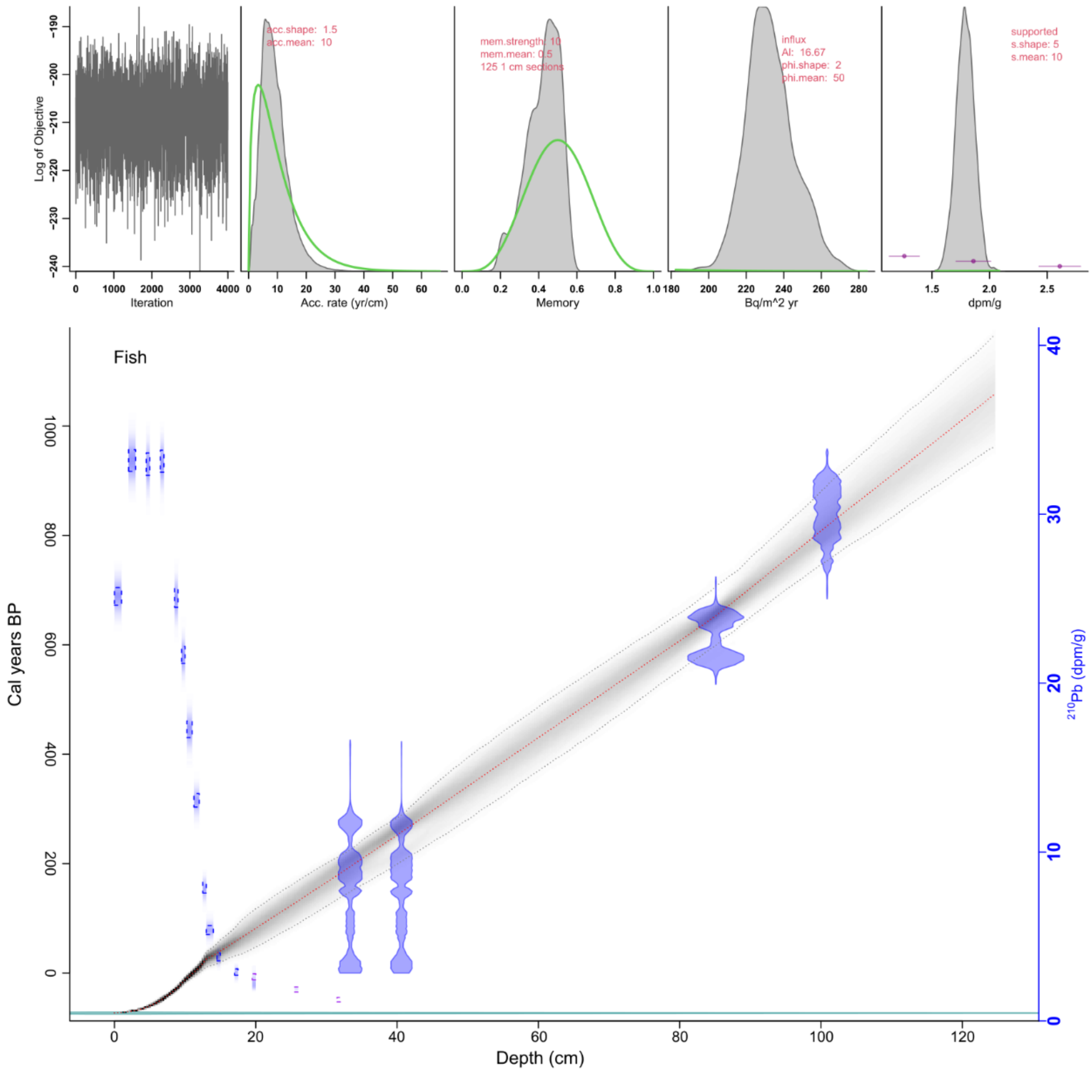



***Figure 4.*** *Age-depth model of the Fish Lake core using the R package rplum based on four $^{14}C$ dates and 15 $^{210}Pb$ dates. The top panels show, from left to right, the MCMC series, and the prior (green) and posterior (grey) distributions for, respectively, the accumulation rate (in yr/cm), the accumulation variability or memory, the flux of $^{210}Pb$ (phi), and the level of supported $^{210}Pb$ (s). Red text indicates the settings. The right-hand axis and left-hand portion of the bottom panel shows the total $^{210}Pb$ activity. The long purple violin plots denote $^{14}C$ dates and their probabilities and the short blue squares denote total $^{210}Pb$ activity and their errors. The greyscale is the age-depth model, the grey dashes are the 95% range, and the red dashes are the mean age-depth model.*

The length of the surface core was 124 cm. In total, 15 $^{210}Pb$ and four $^{14}C$ dates were obtained on the surface sediment core (Tables 1 and 2). The plot of total $^{210}Pb$ activity showed a negative exponential decay (the very dilute uppermost two samples were difficult in which to measure activities), hence the CRS $^{210}Pb$ modelling was successful (Figure 4). Despite the close proximity of two of the $^{14}C$ dates near core top, and hence their wide calibrated date ranges, the $^{14}C$

dates showed no reversals (Table 2 and Figure 4). Therefore, all four $^{14}C$ dates were used in the construction of the age-depth model. The chronology of the surface core spanned over a millennium, from AD 890 to AD 2023 (1060 BP to -69 BP). Therefore, the core spanned both the Medieval Climate Anomaly (AD 900-1400) and the Little Ice Age (AD 1400-1850), enabling the reconstruction of the dynamics of the Acadian forest at Fish Lake over this time span using pollen and charcoal analysis.

## Loss-on-ignition results

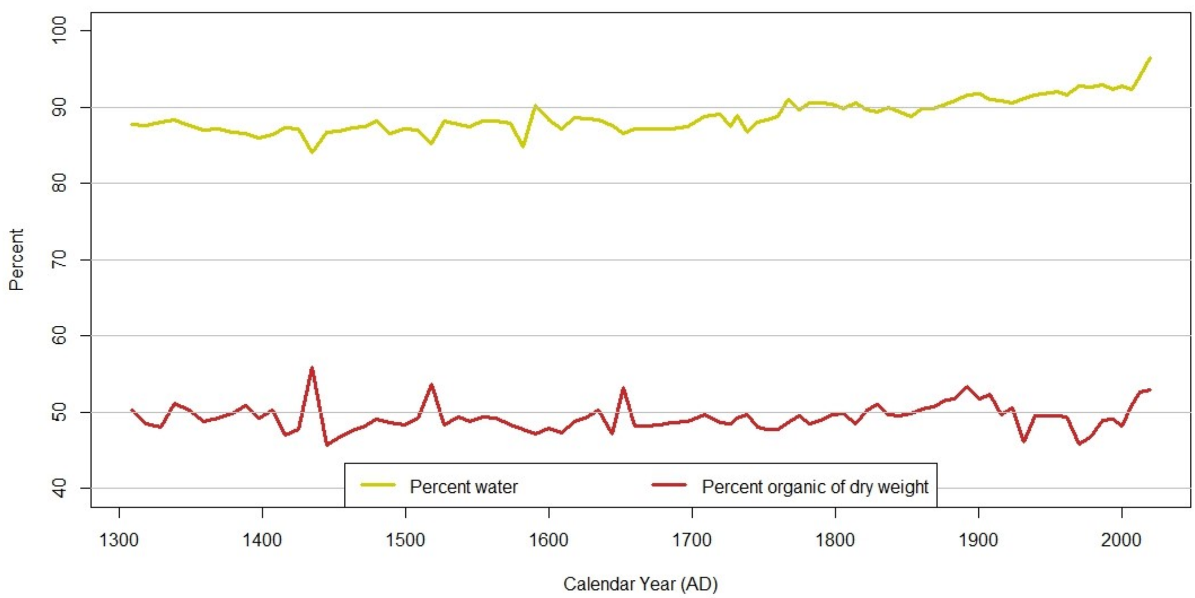



***Figure 5.*** *Loss-on-ignition results for AD 1300 – 2023 from Fish Lake, Douglas Parish, New Brunswick.*

Loss-on-ignition results demonstrated a fairly linear declining percentage of water in the core towards the bottom and a more variable percentage of organic material (Figure 5). Organic material was at its lowest points in the early 20th century and at three points during the LIA: AD 1445, 1530, and 1660.

## Pollen relative abundance and influx results

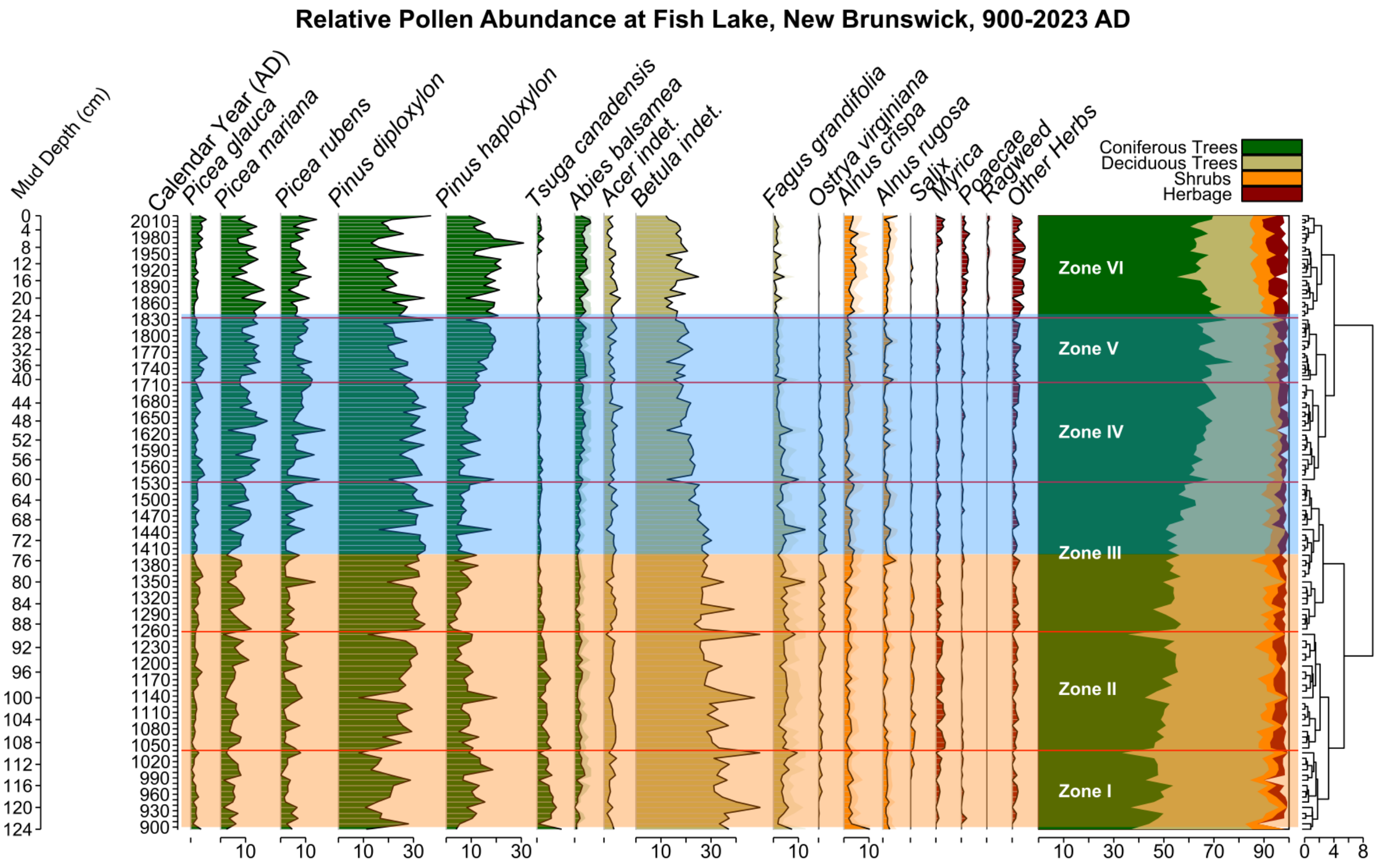



***Figure 6***. *Pollen relative abundances (%) for AD 900 – 2023 from Fish Lake, Douglas Parish, New Brunswick, showing the most important taxa. Zonation was done using CONISS with the broken stick test to determine that the zones were significant. The orange shading denotes the Medieval Climate Anomaly, and blue shading denotes the Little Ice Age. A cumulative plot showing the percentage of each grouping present in each sampling appears after the individual species plots.*

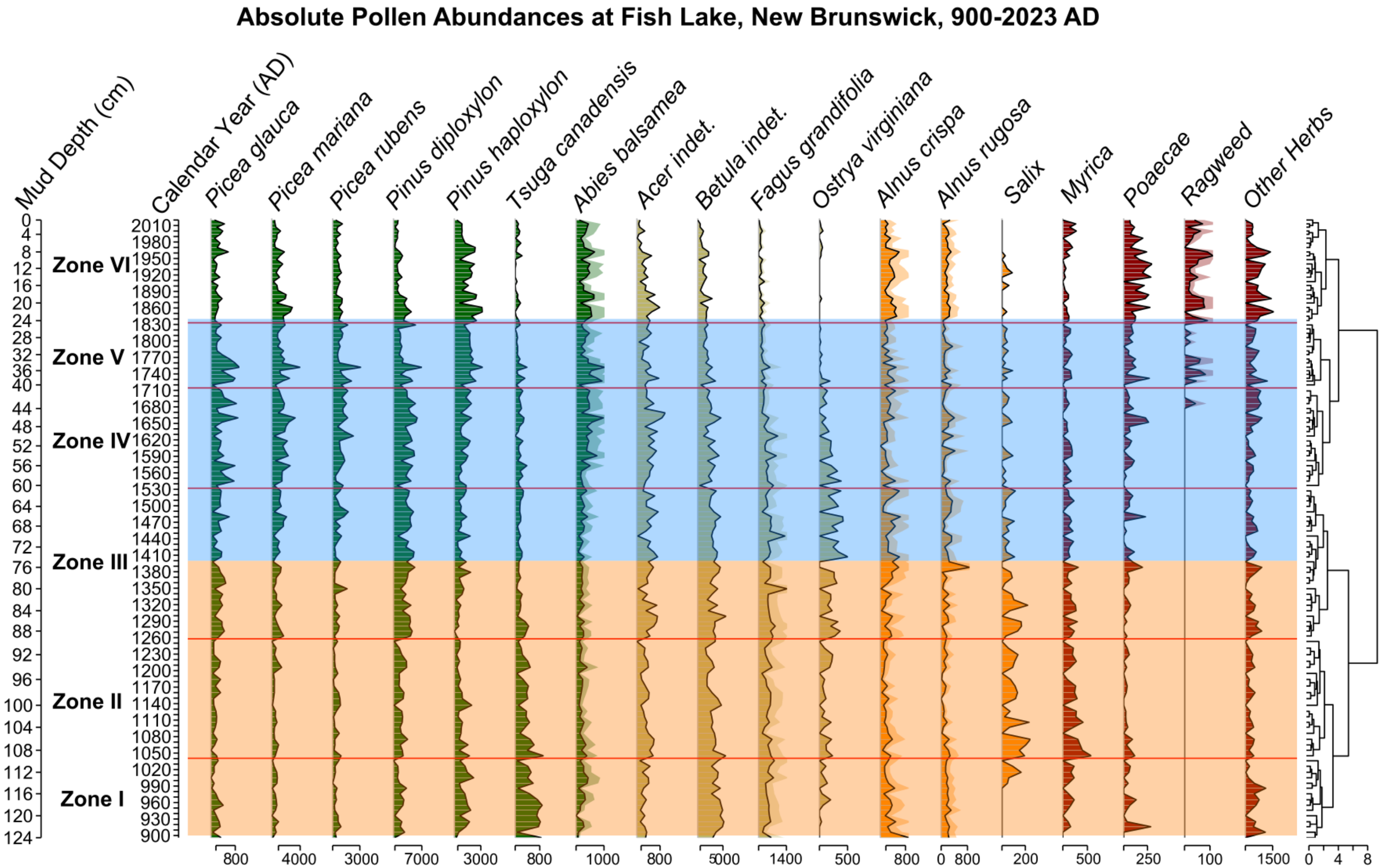



***Figure 7.*** *Pollen influx (grains/cm²·yr) for AD 900 – 2023 from Fish Lake, Douglas Parish, New Brunswick, showing the most important taxa. The orange shading denotes the Medieval Climate Anomaly and the blue shading denotes the Little Ice Age.*

The broken-stick model and CONISS identified six distinct pollen zones. These zones are of variable lengths of time, with the briefest zone at the top of the core.

### *Pollen zone I: Early Medieval Climate Anomaly (AD 895-1045)*

The dominant pollen taxa at Fish Lake in pollen zone I and during the early MCA was *Betula spp.* (birch) (Figures 6 and 7). *Tsuga canadensis* (L.) Carrière (eastern hemlock) was present with its highest abundance and influx in this zone. The three *Picea* (spruce) species and *Pinus* haploxylon (*Pinus strobus*) and *Pinus* diploxylon (*Pinus resinosa* Sol. ex Aiton (red pine) and *Pinus banksiana* Lamb. (jack pine) were abundant; however they had lower relative abundances and influxes in this zone than subsequently in the succeeding zones. *Fagus grandifolia* Ehrh. (American beech) was relatively prominent. Little pollen from shrubs such as *Salix* (willow) and *Alnus* (alder), as well as from other herbs, indicated that the forest was likely mature and largely closed during this time.

### *Pollen zone II: Middle Medieval Climate Anomaly (AD 1045-1265)*

At the end of pollen zone II and the MCA, *Pinus* diploxylon increased in relative abundance relative to pollen zone I and the early MCA, and the *Picea* species slightly increased (Figures 6 and 7). *Pinus* haploxylon (i.e. *Pinus strobus*) either remained the same or even slightly decreased in percentage and influx. *Betula* began a decline in relative and absolute abundances that continued through the rest of the record; as did *Tsuga* canadensis. The abundance and influx of *F. grandifolia* remained similar to that in pollen zone I. *Salix* and *Myrica gale* L. (sweetgale) increased in abundance and influx, while the abundance of *Alnus* remained similar to that of pollen zone I. *Acer* reached its highest relative abundance in this zone.

### *Pollen zone III: Transition from Medieval Climate Anomaly to Early Little Ice Age (AD 1265-1530)*

The end of the MCA brought a resurgence of conifers to complement a relatively robust deciduous pollen signal (Figures 6 and 7). In pollen zone III, *P. mariana* became more abundant in both percent and influx, as did *P. rubens* and *P. glauca* to a lesser extent. *Pinus* haploxylon reached a nadir in relative abundance but not influx, while conversely *Pinus* diploxylon increased and reached its highest relative abundance and influx in this zone and the subsequent one. *Acer* remained steady and slightly elevated in percent and influx relative to the early MCA (pollen zone I). *Tsuga canadensis* declined substantially in percent and influx in this zone, and *F. grandifolia* began to decline in percent and influx towards the upper bounds of this zone. *Betula* declined in relative abundance but increased in influx. *Ostrya virginiana* (Mill.) K. Koch reached its maximum relative abundance and influx. *Abies balsamea* was a minor constituent. The percentage and influx of the other herbs increased in this zone relative to its predecessor.

### *Pollen zone IV: Middle Little Ice Age (AD 1530-1720)*

Encompassing the beginnings of European (French) colonization of the region as the LIA continued in Atlantic Canada, the conifer signal began a significant rise (Figures 6 and 7). Every conifer taxon increased in abundance in this zone except for *Tsuga*. Particularly strong increases in abundance can be seen in *P. mariana* and *P. rubens*. Pollen zone IV or the middle LIA began with a continuing increase in the relative abundances and influx of *P. mariana* and *P. rubens.* The relative abundance and influx of *A. balsamea* also increased at the beginning of this period. *Pinus* diploxylon abundance remained constant in pollen zone IV, while influx increased. *P. strobus* abundance and influx increased towards the end of this zone. Declines in *Betula* and *Fagus* percent and influx accelerated in this zone. *Ostrya* similarly declines relative to its high point in zone III. *Acer* remained fairly unchanged in percentage and influx, whereas *Alnus* declined. Notably, the first *Ambrosia* (ragweed) pollen appeared in this zone around AD 1680.

### *Pollen zone V: Early colonial period (AD 1720-1840)*

Pollen zone V showed a general continuation of the continuing decline in deciduous taxa with a matching increase coniferous taxon (Figures 6 and 7). *Betula* and *F. grandifolia* continued to decline in percent and influx, and *Acer* declined in influx. *Picea mariana* and *P. rubens* remained relatively constant in percentage and influx during this zone, while *P. glauca* increased. *Pinus* haploxylon (*P. strobus*) increased in percentage and influx in this zone, while *Pinus* diploxylon decreased. *Tsuga* was reduced in both abundances, while the abundance of *Abies balsamea* continued to rise. The relative abundances and influx of Poaceae, *Ambrosia* and other herbs increased throughout pollen zone V.

### *Pollen zone VI: British colonial and modern periods (AD 1840 - present)*

The topmost section of the core began in AD 1840 and formed the modern part of the reconstruction (Figures 6 and 7). *Betula*, *Acer*, and *F. grandifolia* relative abundances and influxes reached their minima. *Ostrya virginiana* practically vanished in this zone. The relative abundances of *P. mariana* and *P. rubens* had high values similar to those in pollen zone V, while percent *Picea glauca* increased at the end of this zone. However, all three *Picea* species showed declines in influx. *Tsuga canadensis* had very low values. Percent *Pinus* diploxylon were similar to that of zone V, however its influx declined throughout zone VI. *Pinus* haploxylon percent and influx reached their maximum in the core. *Abies balsamea* reached its maximum percentage in the entire record, whereas its influx was similar to that of the two preceding zones. Both *Alnus rugosa* and *Alnus crispa* had sustained high relative abundances and influxes. Poaceae, *Ambrosia* and other herbs reach their highest relative abundances and influxes in pollen zone VI.

## PCA of pollen relative abundances

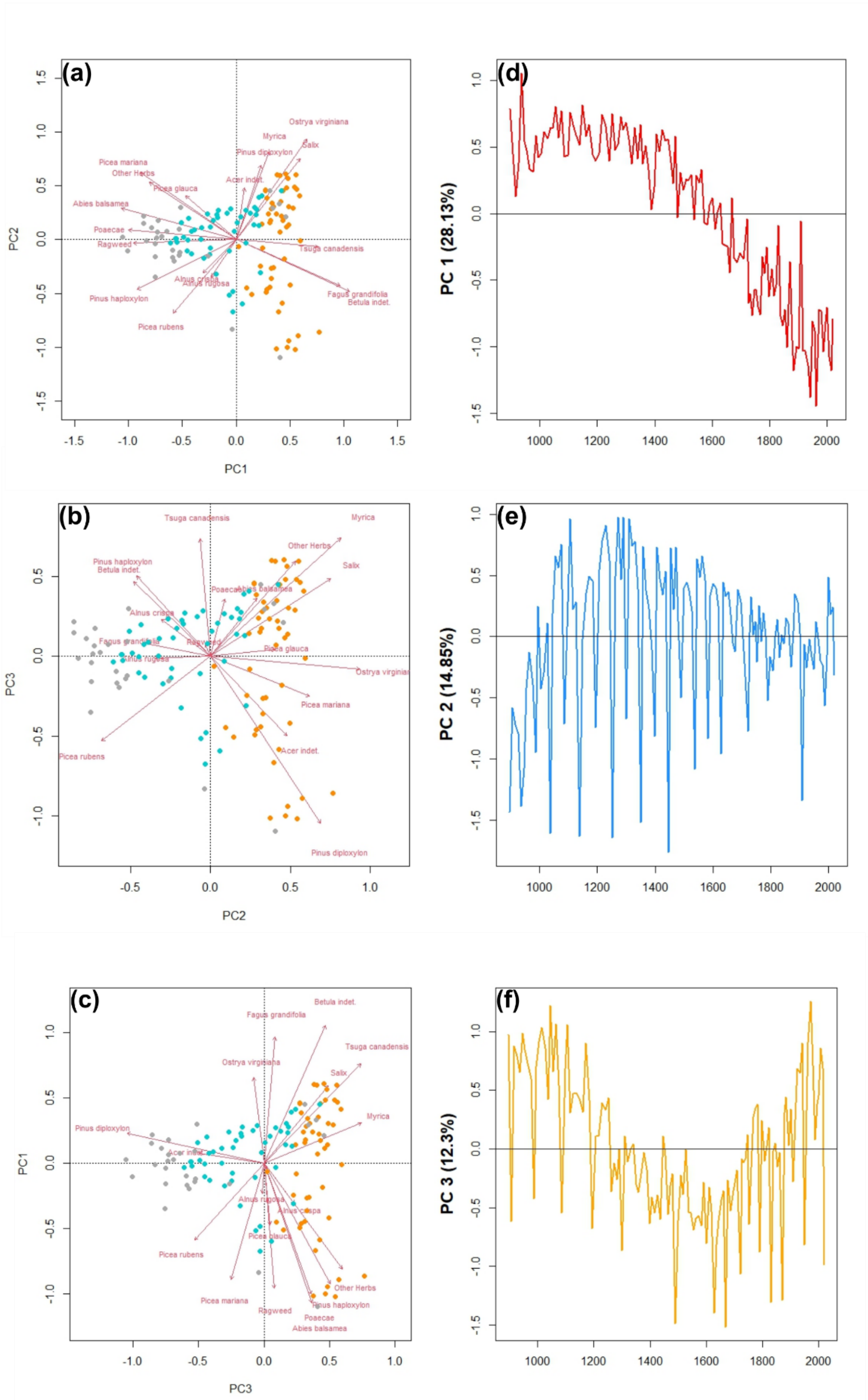


***Figure 8.*** ***(a)*** *Biplot of the first two principal components of the Fish Lake pollen data (left hand side),* ***(b)*** *biplot of the second and third principal components,* ***(c)*** *biplot of the first and third principal components,* ***(d)*** *plot of the first component versus time,* ***(e)*** *plot of the second component versus time, and* ***(f)****, a plot of the third component versus time. In the biplots, the sample dots are colored according to sample age: orange dots denote samples from the MCA, teal dots from the LIA, and gray dots pollen zone VI or modern.*

PCA was used to uncover the main patterns of pollen variation, explaining 55.3 % of the total pollen variation with the first three significant principal components (Figure 8). PCA Axis 1 explained 28.1 % of the pollen variation and was defined by warmer *T. canadensis, F. grandifolia* and *Betula* (highest positive first axis species scores), and colder coniferous taxa: *P. mariana, P. rubens, A. balsamea* and *P. strobus*, together with *Ambrosia* and *Poaceae* (lowest negative first axis species scores) (Figure 8a). PC 1 sample scores were highest in the MCA, clustered around zero and were more variable in the LIA and were lowest and had the smallest range during European settlement (Figure 8a). PCA Axis 2 explained 14.9 % of the pollen variation and was defined by *Ostrya virginiana, Myrica*, other herbs, and *Pinus* diploxylon (highest positive second axis species scores), and the coniferous pollen of *Picea rubens* and *Pinus* haploxylon (lowest negative second axis species scores) (Figure 8a). PC 2 sample scores exhibited high frequency and amplitude in the MCA and LIA, with reduction in both frequency and amplitude during European settlement (Figures 8b). PCA Axis 3 explained 12.3% of the pollen variation and was defined by *T. canadensis* and *Myrica* (highest positive third axis species scores) and *Pinus* diploxylon, *Acer* spp., and *P. rubens* (lowest negative third axis species scores) (Figure 8c). PC 3 sample scores exhibited a U-shape, declining in the LIA and returning to higher values during European settlement (Figure 8c). The frequency and amplitude of the PC 3 sample scores remained reasonably constant throughout the last millennium.

## Pollen-inferred climate reconstructions

Using our Maritimes-focused pollen-climate calibration subset from Whitmore et al. (2005), the best temperature reconstruction was that of MAM-averaged temperature using two significant WA-PLS components, with an $R^2$ = 0.57, *RMSE* = 1.504 °C, average bias = -0.018 °C, and maximum bias = 3.065 °C when run on itself using leave-one-out cross-validation. Close modern analogs existed for 89% of the Fish Lake pollen samples in the Maritimes calibration set, modern analogs existed for a further 8% of the samples; and only 3% of the samples had no modern analog (Figure 9a). The reconstructed spring temperature showed a warm MCA, and a distinct cold LIA (Figure 9b). The reconstructed warm period spanned AD 900–1400 included the MCA and the very beginning of the LIA with an average spring temperature of 3.2 °C, and the succeeding cold period spanned AD 1400–1850 and included most of the LIA with an average spring temperature of 2.2 °C. The best precipitation reconstruction was that of DJF-averaged precipitation using three significant WA-PLS components, with an $R^2$ = 0.37, *RMSE* = 48.7 mm, average bias = -0.63 mm, and maximum bias = 89.6 mm using leave-one-out cross-validation. The reconstructed annual precipitation showed a generally drier MCA (AD 900-1400) with an average winter precipitation of 245 mm, whereas the early LIA (AD 1400-1600) was wetter with an average winter precipitation of 254 mm, and the later LIA (AD 1665-1850) was drier again with an average winter precipitation of 245 mm (Figure 9c). Post-1900, the climate reconstructions become unreliable due to well-documented human-caused landscape modification (St-Jacques et al., 2015).

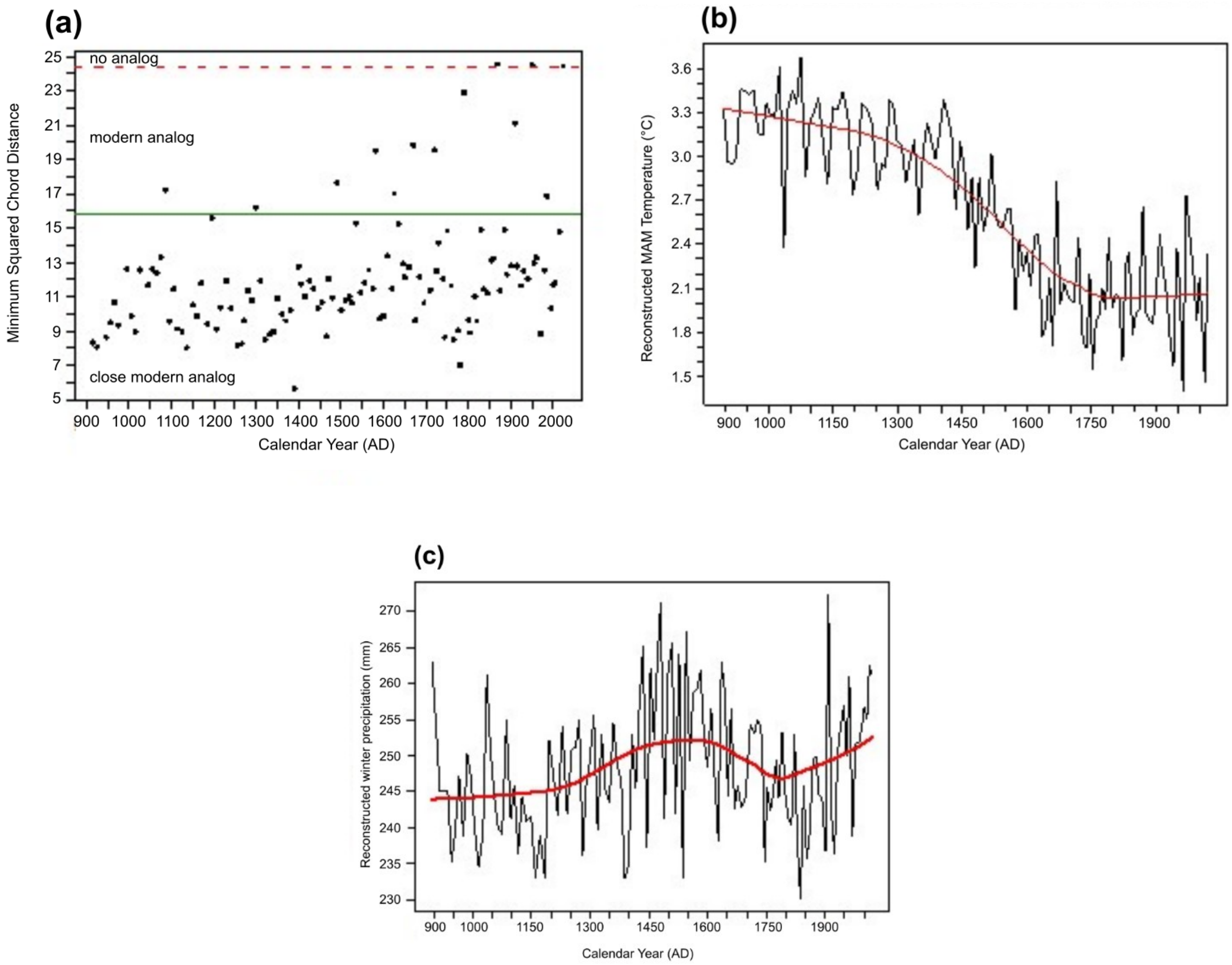



***Figure 9.*** *Pollen-based climate reconstructions from Fish Lake, New Brunswick:* ***(a)*** *minimum squared chord distances for the Fish Lake pollen samples to the Maritimes pollen-climate calibration set* ***(b)*** *March-May temperature (°C), and* ***(c)*** *December-February precipitation (mm). For (a) values less than the solid green line at 15.87 (the 5th percentile of distances within the calibration set) mean that a close modern analog exists in the calibration set, values less than the dashed red line at 24.37 (the 20th percentile of distances within the calibration set) mean that modern analogs exist in calibration set), and values greater than the dashed red line mean that no modern analogs exist in calibration set.*

## Charcoal analysis results

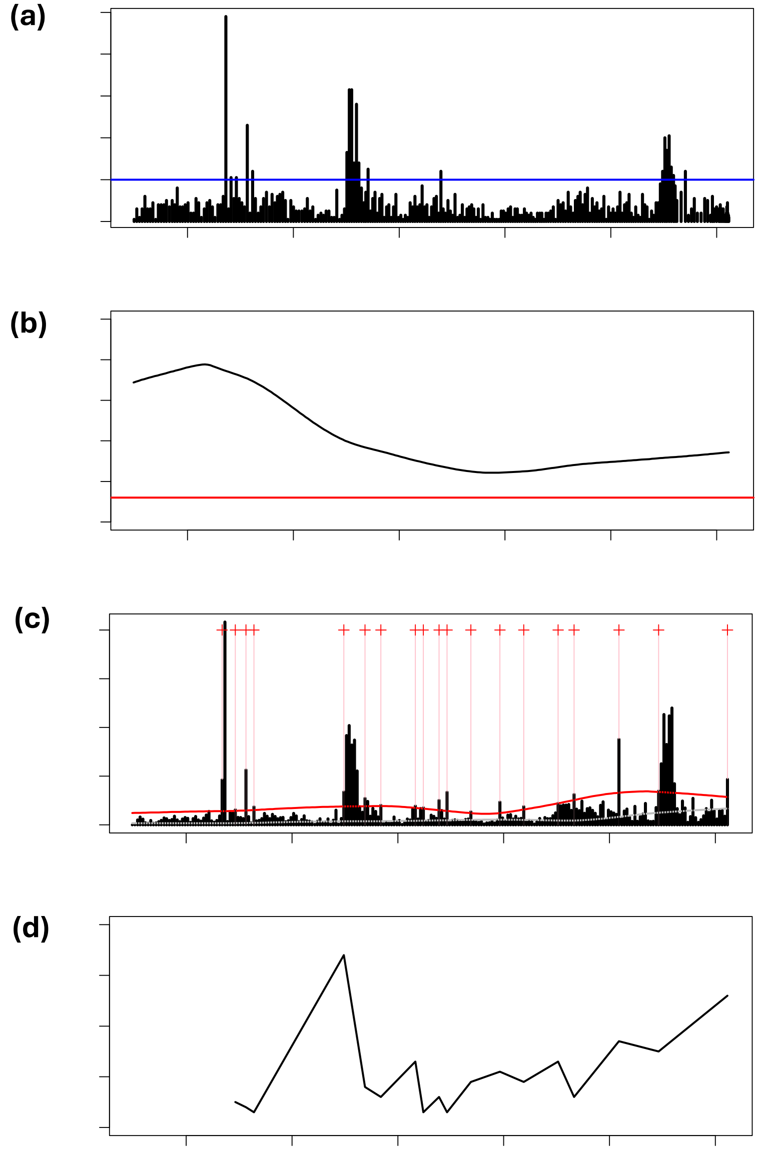



***Figure 10.*** *Fish Lake fire record for AD 900 – 2023.* ***(a)*** *Plot of the number of raw charcoal particles per sample.* ***(b)*** *Plot of the smoothed signal to noise index (SNI), together with a red line at 3, the SNI cut-off.* ***(c)*** *Plot of the interpolated charcoal accumulation rate (µm²·cm⁻²·yr⁻¹) record (black bars). Local fire peaks are marked by red crosses and pink vertical lines. The grey line shows background charcoal (BCHAR) and the red line marks the 99% threshold of the Gaussian noise models.* ***(d)*** *Plot of fire return intervals (FRIs).*

In total, 249 charcoal samples were counted from the Fish Lake core. Charcoal content varied from 0 (8 samples) to 98 pieces per sample, with a mean of 9.1 and a median of 7.0 pieces per sample (Figure 10a). The SNI was ≥ 3 for the entire Fish Lake record (Figure 10b) and there were good fits between the noise component of CHAR and the Gaussian mixture models in 88% of the record as assessed by the Kolmogorov-Smirnov test. The mean and median interpolated charcoal accumulation rates were 3.0 x $10^4$ $\mu m^2/cm^2 \cdot yr$ and 1.5 x $10^4$ $\mu m^2/cm^2 \cdot yr$, respectively (Figure 10c). CharAnalysis identified 19 local fire peaks in the Fish Lake core that occurred in AD 898, 1068, 1093, 1113, 1128, 1298, 1338, 1368, 1433, 1448, 1478, 1493, 1538, 1593, 1638, 1703, 1733, 1818, 1893, and 2023. The dates of the four fires with the highest charcoal accumulation rates were: AD 1068, 1298, 1818, and 1893. Background charcoal increased over the last 200 years relative to the earlier record (Figure 10c). Local fires occurred more frequently in the LIA than in the MCA (Figure 10c), as there were 7 fires in the MCA (AD 900-1400) with a mean FRI (fire return interval) of 67 years with a standard deviation of 71 years, versus 10 fires in the LIA (AD 1400-1850) with a mean FRI of 43 years with a standard deviation of 23 years. Overall, the mean FRI between AD 900 and 2023 was 59 years with a standard deviation of 49 years (Figure 10d), equivalent to 16.9 fires per millennium. (Note that because CharAnalysis uses interpolated dates, the dates are slightly different from those in the other analyses.)

# Discussion

## Synopsis

The Fish Lake Acadian forest of the Medieval Climate Anomaly (AD 900–1400) was characterised by deciduous taxa, with *Betula* as the dominant taxa and *Fagus grandifolia* as an important sub-dominant (Figures 6 and 7). Conifer taxa were present, i.e., the three *Picea* species, the two *Pinus* sections, and *Tsuga canadensis*, but they were not dominants or sub-dominants. Seven local forest fires occurred, but fire return intervals could be relatively long, on the order of

150 years (Figure 10). The Little Ice Age (AD 1400-1850) Acadian forest at Fish Lake was characterised by coniferous taxa, i.e. dominant *Pinus strobus*, with sub-dominants *Pinus* haploxylon, *Picea mariana, P. rubens*, together with increasing amounts of *Abies balsamea* and decreasing amounts of *T. canadensis*. Deciduous *Betula* and *F. grandifolia* were present, but declining. Local fires became more frequent around Fish Lake, i.e. 10 fires with regular, shorter fire return intervals of ~50 years. The Fish Lake Acadian forest of the later British colonial and modern periods was characterized by the rise of the disturbance taxa: *Alnus crispa* and *A. rugosa*, Poaceae, *Ambrosia* and other herbs. Only two local fires occurred in these latter periods.

## Climate change over the last millennium at Fish Lake

We converted the Fish Lake pollen data into temperature and precipitation reconstructions and compared our site's climate reconstructions with those from broader regional paleoclimate syntheses and other nearby high-resolution, terrestrial and marine sediment-based climate reconstructions within a ~350 km radius (Figures 3, 9, and 11) (Marlon et al., 2017; Ladd et al., 2018; Shuman et al., 2018; Wu et al., 2022). We made the assumption that if Fish Lake's climate reconstructions are similar to the above, then the forest changes in our pollen record are probably caused by regional climate change, and not internal drivers such as succession. The Fish Lake spring MAM temperature reconstruction matched the coherent cooling pattern over the past 1000 years found in Marlon et al. (2017)'s synthesis paper which covers the northeastern United States. Focusing more locally, our spring temperature reconstruction also closely corresponded to pollen-based mean summer (JJA) reconstructions from Gajewski (1988) who finds a shift from a warmer MCA to a colder LIA at ~AD 1450–1500 at Conroy Lake and Basin Pond in Maine. Wu et al. (2022) in their dinocyst-based summer sea surface temperature (SST) reconstruction from a core in the Laurentian Channel in the Gulf of the St. Lawrence offshore of New Brunswick find a steady cooling of ~3°C from AD 900 to AD 1850. Hence, our temperature reconstruction followed the coherent broad regional temperature decline, suggesting that the deciduous to coniferous shift in forest composition at Fish Lake was driven in part by this regional cooling.

Additionally, the Fish Lake winter precipitation reconstruction (Figure 9) matched the general wetting pattern of the most recent 1000 years for northern New England described in the reviews of Marlon et al. (2017), Ladd et al. (2018), and Shuman et al. (2018), i.e., a wet LIA relative to a drier MCA. A winter pollen-based reconstruction may at first glance seem odd since vegetation is dormant at this time, but snowpack is crucial in New Brunswick for soil moisture recharge for the subsequent growing season. Focusing on close high-resolution reconstructions, Gajewski (1988)'s pollen-based annual precipitation reconstruction from Conroy Lake, Maine, demonstrates this wetting trend over the past millennium, as does Clifford and Booth (2013)'s testate amoebae-based water-table depth reconstruction from Sidney Bog, Maine (Figures 3 and 11). However, Gajewski (1988)'s pollen-based annual precipitation reconstructions from Basin Pond, Maine, does not.  Wu et al. (2022) show a pronounced freshening in the Laurentian Channel in their dinocyst-based summer sea surface salinity (SSS) reconstruction during AD 1400-1800. However, this LIA wetting precipitation trend was less coherent in northern New England than the cooling temperature one was. Some compiled records demonstrate opposite or mixed trends as both rain and snow are more heterogenous over small spatial scales than temperature is (Shuman et al., 2018). In sum, our winter precipitation reconstruction follows a general northern New England pattern, suggesting that the shifts in forest composition at Fish Lake are also being driven in part by regional LIA wetting, as well as by the aforementioned regional cooling. Therefore, together the late Holocene cooling and wetting trends in the northern New England and New Brunswick regions appear to be driving the forest composition changes seen at Fish Lake.

A number of cautions must be raised with respect to the Fish Lake climate reconstructions. A major issue in doing climate reconstructions based upon modern pollen-climate calibration sets arises because human-caused landscape disturbance is so severe in much of the world (certainly in northern New England, the Maritimes, and southern Québec) that vegetation no longer reflects climate in the same way that it used to prior to this severe anthropogenic disturbance (Kujawa et al., 2016; St-Jacques et al., 2008, 2015). Hence, when transfer functions constructed using modern pollen-climate calibration sets are used for the inference of past climates of more pristine landscapes, unavoidable errors arise such as substantial climate signal bias and underestimation (St-Jacques et al., 2008, 2015). A further source of loss of sensitivity in our reconstructions arises from having to pool all *Picea*, all *Pinus*, all *Alnus* and all *Acer* species together, despite their different climate optima (Thompson et al., 2015) due to the low taxonomic resolution used by previous researchers whose compiled results from the pollen-climate calibration set (Whitmore et al., 2005). Despite issues existing with the precise values of our climate reconstructions, they are sufficiently reliable for comparison to the general patterns found in regional syntheses (e.g. Ladd et al., 2018; Marlon et al., 2017; Shuman et al., 2018).

## The rise of *Picea rubens*

Conditions for the arrival of *Picea rubens*, a pivotal species in the Acadian forest, might have become optimal during the LIA. Red spruces are long-lived, cold-adapted, shade-tolerant conifers which define the Acadian forest and have been a constant presence since European settlement (DeWolfe, Simard and Coon, 2005; Taylor et al, 2017). Hamburg and Cogbill (1988) identified warmer temperatures through the 1800s as a possible agonist reducing the populations of red spruce in New Hampshire, highlighting the species' intolerance of disturbances generally and warming specifically. This need for cooler temperatures has resulted in the emergence of refugia for this species; for this research, coastal Maine is the most significant (Schauffler and Jacobson, 2002). From these positions in Maine, genetic research done by Bashalkhanov et al. (2023) hints that red spruce may have hybridized with the hardier *Picea mariana* over time, giving red spruce the hardiness necessary to move inland towards the Fish Lake coring site.

Mott's (1975) hypothesis that the red spruce emerged in the inland Acadian forest between 1,000 – 2,000 years ago is supported partially by our pollen record, although the LIA was again a significant change factor insofar as red spruce populations appear to increase significantly during that time. Unfortunately, our record did not contain the first millennium AD. Paquette and Gajewski (2012) note an increase in *Picea* during the LIA in southwestern Quebec, as does O'Neill-Sanger (2021). Houle et al (2012) similarly reports an abundance of *Picea rubens* in the LIA and a corresponding decline in *Fagus grandifolia* in Charlevoix, Quebec, a result similar to this study. This study's results for *Picea rubens* support the claims by Schauffler and Jacobson (2002) that cooler temperatures in the last 1,000 years promoted the spread of *Picea rubens* outside of its coastal refugia. The available regional evidence is somewhat scarce but speaks broadly to a coniferous shift in regional forest compositions, while regional climate reconstructions generally describe conditions ideal for red spruce growth in the Acadian forest during the LIA (Marlon et al 2017; Wu et al, 2022).

## Pre-European fire dynamics of the Acadian forest at Fish Lake

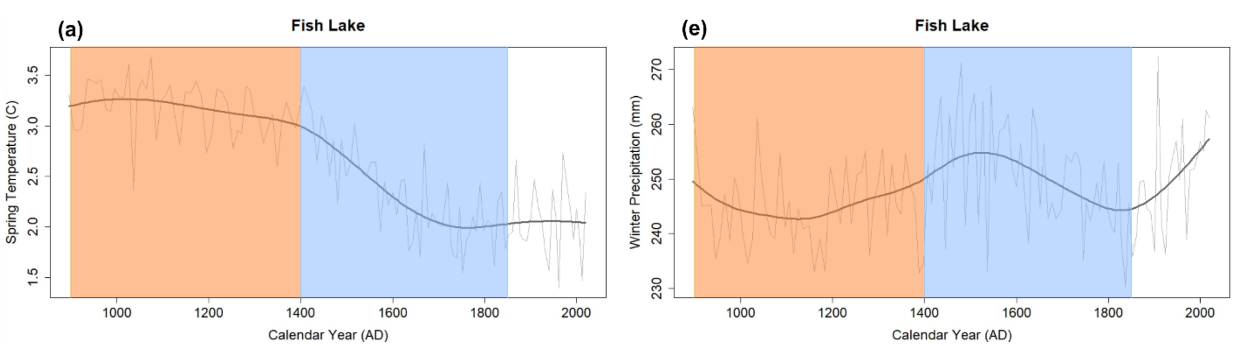
It has been argued that the Acadian forest of New Brunswick was simply too humid to experience naturally occurring wildfires in the last millennium (De Lafontaine and Payette, 2012). However, this study showed that the forest surrounding Fish Lake experienced frequent forest fires, especially in the LIA (Figure 10).

The MCA (AD 900-1400) at Fish Lake was characterized by warmer, drier regional conditions and a forest with a high proportion of hardwoods, particularly *Betula* and *Fagus* grandifolia (Figures 6 and 7). The fire record suggests fewer fires than in the MCA than in the LIA (AD 1400-1850) (Figure 10). The relative paucity of fires in the MCA compared to in the LIA is also supported by the lower amounts of *Alnus* pollen (a pioneer species indicating disturbance and a more open canopy) in the MCA than in the LIA (Figure 6). This is counterintuitive given the warmer, drier MCA identified by multiple regional climate reconstruction studies (Marlon et al 2017; Wu et al, 2022). A possible explanation is that the hardwood-heavy composition of the Acadian forest at this time limited the conditions conducive to fire, as deciduous trees are generally less combustible than conifers on account of the greater moisture content of their leaves vis-à-vis conifer needles (Park et al., 2024).

Long MCA fire intervals also suggest that local Indigenous populations were not widely using fire as a land clearance technique locally. This, together with the limited indications of land disturbance in the pollen record (Figure 6), further supports research by Betts and Hrynick (2021), suggesting that Indigenous populations in the area did not practice extensive land clearing.

## European impacts on the Acadian forest: the French regime

French explorers in the latter half of the LIA identified the presence of both the tree taxa that we found and forest fires in the Acadian forest, supporting our results. Nicolas Denys, the governor of the French Cape Breton Company, wrote in 1633 recounting the presence of "Oaks...[pines], [firs] of three sorts, [birches], [black birches], [aspens], [maples], [and ashes]" on the shores of what is now Annapolis Royal, Nova Scotia (Denys, 1908). In 1677, Father Leclercq commented on what was presumably the scars of a wildfire that had burned "two hundred and fifty leagues" near the modern community of Pabineau Falls, New Brunswick, noting that trees were blackened very high on their trunks (Hay, 1903).



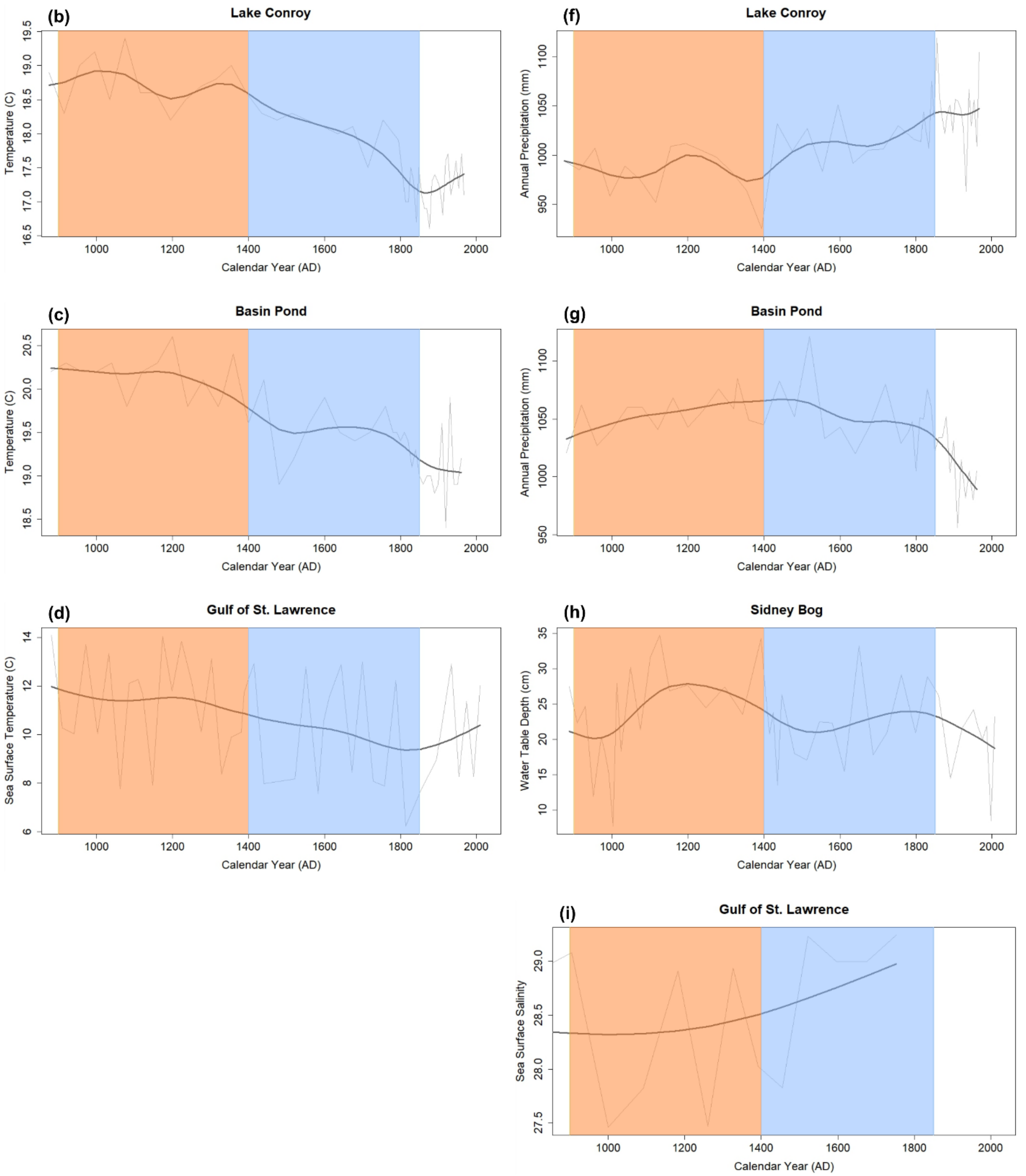



***Figure 11.*** *Lefthand side: reconstructed temperatures from high-resolution sites within 350 km of Fish Lake:* ***(a)*** *spring (MAM) temperature (°C) from this study,* ***(b)*** *mean summer (JJA) temperature (°C) from Conroy Lake, Maine (Gajewski, 1988),* ***(c)*** *mean summer (JJA) temperature (°C) from Basin Pond (Gajewski, 1988), and* ***(d)*** *summer sea-surface temperature (SST) (°C) from dinocyst assemblages in the Gulf of St. Lawrence (Wu et al., 2022). Righthand side: reconstructed moisture from nearby high-resolution sites:* ***(e)*** *winter (DJF) precipitation (mm/season) from this study,* ***(f)*** *annual precipitation (mm/yr) from Conroy Lake, Maine (Gajewski, 1988),* ***(g)*** *annual precipitation (mm/yr) from Basin Pond (Gajewski, 1988),* ***(h)*** *Sidney Bog, Maine, water table depth (cm) reconstruction residuals, with more negative residuals meaning wetter conditions (Clifford and Booth, 2013), and* ***(i)*** *summer sea-surface salinity (SSS) (psu) from dinocyst assemblages in the Gulf of St. Lawrence (Wu et al., 2022).*

The earliest surviving records of the population of the early French colonizers or Acadian settlers currently known come from the census of 1671, recording 392 colonists (Massignon, 1947) (Figure 12). The Acadians primarily relied on fishing and fur trading for sustenance until equipment and especially horses arrived, facilitating the earliest known timbering industry in what is now New Brunswick. Their first sawmill was constructed in 1692 and the eastern white pine industry for ship's masts started in 1695 (Hay, 1903). Our record's first *Ambrosia* pollen in AD 1680 appears to have captured early Acadian agriculture (Figure 6), potentially from Fort Nashwaak, an Acadian garrison constructed near modern Fredericton in 1692 (Parks Canada, 2025). Post-1715, the Acadian economy shifted more towards agriculture and the increasing population may have spread and amplified Acadian land disturbances. The expulsion of the Acadians from the region in 1755 resulted in the widespread burning of Acadian farms and a broader attempt to stamp out the Acadian identity (Hynes, 1973). It is possible that our 1733 fire is this 1755 burning, though proving this conclusively given dating uncertainty would be difficult (Figure 10). With the Acadians expelled from some of the best agricultural lands, the British began consolidating and stabilizing what would become known as New Brunswick in 1784. The wave of Loyalist refugees from New England after US independence, seeking new farms, received significant tracts of land that were once farmed by Acadians.

## European impacts on the Acadian forest: the British Colonial Period

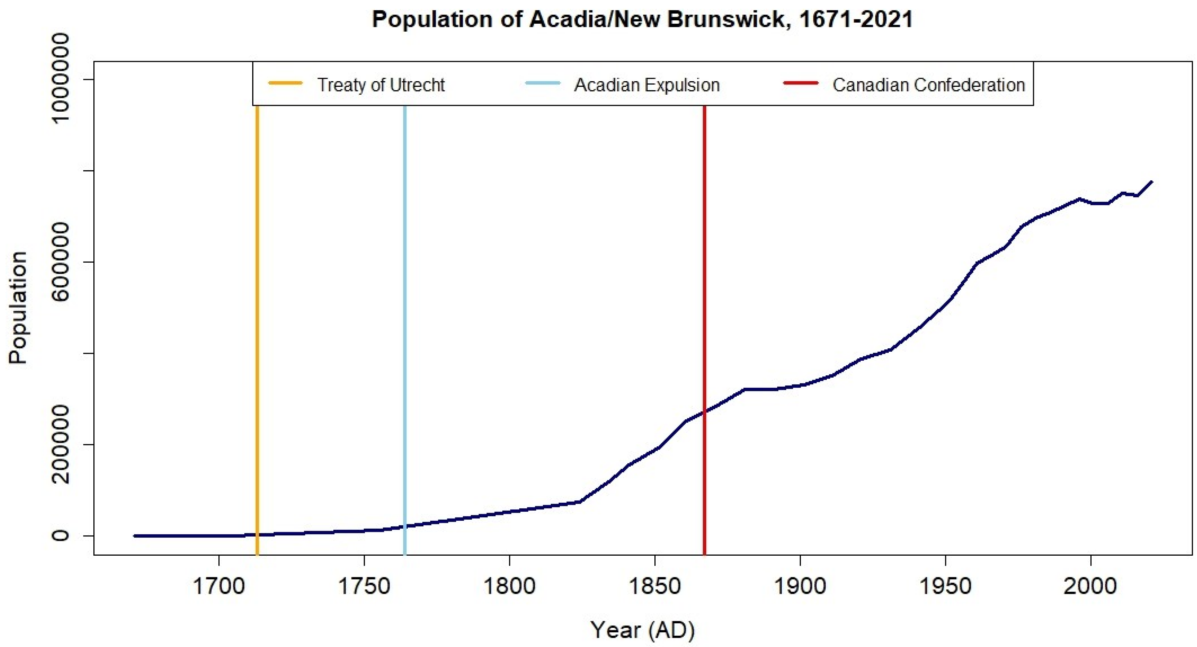



***Figure 12.*** *Population of Acadia and, later, New Brunswick, from the earliest surviving census in 1671 to 2021. The early data reflects the entire population of Acadia, which included modern Nova Scotia and sometimes modern Prince Edward Island. The major population increase starting after 1755 and continuing through the 19th century coincides with the timbering boom in the province and with the onset of the British colonial period (Statistics Canada; Massignon, 1947; Caroline-Isabelle, 2015).*

Newly created New Brunswick marked a turning point for the anthropogenic disturbance regime impacting the Acadian forest. Witness tree data from early British land surveyors in the nearby Miramichi basin identified spruce, birch, and fir as the common trees of the pre-Colonial regional forest (Aubé, 2008). At Fish Lake, disturbance indicators Poaceae, *Ambrosia* and other herbs reach their highest relative abundances and influxes in this period, as do pioneer successional *Alnus rugosa* and *A. crispa* (Figures 6 and 7). The population of the British colony increased significantly with the arrival of American Loyalists and a more diversified economy, increased exploitation of regional natural resources, and a rapid expansion of timbering and shipbuilding operations occurred (Figure 12). By 1835, major stands of eastern white pine were largely deforested (Austin, 1980). Timbering continued to adapt through-out the 19$^{th}$ century, with an opening of the American market to colonial timber products (Parenteau 2013). Sawmills opened and closed through the 1800s (Austin, 1980), and by the beginning of the 20th century hydroelectric projects further industrialized New Brunswick's timbering operations. This growth of both population and forestry in New Brunswick thus accelerated the transformation of the Acadian forest in a manner concurrent with the borealization hypothesis posited by Noseworthy and Beckley (2020).

In Fredericton, the present-day provincial capital located 28 km from Fish Lake, English settlement began in 1785 with its establishment as an administrative capital and garrison town and continued as the city's logging industry grew. Like much of the rest of New Brunswick, Fredericton experienced cycles of booms and busts in the timbering industry and a surging population (Austin, 1980). Fredericton's industrialization continued through the 1880s, epitomized by the city's Gibson sawmill empire, and slowed by the dawn of the 20th century.

Several major fires during the English colonial period were visible in our charcoal record. The 1825 Miramichi fire burned one fifth of the province and was the largest forest fire in recorded northeastern North America (CBC News, 2020). Our study's 1818 fire likely corresponds to it (Figure 10c). In Fredericton, the Gibson sawmill burned down in a major fire in 1893, which our charcoal record records as occurring in this year. Major fires in Saint John, New Brunswick, took place in 1816, 1823, 1841, 1845, 1847, and 1871 (Stewart, Jr., 1877). Hence, historical records in New Brunswick contain ample record of fires in the 1800s, likely explaining the increase in background charcoal found in the charcoal record (Figure 10c).

## Conclusions

Our study showed that the Acadian forest at Fish Lake, New Brunswick, underwent a compositional shift from a mix of hardwoods and softwoods in the MCA to a more softwood-dominated forest in the LIA. Mott (1975)'s hypothesis that *Picea rubens* arrived in the interior of the Acadian forest as a minor species between 1,000-2,000 years ago is probably true, but the emergence of *P. rubens* as a major species at our site appeared to occur within the last 600-700 years. Our terrestrial climate reconstruction affirmed the regional temperature shifts found by Wu et al. (2022) offshore in the Gulf of the St. Lawrence and Marlon et al. (2017) in their New England synthesis, by showing a warmer, drier MCA and a cooler, wetter LIA. Our charcoal study shows that the role of fire in shaping the Acadian forest appears to have been much greater than previously expected by De Lafontaine and Payette (2012). With fires being more frequent in the wet LIA than the dry MCA, the results suggest that the shift in forest composition from mixed deciduous/coniferous to coniferous played a greater role in intensifying the fire regime of the Acadian forest than temperature change did. The relationship between fire and vegetation in the Acadian forest is informed by the increasing quantity of conifers, which burn more readily than harder deciduous trees.

This study also demonstrated the impacts of human habitation on the Acadian forest. A lack of palynological and charcoal evidence in the pre-European contact record supports the existing archaeological consensus that the Maliseet and Mi’kmaq populations did not practice agriculture that required land clearance (Betts and Hrynick, 2021). Evidence of Acadian colonization include the first sighting of *Ambrosia* pollen circa 1680 and a rise in early successional species such as *Alnus* and herbaceous pollen, while an increase in the number of fires recorded in the 19$^{th}$ century can be plausibly connected to the historical fire record of the timber industry in post-Expulsion New Brunswick. A decline in *Pinus strobus* beginning in the 17$^{th}$ century might correspond to the harvesting of mast pines coveted by both French and British colonizers. Our record furthers existing consensus on the long history of the Acadian forest, including its early modification by European settlers.

## References


Alley, R. B. and Ágústsdóttir, A. M. (2005). The 8k event: cause and consequences of a major Holocene abrupt climate change. *Quaternary Science Reviews*, *24*(10), 1123–1149

Anderson, T. W. (1980). Holocene vegetation and climatic history of Prince Edward Island, Canada. *Canadian Journal of Earth Sciences*, *17*(9), 1152–1165

Aquino-Lopez, M.A., Blaauw, M., Christen, J.A., Sanderson, N., 2018. Bayesian analysis of 210Pb dating. *Journal of Agricultural, Biological, and Environmental Statistics* 23, 317-333

Aubé, M. (2008). The pre-European settlement forest composition of the Miramichi River watershed, New Brunswick, as reconstructed using witness trees from original land surveys. *Canadian Journal of Forestry Research* 38, 1159-1183

Austin, W. (1980). History of Fredericton: the Last 200 Years. Centennial Print and Litho, Ltd., Fredericton, New Brunswick

Barsanti, M. et al (2020). Challenges and limitations of the $^{210}$Pb sediment dating method: Results from an IAEA modelling interlaboratory comparison exercise. *Quaternary Geochronology* 59. https://doi.org/10.1016/j.quageo.2020.101093.

Bashalkhanov, Stanislav, Johnson, Jeremy, and Rajore, Om (2023). Postglacial phylogeography, admixture, and evolution of red spruce (*Picea rubens* Sarg.) in Eastern North America. *Frontiers in Plant Science* 12(14)

Bassett, John, Crompton, Clifford, and Parmalee, John (1978). *An atlas of airborne pollen grains and common fungus spores of Canada*. Agriculture Canada: Ottawa

Bennett, K. D. and Fuller, J.L. (2002). Determining the age of the mid-Holocene *Tsuga canadensis* (hemlock) decline, eastern North America. *The Holocene* 12, 421-429

Benninghoff, W. S. (1962). Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities. *Pollen and Spores* 4, 332–33

Betts, M. W. and Hrynick, M. G. (2021). *The Archaeology of the Atlantic Northeast*. Toronto: University of Toronto Press

Bonny, A.P. (1972). A method for determining absolute pollen frequencies in lake sediments. *New Phytologist* 71, 393-405

Borns, Jr., H. and Maasch, K. (2015). *Foot Steps of the Ancient Great Glacier of North American: A Long Lost Document of a Revolution in 19th Century Geological Theory*. Springer International: Cham, Switzerland

Brooke, J. (2014). *Climate Change and the Course of Global History: A Rough Journey (Studies in Environment and History).* Cambridge: Cambridge University Press

Burrell, B. C. and Anderson, J. E. (1991). Regional hydrology of New Brunswick. *Canadian Water Resources Journal* 16(4), 317-330

Canham, C. (2020). *Forests Adrift: Currents Shaping the Future of Northeastern Trees*. Yale University Press, New Haven, Connecticut

Caron, Caroline-Isabelle (2015). The Acadians: Immigration and Ethnicity in Canada Series. Canadian Historical Association: Ottawa

CBC News, Oct 07, (2020). The Great Miramichi Fire may be the biggest forest fire ever, but few have heard of it. https://www.cbc.ca/news/canada/new-brunswick/nb-author-great-miramichi-fire-remember-1.5751761

Clayden, S.R., Cameron, R.P., McCarthy, J.W. (2011). Perhumid Boreal and Hemiboreal Forests of Eastern Canada. In: Temperate and Boreal Rainforests of the World: Ecology and Conservation. Island Press, Washington, D.C.

Clifford, M.J. and Booth, R.K. (2013) Increased probability of fire during late Holocene droughts in northern New England. *Climate Change* 119: 693–704

Colpitts, M. C., Fahmy, Sherif H., MacDougall, J. E., Ng, Tom T. M., McInnis, B. G. and Zelazny, V. F. (1995). Forest Soils of New Brunswick. Agriculture and Agri-Food Canada

Crawford, Alastair and Belcher, Claire (2014). Charcoal morphometry for paleoecological analysis: The effects of fuel type and transportation on morphological parameters. *Applications in Plant Sciences* 2(8)

Davis, R. B., Norton, St. A., Kuhns, C. M. and Halteman, W. A. (2021). A natural history of northern Maine, USA, since Deglaciation. *Northeastern Naturalist* 28(19), 1-77

Davis, M. B. (1981). Outbreaks of forest pathogens in Quaternary history. Proceedings IV International Palynological Conference, Lucknow (1976-77), 3, 216-227

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

De Lafontaine, G. and Payette, S. (2012). How climate and fire disturbances influence contrasted dynamics of *Picea glauca* ecotones at alpine tree lines in Atlantic and continental eastern North America. In *Ecotones Between Forest and Grassland*, ed. Randall W. Myster

Denys, N. (1908). *The description and natural history of the coasts of North America (Acadia)*. The Champlain Society: Toronto

Dewolfe, K., Simard, I. and Coon, D. (2005). *Our Acadian forest in Danger: the State of Forest Diversity and Wildlife Habitat in New Brunswick*. Conservation Council of New Brunswick: Fredericton

Fægri, K., Iversen, J., Kaland, P., and Krzywinski, K. (1989). Textbook of pollen analysis, fourth edition. Blackburn Press, Caldwell, New Jersey

Fagan, B. (2002). *The Little Ice Age: How Climate Made History, 1300-1850*. Basic Books: New York

Farr, K. (2003). *The Forests of Canada*. Natural Resources Canada, Canadian Forest Service: Ottawa

Filion, L. and Quinty, F. (1993). Macrofossil and tree-ring evidence for a long-term forest succession and mid-Holocene hemlock decline. *Quaternary Research* 40(1), 89-97

Foster, W. C. (2012). *Climate and Culture Change in North America AD 900-1600*. Austin: University of Texas Press

Gajewski, Konrad (1988). Late Holocene climate changes for eastern North America estimated from pollen data. *Quaternary Research* 29, 255-262

Ghaleb, B. (2009). Overview of the methods for the measurement and interpretation of short-lived radioisotopes and their Limits." IOP Conference Series: Earth and Environmental Science 5 (January)

Griffiths, N. E. S. (2005). *From migrant to Acadian: a North American border people, 1604-1755*. Kingston: McGill-Queen's University Press

Hamburg, Steven and Cogbill, Charlie (1988). Historical decline of red spruce populations and climatic warming. *Nature* 331(4), 428-431

Hay, G. U. (1903). A History of New Brunswick, W. J. Gage Co., Toronto

Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology 25, 101–110

Higuera, P.E., Brubaker, L.B., Anderson, P.M., Hu, F.S. and Brown, T.A. (2009a). Vegetation mediated the impacts of postglacial climatic change on fire regimes in the south-central Brooks Range, Alaska. *Ecological Monographs* 79, 201-219

Higuera, P.E. (2009b) CharAnalysis 0.9: Diagnostic and analytical tools for sediment-macrocharcoal analysis. Available at: https://github.com/phiguera/CharAnalysis (accessed October, 2023).

Houle, D., Richard, P. J. H., Ndzangou, S. O. and Richer L. (2012). Compositional vegetation changes and increased red spruce abundance during the Little Ice Age in a sugar maple forest of north-eastern North America. *Plant Ecology* 213, 1027-1035

Hunt, B. G. (2006). The Medieval Warm Period, the Little Ice Age and simulated climatic variability. *Climate Dynamics* 27, 677-694

Hynes, Gisa (1973). *Some Aspects of the Demography of Port Royal, 1650-1755*. Acadiensis 3(1), 3-17

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

Juggins, Steve (2024). Rioja: Analysis of Quaternary Science Data. https://cran.r-project.org/web/packages/rioja/rioja.pdf

Kelly, Ryan, Higuera, Philip, Barrett, Carolyn, and Hu, Feng Sheng (2011). Short Paper: A signal-to-noise index to quantify the potential for peak detection in sediment-charcoal records. *Quaternary Research* 75(1), 11-17

Kottek, M., Grieser, J., *Beck, C., Rudolf, B., and Rubel, F. (2006). World map of the K*öppen-Geiger climate classification updated. *Meteorologische Zeitschrift* 15(3), 259-263

Kujawa, E.R., Goring, S., Dawson, A., et al. (2016) The effect of landcover change on pollen-vegetation relationships in the American Midwest. Anthropocene 15: 60–71

Ladd, M., Viau, A.E., Way, R.G., Gajewski, K. and Sawada, M.C. (2018). Variations in precipitation in North America during the past 2000 years. *The Holocene* 28(4), 667-675

Levesque, A. J., Mayle, F. E., Walker, I. R., and Cwynar, L. C. (1993). A previously unrecognized late-glacial cold event in eastern North America. *Nature* 361(6413), 623-626

Lindbladh, M., O'Connor, R., and Jacobson Jr., G. L. (2002). Morphometric analysis of pollen grains for paleoecological studies: classification of *Picea* from eastern North America. *American Journal of Botany*, 89(9), 1459–1467

Lindbladh, M., Jacobson Jr., G.L., and Schauffler, M. (2003). The postglacial history of three Picea species in New England, USA.*, Quaternary Research*, 59(1), 61–69

Marlon, J. R., Pederson, N., Nolan, C., Goring, S., Shuman, B., Robertson, A., Booth, R., Bartlein, P. J., Berke, M. A., Clifford, M., Cook, E., Dieffenbacher-Krall, A., Dietze, M. C., Hessl, A., Hubeny, J. B., Jackson, S. T., Marsicek, J., McLachlan, J., Mock, C. J. et al. (2017). Climatic history of the northeastern United States during the past 3000 years. *Climate of the Past*, *13*, 1355–1379

Marsicek, J.P., Shuman, B., Brewer, S., Foster, D.R., and Oswald, W.W. (2013). Moisture and temperature changes associated with the mid-Holocene *Tsuga* decline in the northeastern United States. *Quaternary Science Reviews*, 80, 129-142.

Massignon, Genevieve (1947). Les parlers francais d'Acadie. *The French Review* 21(1), 45-53

Mayle, F. E., Levesque, A. J. and Cwynar, L. C. (1992). Accelerator-mass-Spectrometer ages for the Younger Dryas Event in Atlantic Canada. *Quaternary Research* 39, 355-360

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

Mayle, F. E. and Cwynar, L. C. (1995). A review of multi-proxy data for the Younger Dryas in Atlantic Canada. *Quaternary Science Reviews* 14, 813-821

McAndrews, J. H., Berti, A. A., and Norris, G. (1973). Key to the Quaternary pollen and spores of the Great Lakes region: Toronto, Royal Ontario Museum, Misc. Publications

Molinari, Chiara, Lehsten, Veiko, Blarquez, Olivier, Carcaillet, Christopher, Davis, Basil, Kaplan, Jed, Clear, Jennifer, and Bradshaw, Richard (2018). The climate, the fuel, and land use: Long-term regional variability of biomass burning in boreal forests. *Global Change Biology* 24(10), 4929-4945

Moore, P. D., Webb, J. A. and Collinson, M. E. (1991). *Pollen Analysis*. Blackwell Scientific Publications, Oxford

Mosseler, A., Lynds, J.A. and Major, J.E. (2003). Old-growth forests of the Acadian forest region. *Environmental Review* 11(1), 47-77

Mott, R. (1975). Palynological studies of lake sediment profiles from southwestern New Brunswick. *Canadian Journal of Earth Sciences* 12(2), 273-288

Mott, R. J. (1977). Late-Pleistocene and Holocene palynology in southeastern Québec. *Géographie Physique et Quaternaire* 31(1-2), 139-149

Mott, R. J., Grant, D. R., Stea, R. and Occhietti, S. (1986). Late-glacial oscillation in Atlantic Canada equivalent to the Allerød /younger Dryas event. *Nature* 323, 247-250

Neukom, R., Steiger, N., Gómez-Navarro J. J., Wang, J. and Werner, J. P. (2019). No evidence for globally coherent warm and cold periods over the preindustrial common era. *Nature: International Weekly Journal of Science*, *571*(7766), 550–554

Noseworthy, J. and Beckley, T. M. (2020). Borealization of the New England – Acadian forest: a review of the evidence. *Environmental Review* 28, 284-293

Noss, R. (2023). New England-Acadian forests. *One Earth*, accessed 12 June 2023 from https://www.oneearth.org/ecoregions/new-england-acadian-forests/

O'Neill-Sanger, C.E., J.M. St-Jacques, M. Peros and K.A. Schwartz (2021). Reconstructed high-resolution forest dynamics and human impacts for the past 2300 years from the *Parc national du Mont-Orford,* southeastern Québec, Canada. *Holocene*, 31, 1019-1032

Oswald, W. W. et al. (2018). Subregional variability in the response of New England vegetation to postglacial climate change. *Journal of Biogeography* 45, 2375-2388

Pace, A.V., J.M. St-Jacques, D.D. Noel and G. Fortin (2025). Filling the Atlantic coastal tree-ring reconstruction gap: A 195-year record of growing season discharge of the Sainte Anne River, Gaspésie, Québec, Canada. *Journal of Hydrology Regional Studies,* 58

Paquette, Nathalie and Gajewski, Konrad (2013). Climatic change causes abrupt changes in forest composition, inferred from a high-resolution pollen record, southwestern Quebec, Canada. *Quaternary Science Reviews* 75, 169-180

Parenteau, Bill (2013). *Looking Backward, Looking Ahead: History and Future of the New Brunswick Forest Industries*. Acadiensis 42(2), 92-113

Park, Juhan, Moon, Minkyu, Green, Tristan, Kang, Minseok, Cho, Sungsik, Lim, Joongbin, and Kim, Su-Jin (2024). *Impact of tree species composition on fire resistance in temperate forest stands*. Forest Ecology and Management 572(15), 1-8

Parks Canada, no date. Fort Nashwaak (Naxoat) National Historic Site of Canada. https://www.pc.gc.ca/apps/dfhd/page_nhs_eng.aspx?id=168

Peros, M., Chan, K., Magnan, G., Ponsford, L., Carroll, J. and McCloskey, T. (2016). A 9600-year record of water table depth, vegetation and fire inferred from a raised peat bog, Prince Edward Island, Canadian Maritimes. *Journal of Quaternary Science*, *31*(5), 512–525

Perschel, R. T., Giffen, R. A. and Lowenstein, F. (2014). *New England Forests: The Path to Sustainability*. New England Forestry Foundation, Littleton, MA

Petersen, James B and Sidell, Nancy Asch (1996). Mid-Holocene Evidence of Cucurbita Sp. from Central Maine. *American Antiquity* 61(4), 685-698

Philbrick, T. C. and Bogle, L. A. (1981). The pollen morphology of the native New England species of the genus *Acer* (Aceraceae). *Rhodora* 83(834), 237-258

Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Ramsey, C. B., et al. (2020). The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon, 62(4), 725–757

Remy, Cécile, Lavoie, Martin, Girardin, Martin, Hély, Christelle, Bergeron, Yves, Grondin, Pierre, Oris, France, Asselin, Hugo, and Ali, Adam (2017). *Wildfire size alters long-term vegetation* *trajectories in boreal forests of eastern North America*. Journal of Biogeography 44. 1268-1279

Richard, P. (1970). *Atlas pollinique des arbres et de quelques arbustes indigènes du Québec*. *Naturaliste Canadien* 97(1), 1-306

Schauffler, M. and Jacobson, G. L. Jr. (2002). Persistence of coastal spruce refugia during the Holocene in Northern New England, USA, detected by stand-scale pollen stratigraphies. *Journal of Ecology* 90, 235-250

Shuman, B. N., and Marsicek, J. P. (2016). The structure of Holocene climate change in mid-latitude North America. *Quaternary Science Reviews*, 141, 38–51

Simpson, G.L. (2012) Analogue methods in paleolimnology. In: Birks HJB, Lotter AF, Juggins S, et al. (eds) Tracking Environmental Change Using Lake Sediments. Developments in Paleoenvironmental Research 5, Dordrecht: Springer Netherlands, pp.495–522

St. Jacques, J.M., B.F. Cumming and J.P. Smol. (2008) A 900-year pollen-inferred temperature and effective moisture record from varved Lake Mina, in west-central Minnesota, USA. *Quaternary Science Reviews,* 27: 781-796

St. Jacques, J.M., Cumming, B.F., Sauchyn , D.J., and Smol, J.P. (2015) The bias and signal attenuation present in conventional pollen-based climate reconstructions as assessed by early climate data from Minnesota. *PLoS-ONE*, 10(1)

Statistics Canada. Censuses of Canada 1665 to 1871. https://www150.statcan.gc.ca/n1/pub/98-187-x/4064809-eng.htm

Stewart Jr., George (1877). "The story of the great fire in St. John, N.B., June 20th, 1877". Belford Brothers: Toronto

Tardif, J., Brisson, J., and Bergeron, Y. (2001) Dendroclimatic analysis of *Acer saccharum, Fagus grandifolia*, and *Tsuga canadensis* from an old-growth forest, southwestern Quebec. *Canadian Journal of Forest Research* 31(9): 1491–1501

Taylor, Anthony, Boulanger, Yan, Price, David, Cyr, Dominic, McGarrigle, Elizabeth, Rammer, Wener, and Kershaw Jr., John (2017). Rapid 21st century climate change projected to shift composition and growth of Canada's Acadian Forest Region. *Forest Ecology and Management* 405, 284-294

Thompson, R.S., Anderson, K.H., Pelltier, R.T., et al. (2015) Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America—revisions for all taxa from the United States and Canada and new taxa from the western United States. U.S. Geological Survey Professional Paper 1650–G, DOI: 10.3133/pp1650G

Van Buuren, Stef (2023). *Broken Stick Model for Irregular Longitudinal Data*. Journal of Statistical Software 106(7)

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

Webb, T. III, Bartlein, P., Harrison, S. P. and Anderson, K. H. (1993). "Vegetation, lake levels, and climate in eastern North America for the past 18,000 years." In *Global Climates since the*

*Last Glacial Maximum*, ed. Wright, H.E., Kutzbach, J.E., Webb, T. III, Ruddiman, W. F., Street-Perrott, F. A., and Bartlein, P. J. Minneapolis: University of Minnesota Press

Wells, J. V., Dawson, N., Culver, N., Reid, F. A. and Siegers, S. M. (2020). The state of conservation in North America's boreal forests: issues and opportunities. *Frontiers in Forests and Global Chance* 3(90), 1-18

Whitmore, J., Gajewski K, Sawada M et al. (2005) Modern pollen data from North America and Greenland for multi-scale paleoenvironmental applications. *Quaternary Science Reviews* 24(16–17): 1828–1848

Wicklund, R. E. and Langmaid, K. K. (1953). *Soil Survey of Southwestern New Brunswick*. Ottawa: Canada Department of Agriculture

Wu, Xiner, de Vernal, Anne, Fréchette, Bianca, Moros, Matthias, & Perner, Kerstin (2022). The signal of climate changes over the last two millennia in the Gulf of St. Lawrence, eastern Canada. *Quaternary Research*, *106*, 28–43. doi:10.1017/qua.2021.56

Yelloff, Dan, Bennett, Keithe, Blaauw, Maarten, Mauquoy, Dmitri, Sillasoo, Ülle, van del Plicht, Johannes, and van Geel, Bas (2006). High precision $^{14}C$ dating of Holocene peat deposits: A comparison of Bayseian calibration and wiggle-matching approaches. *Quaternary Geochronology* 1(3), 222-235

## Final Conclusions

Our study showed that the MCA and LIA had a significant impact on the vegetation and composition of the Acadian forest. Mott (1975)'s hypothesis that *Picea rubens* arrived in the interior of the Acadian forest as a minor species between 1,000-2,000 years ago is likely true, but the emergence of *P. rubens* as a major species at our site appeared to occur within the last 600-700 years. Our terrestrial climate reconstruction affirmed the regional temperature shifts found by Wu et al. (2022) offshore in the Gulf of the St. Lawrence and Marlon et al. (2017) in their New England synthesis research, by showing a warmer, drier MCA and a cooler and a wetter LIA. Our charcoal study shows that the role of fire in shaping the Acadian forest appears to have been much greater than previously expected by De Lafontaine and Payette (2012). Because the fact that fires were more frequent the wet LIA than the dry MCA suggests that the shift in forest composition from mixed deciduous/coniferous to coniferous played a greater role in intensifying the fire regime of the Acadian forest than temperature change did.

This study also demonstrated the impacts of human habitation on the Acadian forest. A lack of palynological and charcoal evidence in the pre-European contact record supports the existing archaeological consensus that the Maliseet and Mi'kmaq populations did not practice agriculture that required land clearance (Betts and Hrynick, 2021). Evidence of Acadian colonization include the first sighting of *Ambrosia* pollen circa 1680 and a rise in early successional species such as *Alnus* and herbaceous pollen, while an increase in the number of fires recorded in the 19$^{th}$ century can be plausibly connected to the historical fire record of the timber industry in post-Expulsion New Brunswick. The fire record in this period also supports written reports of burnt portions of the Acadian forest in the 17$^{th}$ century. A decline in *Pinus strobus* beginning in the 17$^{th}$ century might correspond to the harvesting of mast pines coveted by both French and British colonizers. The 20th century record and its significant increase in herbage completes a record that underscores the complex relationship between vegetation, fire, and land use patterns.

Additionally, this research points to the validity of high-resolution coring. The written and derived charcoal records can be compared against one another; while exact dating of specific charcoal events and identifying causes of fires cannot be done with charcoal records, the resolution of these records, particularly in conjunction with written records, provides evidence that the recorded fires are indeed forest fires. Connecting timbering records to palynological records presents additional challenges that are beyond the scope of this research project, but the decline in mast pines and compositional shifts that correspond to population increase suggest the potential utility of such a research project.