# TREE-RING RECONSTRUCTION OF ISLAND AND MAINLAND FIRE EVENTS ALONG A HISTORIC CANOE TRAVEL CORRIDOR IN MINNESOTA'S BOUNDARY WATERS WILDERNESS

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## DEDICATION

> Taken apart and offered for inspection, the Quetico-Superior doesn't hold up very well. It lacks the grandeur of Yellowstone, the mystery of the Everglades, the drama of Acadia or the serenity of Denali…. Put together, however, and experienced as an interconnected web of geological, biological, and cultural features, the Quetico-Superior takes on new life. More than the sum of its parts, the region transcends its value as a stage for two-week vacations or a laboratory for scientists and resource managers. It becomes a vital presence…it works slowly on one's psyche. It gets into one's blood. Into one's soul. It deserves more than abstract management plans and impact studies. It deserves a respect and a love seasoned with wisdom.
>
> —Craig Blacklock, *Border Country: Photographs from the Quetico-Superior Wilderness*

This thesis is dedicated to the memory of Dr. Miron "Bud" Heinselman, the scientist, scholar, and wilderness advocate whose passion for learning and sharing knowledge with others has changed the way many perceive Minnesota's premier natural area – the Boundary Waters Canoe Area Wilderness.

## ABSTRACT

Tree-rings of ancient, well-preserved red pine (*Pinus resinosa*) stumps provide an exceptional opportunity to examine the proto-historic fire frequencies of red pine stands in the Quetico-Superior region of northern Minnesota and northwest Ontario. The primary purpose of this research undertaking has been to determine the level of human influence on fire occurrence along a historic canoe travel corridor in Minnesota's Boundary Waters Canoe Area Wilderness (BWCAW). I approached this research challenge by testing three research questions in a small portion of the naturally fragmented BWCAW landscape. First, can island fire frequencies be explained by rates of lighting-ignited fire occurrence alone? Second, are surface fires within the focus area synchronous in time and space? And third, are local surface fires significantly associated with patterns of regional drought?

I developed spatially explicit and annually resolved records of surface fires using dendrochronological methods, with 71 stump cross-sections from a ≈ 2,170 hectare study area on the islands of eastern Lac La Croix (centered at 48°18'08"N, 92°03'15"W). Between 1590 and 2010 there were 79 separate fires within the study area recorded by tree-rings. All but two of the reconstructed fires occurred before 1922. Sixty-one fires were recorded at single sites with the other 18 burning at 2-5 sample sites. Ten of the 79 fires were recorded at both mainland and island sites. In the same area, from 1929 to 2010, thirteen lightning-ignited fires have been detected and suppressed by the Superior National Forest (only two in island settings).

When comparing the conservative, tree-ring reconstructed estimate of pre-modern

fire occurrence and the nearly 100% complete modern lighting-caused fire record (1929 - present), there is a noticeable change in the distribution and frequency of fires within the study area. The tree-ring reconstructed fires are spatially and temporally asynchronous and, as a whole, are not strongly associated with regional drought ($p > 0.05$). My results suggest that proto-historic Ojibwe land use activities in this part of the Boundary Waters landscape likely contributed to the frequency of proto-historic fire occurrence. These findings have important and direct implications for fire and wilderness management practices in the BWCAW and the greater Quetico-Superior region.

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# CHAPTER 1

## Thesis Overview

## INTRODUCTION

The Quetico-Superior of northern Minnesota and northwest Ontario is an excellent example of a fire-adapted ecosystem. No other natural disturbance agent has had a greater role in determining the composition, structure, and distribution of vegetation across the region's terrestrial landscape (Ahlgren & Ahlgren 1960, Ohmann & Ream 1971). The Quetico-Superior is an ecotone where the temperate-deciduous forests of central Minnesota transition to the vast taiga of northern Ontario. Water is a dominant feature in the region with abundant lakes, rivers, and streams – many navigable by boat – dissecting the densely forested landscape. The region contains a conglomeration of federally managed natural areas encased by numerous other state, crown, and tribal lands stretching from the western shore of Lake Superior to Lake of the Woods. The collective of natural areas includes Minnesota's Superior National Forest (≈ 1,214,057 ha), Voyageurs National Park (≈ 88,243 ha), Grand Portage National Monument (≈ 121 ha), Ontario's Quetico Provincial Park (≈ 477,529 ha), and Le Verendrye Provincial Park (≈ 18,280 ha). The core of the Quetico-Superior includes roughly 916,208 hectares of mostly unbroken wilderness, which includes the Superior National Forest's Boundary Waters Canoe Area Wilderness or BWCAW (≈ 438,679 ha) and Quetico Provincial Park. When combined, these protected natural areas are the largest designated wilderness area east of the Rocky Mountains (Figure 1.1). The Quetico-Superior's proximity to large

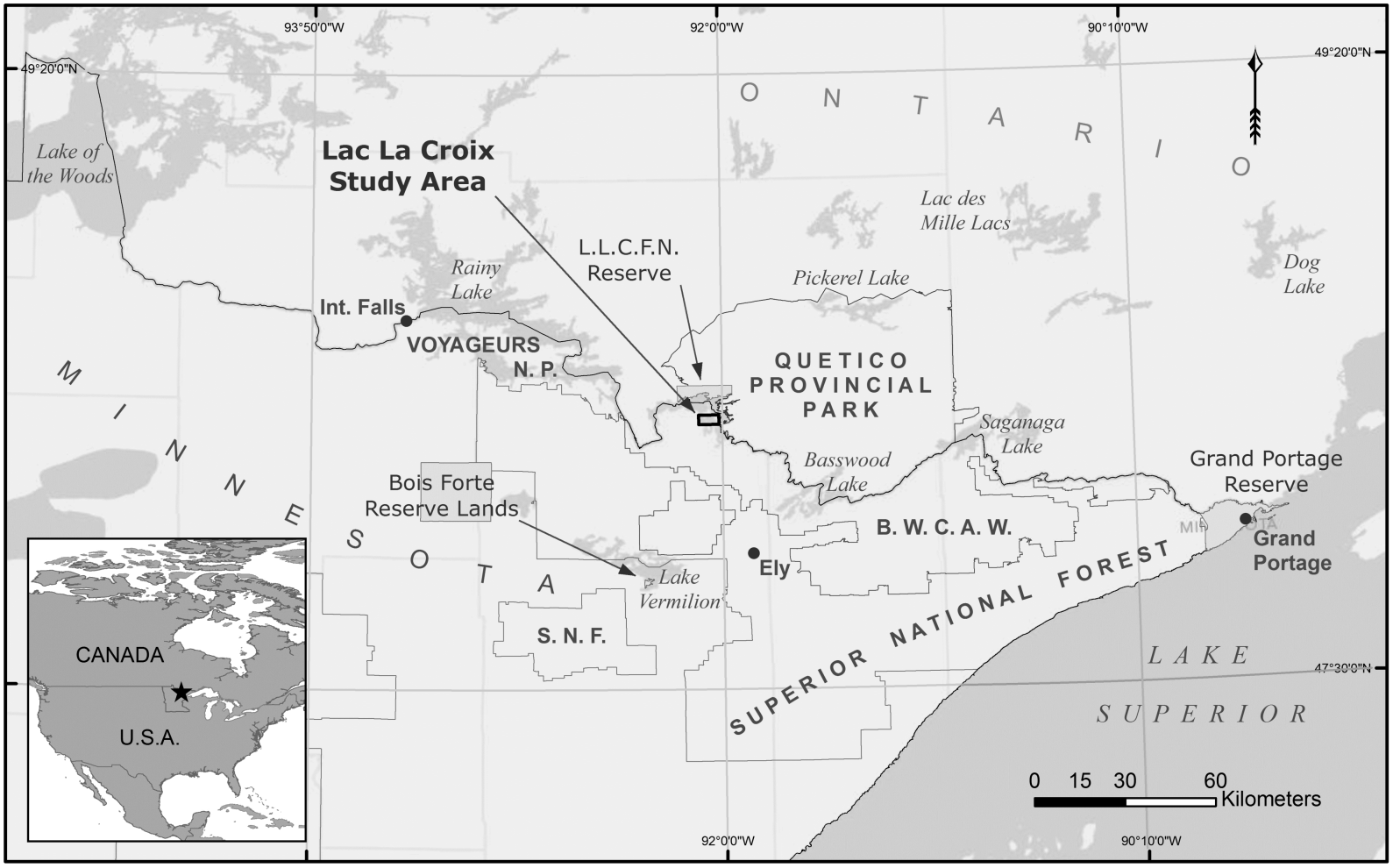



**Figure 1.1**: Map of the Quetico-Superior region including the Boundary Waters Canoe Area Wilderness and Quetico Provincial Park.

metropolitan areas, like Minneapolis-St. Paul and Chicago, also makes the BWCAW the most visited wilderness in the United States (SNF website 2012).

### *Research Motivation*

Successful stewardship of the modern Quetico-Superior landscape hinges upon the development and implementation of ecologically sound and socially acceptable fire management practices. Current fire management objectives within the BWCAW and Quetico Provincial Park are designed to maintain, within the bounds of public safety, fire as a critical natural process (USFS 2004) and restore ecological integrity to the system (Quetico 2009). Despite these management objectives, it remains unclear what constitutes a natural fire regime in many portions of the Quetico-Superior landscape.

The environmental impacts of long-term aboriginal subsistence strategies, particularly through fire use, could have long-lasting legacies that remain present in portions of the Quetico-Superior's landscape. Prior to the 20$^{th}$ century, human ignitions may have overridden climate and lightning controlled fire regimes, in particular places, to create a complex and patchy forest mosaic with mixed-age stands of timber and an abundance of early-successional species. Therefore, the determination of early cultures' effects on fire regimes in the Quetico-Superior is critically important for long-term fire management within the region's natural areas. If indigenous groups were active participants in augmenting pre-modern fire frequencies, passive fire management activities may be insufficient to preserve the present character of many portions of the present day Quetico-Superior. For example, lightning-ignited fires alone could be too

infrequent or severe to restore or maintain the landscape configurations representative of a healthy ecosystem (based on the region's historic range of variability; Callicott et al. 1999). This might suggest instead that more active fire management programs that emulate aboriginal propagation of fire are needed to meet management objectives. This assumes the preferred condition of the primary-growth forests of the Quetico-Superior region includes, at some level, the historic role of indigenous hunter-gather cultures on fire regimes (e.g. fire frequency, seasonality, and intensity) and subsequent vegetation compositions, patterns, and structures.

***Research Background***

Fire history research by forest ecologist Miron Heinselman in the late 1960s and early 1970s laid an exceptional baseline for understanding the history of fire in the Quetico-Superior. Heinselman's work primarily documented the history of stand-replacing fire events over the Boundary Waters Canoe Area Wilderness in its entirety (Figure 1.2), but left open several questions critical to best managing the wilderness and restoring fire as an important ecosystem service. Heinselman and Wright, in their preface to a 1973 volume of *Quaternary Research* dedicated to fire history and restoration, emphasized the "…need to understand more thoroughly the relative roles of lightning and man as fire factors in the primeval system" (325). Key to any knowledge of fire history is an understanding of the mechanisms related to past fires' ignitions, and whether lighting alone can serve as an adequate ignition source to account for areas burned over the nearly 300+ year tree-ring reconstructed fire record.

**Figure 1.2**: Example of Heinselman's (1973, 1996) fire-year/stand-origin maps for the BWCAW. This is the map for the Coleman Island 7.5' USGS Quadrangle.

Four decades later, this question remains largely unanswered for the Quetico-Superior region, as well as for forested ecosystems across the Upper Great Lakes. Identifying the relative roles of natural lightning and human ignition sources is a critical issue with respect to wilderness fire management. If humans served as an important ignition source in the past, then the impact of past human activities likely remains subtly imprinted on the structure and composition of today's extant primary-growth forests.

### *Thesis Objectives*

The primary aim of my research has been to investigate the potential for proto-historic, human influence on fire frequencies in the Quetico-Superior region of northeast Minnesota and northwest Ontario. For the purposes of this study, the term *proto-historic* generally refers to the 200-years preceding the 20$^{th}$ century – a time of sporadic Euro-American documentation of Ojibwe land tenure within the Quetico-Superior. I approached my research challenge by testing three research questions adjacent to a traditional canoe travel corridor in a small portion of the BWCAW's naturally fragmented (lake-island) landscape. First, can island fire frequencies be explained by rates of lighting-ignited fire occurrence alone? Second, are surface fires within the naturally fragmented focus area synchronous in time and space? And third, are local surface fires significantly associated with patterns of regional drought? Combined, these research questions were intended to explore the relative role of human- and lightning-ignitions in influencing the spatial and temporal pattern of past tree-ring reconstructed surface fire events. Ultimately, a better understanding of proto-historic fire causality will

help elucidate the fine-scale nuances of the Quetico-Superior region's past fire activity and the ecosystem's historic range of variability (Landres et al. 1999).

### *Research Contributions*

My tree-ring based fire history research is the first of its kind to explicitly test for human influence on the Quetico-Superior's proto-historic fire frequencies and demonstrate the complexity of pre-fire suppression fire events in the island and mainland pine stands of the BWCAW. Past fire history investigations in the Quetico-Superior have lacked the spatial-temporal resolution and cultural context needed to fully assess any potential impacts of an aboriginal-influenced fire regime (Swain 1973, Heinselman 1973, Woods & Dey 1977). It is possible that in many areas used historically by the Bois Forte Ojibwe (one Band of the Lake Superior Chippewa), surface fire frequencies in mixed pine forests were more spatially and temporally complex than can be understood by age-class mapping of stand-replacing fires alone (e.g. Heinselman 1973; Figure 1.2).

As part of this undertaking, fine-grained field survey and sampling of remnant, fire-scarred red pine was conducted and all collected samples were dated using dendrochronological techniques (Stokes & Smiley 1968) to develop the most complete and accurate fire record within my study area. High survey and sampling intensity necessitated a relatively small study area of roughly 2,170 hectares. My purposeful selection of a naturally fragmented study area with primary growth forest, coupled with a reasonably developed record of traditional Ojibwe occupation, provided an exceptional opportunity to explore the potential for human-modified fire regimes within this portion

of the BWCAW.

Concentrated sampling and dendrochronological analysis (discussed below) of fire-scars makes this fire history study fundamentally different from Heinselman's (1973) fire history research. For example, Heinselman used only 295 fire-scars from 179 trees to construct his fire chronology for the entire BWCAW (≈ 438,679 ha) in comparison to my 247 fire-scars from 71 samples for a small subsection of the BWCAW (≈ 2,170 ha). Furthermore, Heinselman's fire years were derived from approximate ring counts of samples collected from living and dead trees rather than exact dates determined with dendrochronological techniques. Fire history datasets constructed from approximate ring counts, rather than crossdated fire years, make the accurate assessment of fire's spatial synchrony and fire-climate relationships extremely difficult (Figure 1.3).

***Fire-Dendrochronology***

Tree-rings are an invaluable tool in the study of forest history as they can serve as proxies of environmental change over decades and centuries at specific locations across wooded landscapes (Kipfmueller & Swetnam 2001). In regions like the Quetico-Superior, fire data derived from fire-scarred trees and even-aged forest patches are irreplaceable in the development of multi-century fire histories (Swetnam 1999). Dendrochronology, the scientific study of tree-rings, allows researchers interested in forest ecology to use accurate and high-resolution tree-ring records that can be studied at a number of spatial and temporal scales to answer questions related to fire, climate, and human land use

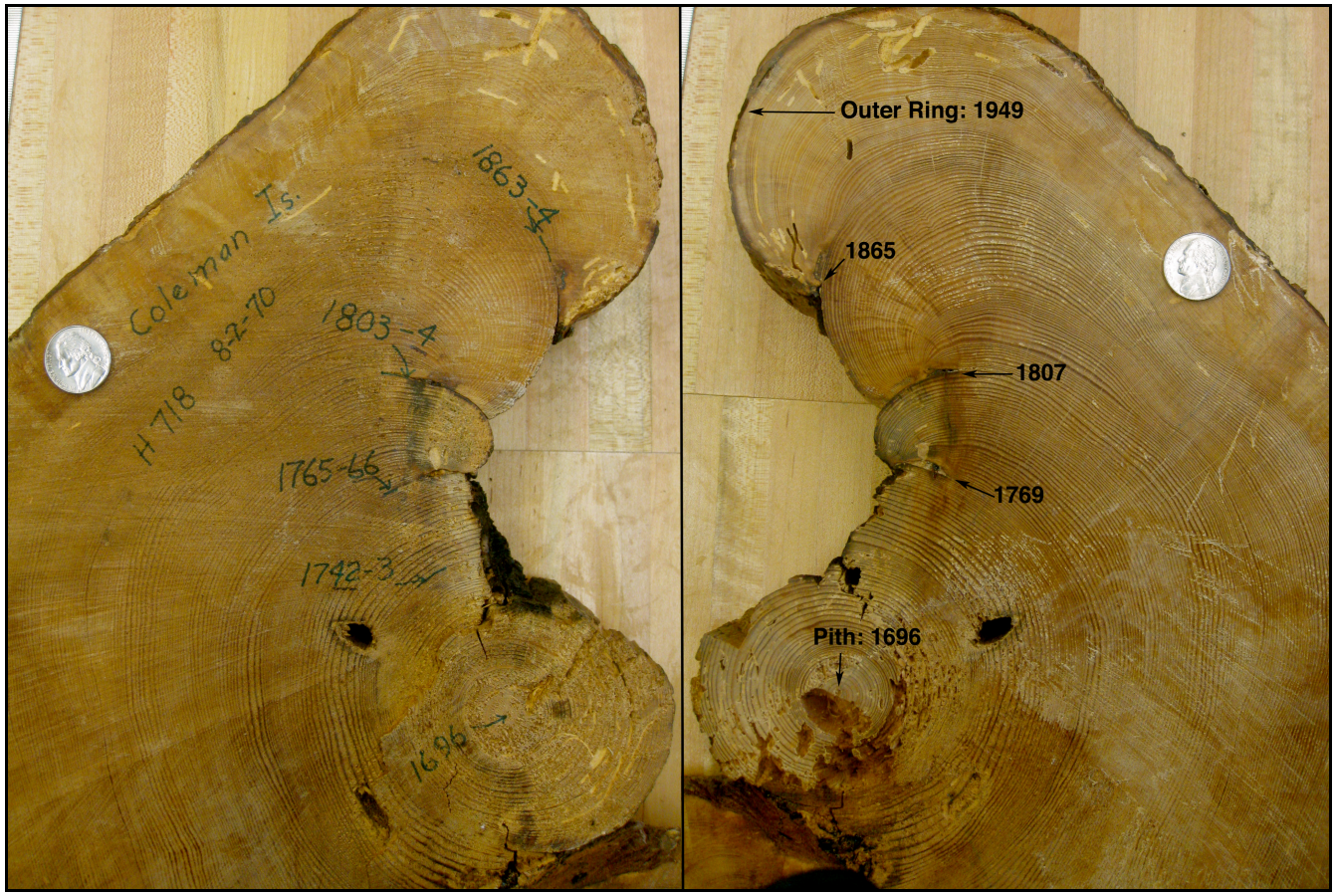
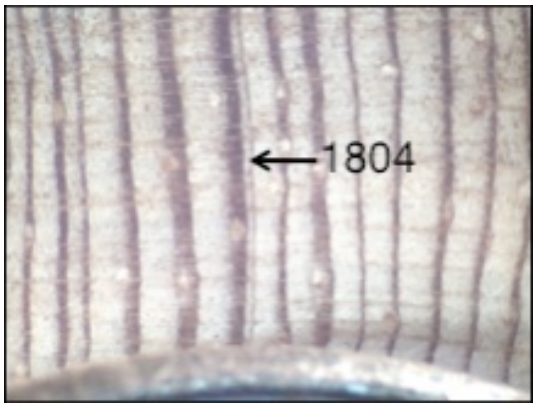



**Figure 1.3**: Fire years estimated with ring counts (left) compared to fire years determined by exact crossdating (right). The sample is a cross-section from a dead and downed red pine on Lac La Croix's Coleman Island collected and dated by Heinselman, August 1970 and crossdated by me, Winter 2011. Heinselman's approximate ring-counted fire dates are 1765-1766, 1803-1804, and 1863-1864 as compared to my crossdated fire years of 1769, 1807, and 1865. U.S. five cent coin for scale.

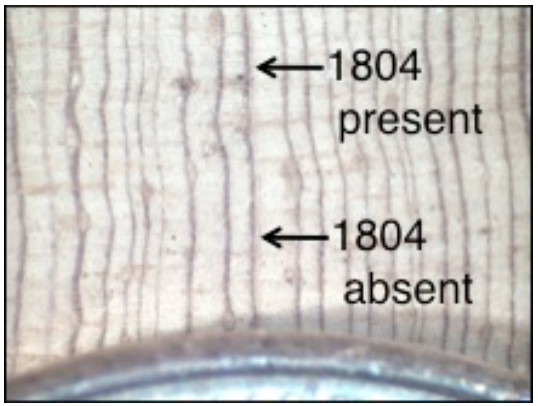
(Falk 2009). Dendrochronology distinguishes itself from basic tree-ring counting in principle and in practice, particularly with the use of *crossdating* – the matching of shared ring-width patterns among trees to aid in their exact dating (Fritts and Swetnam 1989).

In principle, the limiting effects of climate on tree growth causes generally synchronous growth patterns among trees in a region allowing comparisons of ring-width sequences between trees and the identification of deviations from general growth patterns for specific ring series (Fritts 1976). In practice, ring-width pattern matching among a collection of tree-ring growth chronologies helps eliminate errors inherent to basic ring counting (e.g. missing rings, locally-absent rings, counting intra-annual latewood bands/false rings; Figure 1.4) and allows the assignment of exact calendar years to single ring-width chronologies (Stokes and Smiley 1968). This precision is highly valuable when conducting fire history research as it allows for the accurate dating of fire-induced basal scars and of early-successional trees germinating after stand-replacing fire events. Furthermore, the dating precision permits confident analysis of fire synchrony at local and regional scales and the association of fire events with climatic and historic events like extreme droughts and human population shifts.

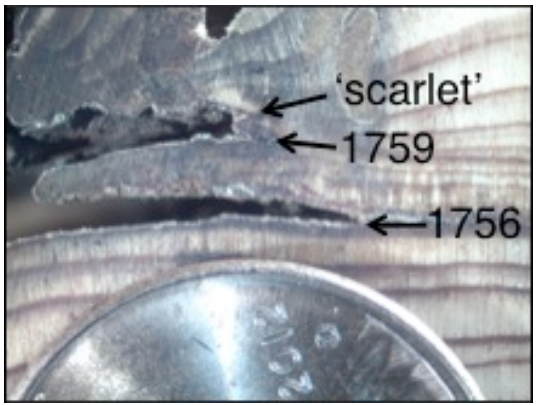
When there is sufficient chronological overlap, crossdating also allows for the collection and use of dead trees in the development of growth and disturbance chronologies, even when the tree's year of death is unknown. The ability to accurately assign calendar years to dead wood is of great significance for fire history research in the BWCAW as fire-scar sampling in the wilderness area, as of late, has been restricted to



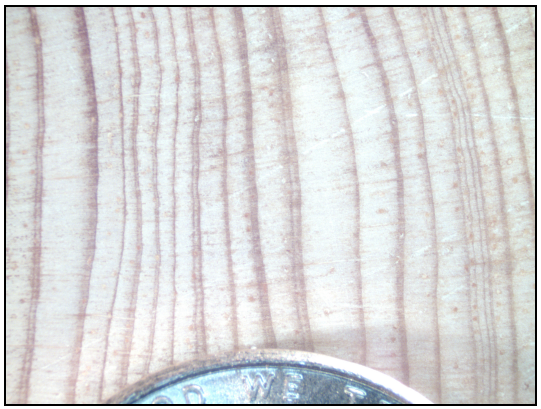

A.) Micro-ring (marker year)



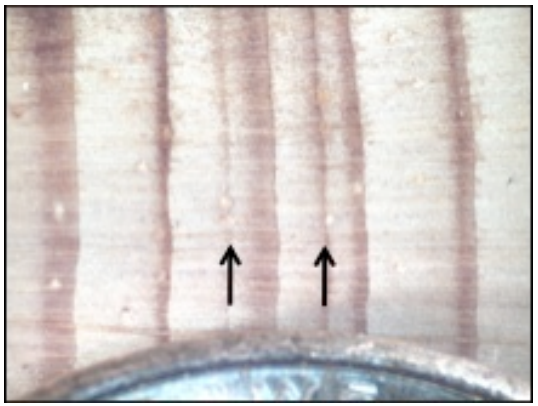

B.) Locally-absent ring (marker year)



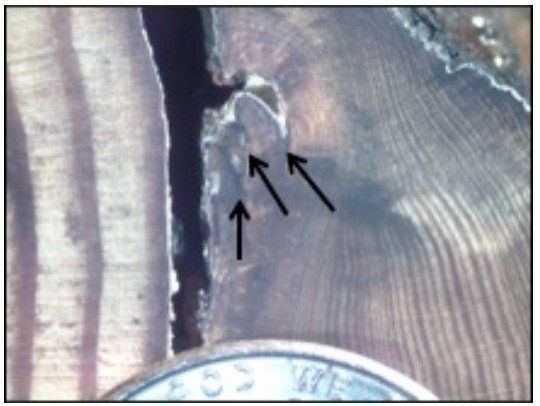

C.) Two fire-scars with a third 'scarlet'



D.) High ring-width variability



E.) False Rings (1.25x)



F.) Compressed rings with three fire-scars

**Figure 1.4**: Images of red pine tree-rings with a U.S. one cent coin for scale. All images taken under 0.63x magnification unless otherwise indicated.

the exclusive use of dead/downed trees and stumps. The dating of remnant wood extends fire history records beyond the two hundred year average residence time of red pine in the BWCAW to make possible the production of multi-century fire records. These fire reconstructions are highly beneficial in understanding the effects of changing climate and human land use on fire occurrence, conducting regional assessments of fire-climate interactions, and guiding future fire management decisions.

### *Thesis Structure*

The following two chapters are intended to address the question of human-influenced fire frequencies in the Quetico-Superior. Chapter II provides historic, cultural context to the possibility of Native American fire use in the Quetico-Superior, specifically by the Bois Forte Ojibwe, a large subset of the region's inhabitants prior to 20$^{th}$ century fire suppression efforts. The information is meant to give regional fire managers a better understanding of the potential for human modification of the historic forest mosaic by traditional (indigenous) land use activities.

Chapter III presents a pilot fire history study of fire frequencies in a subsection of the Quetico-Superior landscape – a large lake on the present day Minnesota-Ontario international boundary called Lac La Croix. The lake is known to have received heavy Ojibwe and European use over my multi-century tree-ring reconstructed fire record (early 1700s to present). The comparison of fire frequencies across a portion of eastern Lac La Croix's naturally fragmented landscape (islands) is used here to test causal assumptions of proto-historic surface fire occurrence in the greater Quetico-Superior region.

# CHAPTER 2

## The Cultural Context for Anthropogenic Fires in Minnesota's Boundary Waters Wilderness

> Thus it is seen that fires are not a novelty in these old woods, but have for hundreds of years been a prominent factor in their history. The coming of the whites and the general distribution of trappers and "couriers du bois" through the woods by the Hudson Bay Company and the American Fur Company 100 to 140 years ago seem to have been prolific of fires, for a very large proportion of the tress are 100 to 140 years of age, and must have started during that period. (Ayers 1900)

### RESEARCH CONTEXT

Researchers have long recognized fire as a major ecological influence on the landscape of the Upper Great Lakes (e.g. Ayers 1900). Maissurow (1941) examined the type and distribution of fire tolerant conifers and fire intolerant hardwoods in northern Wisconsin and inferred that fires had, at some point, influenced 95% of the region's old-growth forests. Spurr (1953) showed the old-growth pine forests of Itasca State Park, representative of what once covered much of north-central Minnesota, were produced and maintained by fire, not just by climate and soils. He used General Land Office survey notes, excerpts from traveler journals, and physical evidence to assign specific years to historic fire events in the park. His conclusions were later verified by Frissell (1973) who used fire-scarred samples collected from living red pine to estimate the dates of 32 fires

within the park's boundaries (a 12,972 hectare study area) that occurred between 1650 and 1920. With fire suppression efforts, the park had only ten fires between 1938 and 1968. Two of these ten fires were attributed to lightning, the other eight to humans. Frissell explained this shift in fire frequency as a product of fire exclusion due to land fragmentation outside the park's boundaries, but also to the removal of Native American ignitions from the park and the surrounding landscape. In the early 1960s, Clifford and Isabel Ahlgren, while not directly involved in fire history studies, published a series of reports on the fire ecology of northeast Minnesota including the effects of fire on soils, flora, fauna, and successional trajectories (Ahlgren 1959, 1960, Ahlgren & Ahlgren 1960).

In 1973, a special volume of *Quaternary Research* was published devoted to fire ecology. Within the volume, which included Frissell's research from Itasca State Park, were two studies from the BWCAW conducted by researchers affiliated with the University of Minnesota. Albert Swain (1973) had sampled sediments in a small lake in the eastern BWCAW to determine the area's vegetation and fire history. From his sediment cores he determined that a forest fire occurred in the lake's small drainage basin, every 66 years, on average (with a range from 20-100 years), for the last 1000 years.

The other article, by Miron Heinselman (1973), reported on a landscape-scale study of past stand-replacing fire events in the BWCAW. Heinselman used ring counts from partial cross sections of living, fire-scarred conifers and forest age class data, coupled with aerial photos, original General Land Office notes, and historic fire records

to determine fire years and stand-origin dates for much of the BWCAW. He reported that 83% of forests in the BWCAW had regenerated after fires that had burned between 1681 and 1894. Several years later, Woods and Dey (1977) produced a series of research reports on the fire history and ecology of Quetico Provincial Park. They reported findings similar to Heinselman and Swain with a drastic shift in mean point fire return intervals in the Park, from every 78 years to 870 years. As a fire management recommendation, Woods and Dey suggested ending absolute fire suppression within the park's boundaries to return, at some level, fire to the ecosystem.

Though difficult to quantify, observations by early Euro-American explorers, can provide first hand accounts of historic fire events in the region, and at times, their intensity, seasonality, and effects. British traveler, Dr. John Bigsby reported a large swath of denuded land on the northwest arm of Rainy Lake in 1823 with "great wastes of grey granite, over which the desolation of fire has passed" (Bigsby 1850: 267). In early June of 1841, fur trader George Simpson experienced forest fire first-hand on the narrows between Namakan and Rainy Lake, northeast of present day Kettle Falls in Voyageurs National Park. He wrote:

> …fire suddenly burst forth in the woods near us. The flames, crackling and clambering up each tree, quickly rose above the forest; within a few minutes more the dry grass on the very margin of the waters was in a running blaze; and, before we were well clear of the danger, we were almost enveloped in clouds of smoke and ashes. These conflagrations, often caused by a wanderer's fire or even by his pipe, desolate large tracts

> of country, leaving nothing but black and bare trunks, and even these sometimes mutilated into stumps, --- one of the most dismal scenes on which the eye and heart can look. (Simpson 1847:37)

While these historic accounts of fire do not provide detailed information on the region's fire regimes, the matter-of-factness of the travelers' accounts reinforces that fire events of differing size, severity, and seasonality were very much part of the region's historic ecology and that human activities, such as abandoned campfires commonly supplemented lightning-fire ignition rates.

At present, lightning ignitions are considered the most significant cause of historic fires in the Quetico-Superior region (Heinselman 1996) with summer lightning-ignition rates heavily influencing the area's fire regimes. Rates of lightning-caused fires are strongly determined, not by lightning strike density or polarity, but by fuel type (Meisner 1993). A study of lightning-ignited fires in northwest Ontario showed that the estimated moisture content of the soils' organic layer was a significant predictor of lightning fire occurrence (Flannigan &Wotton 1991). Nash & Johnson (1996) found similar results in studying lightning fire frequency across the Canadian boreal forest. The effectiveness of lightning increases with low fine fuel moisture (e.g. grasses, leaves, needles) and during extended periods of high atmospheric pressure (with limited precipitation). Lastly, Podur et al. (1993) studied the spatial pattern of lightning ignitions in northwest Ontario from 1976-1998. Their analysis showed areas of high and low lightning-ignited fires over a twenty-two year period with fire occurrence, again, strongly associated with extended dry periods during the growing season. Lightning-ignited fires were spatially clustered in

areas of higher elevation, which is likely explained by the greater presence of dry, fine fuels in areas of well-drained, upland tracts of boreal forest.

In the late 1990s, only 35% of Canada's wildfires were attributable to lightning, but they accounted for 85% of Canada's area burned (Weber & Stocks 1998). Unfortunately, due to modern fire suppression efforts, these numbers cannot serve as a historic analog of fire ignitions. The high percentage of area burned by lightning-caused fires is attributable to the logistical challenges of fire suppression in remote areas where lightning storms can ignite a complex of wildfires over a short time. Prior to fire suppression, fires of human origin would have burned as freely as lightning-caused fires. Still, when relating modern lightning ignitions to pre-Euro-American settlement conditions, the general relationship between lightning strikes, fuels, and climate remains applicable.

While fire managers and researchers understand how lightning ignition frequency contributes to the dynamics of local fire regimes, the historic role of humans as a significant alternative ignition source remains highly speculative in many regions. This speculation is partially attributable to limited or weak physical evidence of Native American fire use but also an outcome of researchers discounting indigenous folklore and traditional knowledge as strong evidence of controlled fire use by Native American groups (Stewart 1963). Fire is, as historian Stephen Pyne claims, both a natural and cultural phenomenon with humans as the "chief vector for the propagation of fire, and the most significant modifier of the fire environment" (Pyne 1982: 4). With the potential for human ignitions considered, it then becomes crucial for ecological studies of fire history

to account for the presence or absence of human input into the fire environment. Because the human component of fire regimes is as complex and changeable as human culture itself, it is a challenge for researchers and fire managers to establish meaningful absolutes regarding the effects of human presence on pre-modern fire regimes. As with any subject in historical geography, context matters. The particularities of time and place must be considered to make truly informed statements on the impacts of human populations on a given fire environment (e.g. by rates of ignition and fuel type modification). Often times the cultural history of an area is not adequately addressed in fire history research and the human variable is regarded as insignificant (e.g. Drobyshev et al. 2010, White & Host 2008).

Exemplary of this shortcoming in fire history research is the paucity of knowledge regarding the historical significance of human-fire relationships in the Quetico-Superior region. Information on aboriginal fire use in the Quetico-Superior is scant and anecdotal, while applicable approaches to testing existing hypotheses have not yet been carried out. For example, Ahlgren & Ahlgren (1984), Heinselman (1996), and Nelson (2009) report that the Bois Forte Ojibwe regularly burned the ridges of United States Point on Basswood Lake in the late 1800s and early 1900s. However, physical evidence of these historic activities has not been sought in the field nor have the implications of these historic land use activities for wilderness fire management been discussed at any length.

To many, the pre-Columbian landscape of North America is perceived as a wild and romantic place where unexplored and unaltered ‘pristine wilderness’ existed in its purest form (Denevan 1992). Contrary to this popular conception of primitive America,

archaeological, ecological, ethnographic, and historic evidence suggests that Native Americans have, in many places, been an important influence on biological resources across North America (e.g. Pyne 1982, Stewart 2003, Boyd et al. 2006). Possibly the greatest way Native Americans modified their living environment would have been their ability to create, control and spread fire across the landscape – both intentionally and accidentally – wherever a receptive fuel bed was present (Bonnicksen 2000, Pyne 1982).

In the late 1940s and early 1950s, cultural geographer Carl Sauer began to amass a collection of writings on fire, human agency, and the cultural modification of landscapes. Sauer was one of the earliest commentators on the human modification of landscapes through fire use. He argued against a pristine America, with rangeland environments as a prime example, stating the "fire-setting activities of man perforce brought about deep and lasting changes on 'natural vegetation', a term that may conceal long and steady pressure by human action on plant assemblages" (Sauer 1950: 19). His commentary cast a large net in the identification of American cultural landscapes and called into question existing policies of fire suppression in the western United States.

The cultural anthropologist Omer Stewart, a protégé of Sauer, produced a manuscript in 1954 with examples of aboriginal fire use in North America listed by State. The book's content was progressive for its time and was thought of by potential publishers to be an unpopular subject among prospective readers. Sixty years later the manuscript was finally published as *Forgotten Fires* (2003). Stewart's general argument, and supporting evidence, was for the ubiquitous, but highly variable, manipulation of the American landscape by aboriginal fires. For Minnesota, Stewart highlighted and provided

implications for a case study of forest succession on Cass Lake's Star Island, on the present-day Chippewa National Forest. Kittredge (1934) reported finding fire-scarred red and white pine on the 486 hectare island with at least five fire years over a 63 year period, between 1808 and 1871, followed by a 50 year fire free interval until his 1924 visit to the area. At the northeast end of Star Island was the site of an Ojibwe village and the decline of fire activity and the subsequent establishment of fire-intolerant trees coincided with this village's dispersal. While Kittredge left the duty of inference to the reader, his ecological study is the only of its kind in northern Minnesota presenting forest fire and forest succession data in a human-centric, historical context.

Purposeful use of fire by aboriginals would have been indispensible in maintaining the stability and predictability of a diverse range of habitats for resource benefits (Lewis 1985). There are two primary reasons to suspect that aboriginal groups utilized fire to manipulate vegetation in the Quetico-Superior region. First, fires may have been deliberately set by Indians to reduce forest undergrowth and maintain openings – for pest control, trail maintenance, ease of hunting, wildfire protection, and improved vantages. Second, it has been widely reported Indians burned to enhance forest productivity, primarily to improve forage for game and to enhance the yields of edible plants (Williams 2003).

While archaeological and historical evidence indicates the Quetico-Superior has been an important cultural landscape for millennia (Nelson 2009, Ahlgren & Ahlgren 1984), the overarching research and management paradigm among regional forest managers and ecologists does not address the potentially important role of aboriginal

ignitions in contributing to pre-modern fire regimes. Heinselman explained that, "people changed these burn patterns [the frequency, distribution, and size of BWCAW fires] only insofar as their ignitions caused burns that would not otherwise have occurred" (Heinselman 1996: 71). These modifications to 'natural', lightning-ignited burn patterns are precisely why an understanding of human input into the Quetico-Superior's historic fire regimes is of ecological significance.

## CULTURAL HISTORY OF THE QUETICO-SUPERIOR

The network of water trails that transects the Quetico-Superior has been the foci of human activity within the region for millennia, easing access to the land's resources for generations of Native Americans, explorers, fur traders, trappers, prospectors, and loggers. The indigneous inhabitants of the region, most notably the Bois Forte Ojibwe, were highly mobile hunter-gatherers. They followed a strict seasonal round, with movements and encampments dictated by the local abundance of ephemeral food sources including maple syrup, wild rice, berries, fish, and game. Trapping grew in importance with increased Ojibwe involvement in the fur trade over the mid-late 18$^{th}$ century. Their primary mode of travel in the ice-free season (also the fire season) was by birch bark canoe (Figure 2.1) focusing historic human land use along navigable waterways. Brenda Child, an Ojibwe historian and band member writes, "water is the defining feature in all Ojibwe landscapes, shaping our culture and history as well as the stories of the parks" (Child 2011: 25). Child's statement is exemplary of the historic Ojibwe' adaption to the physical geography of Lac La Croix and the greater Quetico-Superior region.

**Figure 2.1**: Ojibwe man paddling a birch bark canoe on Rainy Lake, west of Lac La Croix, date unknown. Credit: Canada Technology and Science Museum.

Lac La Croix is centered amidst a vast network of water routes connecting historic Ojibwe villages at Basswood Lake, Lake Vermilion, and Rainy Lake and directly on a historic fur trade thoroughfare used extensively by European fur traders (Nute 1941). Though the archaeological record of human occupancy on Lac La Croix is poorly developed (L.R. Johnson, personal communication, October 24, 2012), tangible remnants of historic aboriginal use on the lake abound. Visible evidence of early indigenous presence on the lake includes pictographs on lakeside granite; old-growth, bark peeled red pine; a small US Forest Service collection of archaeological materials; and stone remnants of an Indian lookout on a small island in La Croix's east channel (Figure 2.2).

French explorer Jacques de Noyan travelled through the Quetico-Superior region in 1688, spending the winter at Rainy Lake, exchanging European goods for furs with the local Indians (Morse 1969). French trader Sieur de la Verendryes and his companions arrived on Rainy Lake in 1731, eventually exploring as far west as Lake of the Woods and Lake Winnipeg by 1740, scouting a fur trade route that would come into great use 40 years later (Morse 1969). Fur trade historian Grace Lee Nute (1941) called this canoe route "The Voyageurs Highway", as it was the most direct, navigable water route from the north shore of Lake Superior to Rainy River and Lake of the Woods. The Grand Portage route running from the Pigeon River west to Lac La Croix by way of Basswood Lake was used from around 1780 to 1802 (Figure 2.3). After 1802, through the 1840s, the Grand Portage route was abandoned to avoid American regulation of trade activities at Grand Portage, Minnesota. A less direct route through British territory, from Fort William at the mouth of the Kaministiquia River near Thunder Bay, Ontario west to Lac

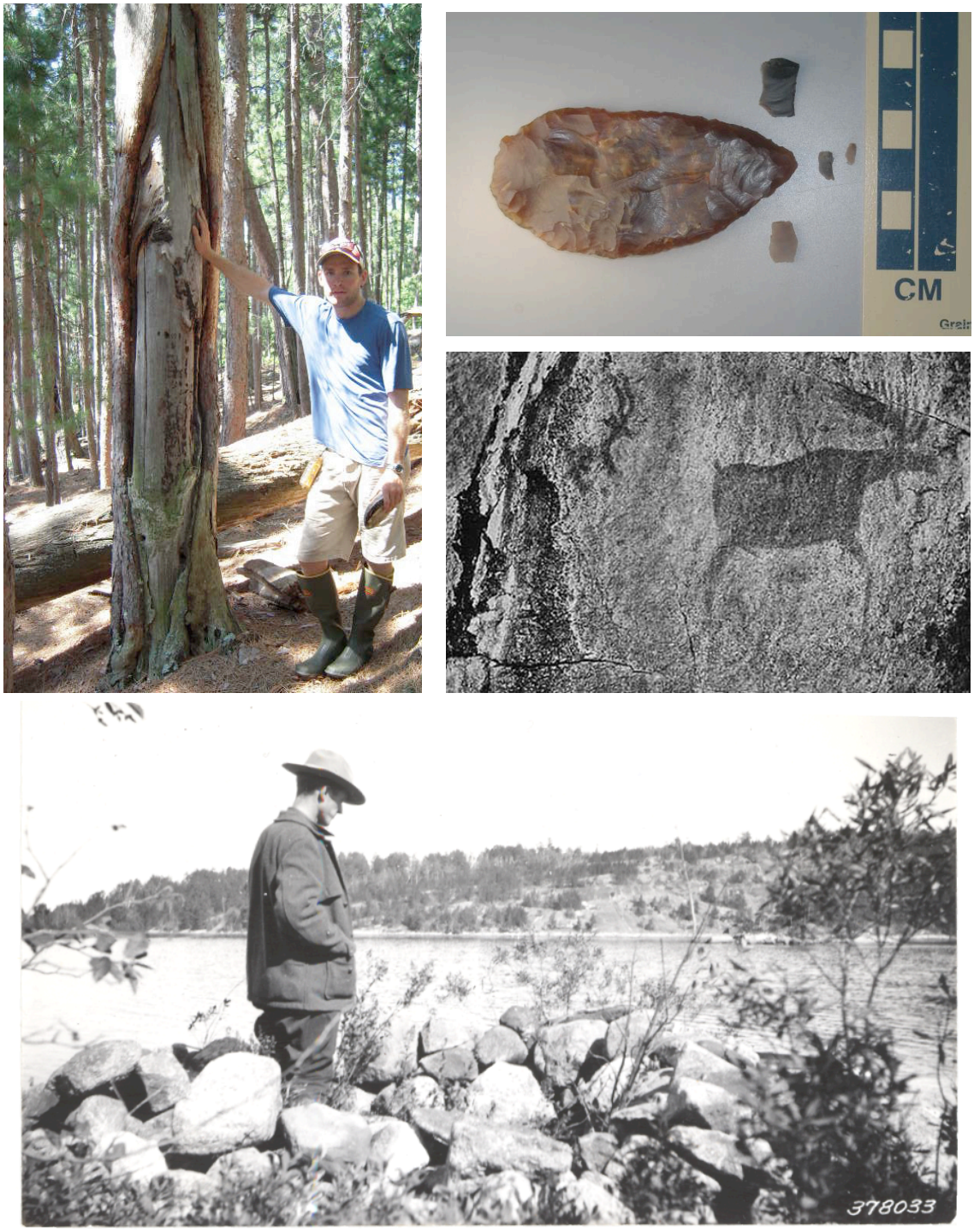



**Figure 2.2**: Clockwise from top left: A bark-peeled red pine culturally-modified in the 1790s with subsequent fire damage – east LLC, August 2011; Prehistoric bi-face cutting tool collected during archaeological survey on LLC (Credit: USDA-SNF); Moose pictograph – east LLC (Credit: MNHS); Stone structure remnants on small island, southeast arm of LLC ca. 1920 (Credit: USDA-SNF).

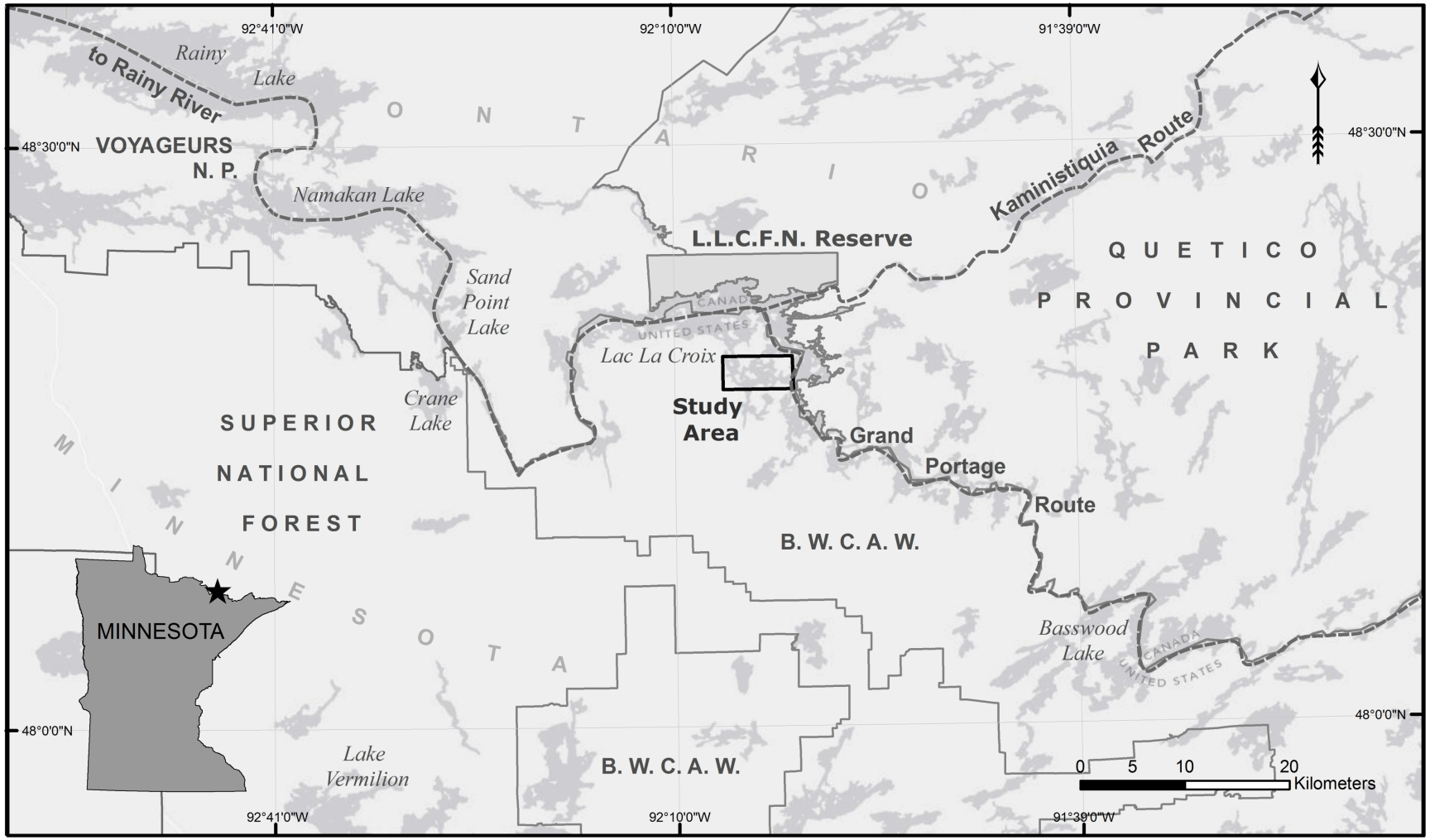



**Figure 2.3**: Study area location map and its proximity to the Grand Portage Route used extensively from 1780 to 1802 (along the present-day International Boundary) and the Kaministiquia Route used from 1803 to the mid-1800s.

La Croix by way of the Dog River, became the primary fur trade corridor for the Europeans (Gates 1965) while the local Ojibwe continued use of the 'old' Grand Portage route.

Ojibwe presence in the western Quetico-Superior region began, at least by ca. 1736, with the westward expansion of southern Ojibwe clans from Wisconsin's Chequamegon Bay area on Lake Superior's south shore (Richner 2002). French explorer Sieur de la Verendrye reported a small Ojibwe settlement at the confluence of the Vermilion River and Crane Lake in 1736 (Burpee 1968), 16 kilometers west of Lac La Croix. Ojibwe use in the area likely began earlier. In 1726, three bands of Monsoni Indians with 140 men – of probable Ojibwe affiliation – utilized the lands between Lake Saganaga and Rainy Lake (Richner 2002). During this period, the Cree and Assiniboine Indians were also present in the Lac La Croix region. By the 1740s the Ojibwe became firmly established in the Quetico-Superior, as far west as Rainy Lake, with the Cree and Assiniboine living further west but still moving peaceably through the region to reach Grand Portage near the confluence of the Pigeon River with Lake Superior (Richner 2002).

Through the 1700s and 1800s, the Indian population on Lac La Croix is difficult to estimate. There was a notable population of Ojibwe at Rainy Lake by the 1760s but much of the area northwest of Lake Superior must have been sparsely populated (Richner 2002). While the Lac La Croix region was an area of territorial expansion for the Bois Forte, intertribal warfare and disease heavily impacted Indian populations (Lovisek 1993). Trader Alexander Henry the Elder visited Lac La Croix in 1775 and noted that

what had once been a large village had been reduced in size, by warfare with the Dakota-Sioux, to only three wigwams (Hickerson 1967). In 1783, trader Jean Baptiste Cadott wrote a letter describing a widespread epidemic from Fond du Lac, part of the modern city of Duluth, north to Rainy Lake and Basswood Lakes, with population losses over 50% (Richner 2002). Despite a decline in local Ojibwe population, Lac La Croix's central location on trade routes and proximity to Crane Lake and the Vermilion River likely resulted in a continuity of Ojibwe presence in the area. Bois Forte subsistence strategies would have encouraged the dispersal of the region's population across large areas of a territory that reached east from Lake Vermilion to Basswood Lake and north to Rainy Lake.

In 1800, Alexander Henry the Younger (nephew of A.H. the Elder) passed through Lac La Croix on his way to Rainy Lake. He camped at "the Point Au Sable" on Lac La Croix for a night. After mentioning the terrible mosquitoes and sandflies, Henry wrote, "found here Indians making canoes" (Gough 1988: 10). There are a limited number of sand beaches on Lac La Croix; Henry's "Point au Sable" may be on the north side of the lake, just east of the modern Indian village at Neguagon reserve. By at least 1800, it is likely that the Ojibwe on Lac La Croix were manufacturing birch bark canoes to be sold to passing European canoe brigades.

In 1824, trader Henry Schoolcraft estimated 300 Bois Forte living in the Vermilion area, between Lake Vermilion and Rainy Lake. By 1832, the Bois Forte population was estimated at 291 with a population increase, despite disease, to 410 persons in 1839 (Richner 2002). In 1850 the Bois Forte population had increased to

roughly 800 with core populations at Vermilion Lake and Rainy Lake and groups utilizing a region from Lake of the Woods east to the mouth of the Pigeon River (Winchell 1911). The Bois Forte ceded this territory in treaties signed with the U.S. government in 1854 and 1866. Two years later the Bois Forte numbered 1,063 individuals, none of which were living at their newly designated reserve lands at Nett Lake, over 65 kilometers southwest of western Lac La Croix. Despite the U.S. government's efforts to encourage Indian farming, the Bois Forte maintained their traditional, seasonal rounds, moving freely throughout their ceded territory (Richner 2002).

In 1873, the Bois Forte Ojibwe living on the Canadian side of Lac La Croix ceded their territory to Queen Victoria. Referred to as the Lac La Croix First Nation, they were assigned a reserve on the north side of Lac La Croix while the Sturgeon Bay First Nation was assigned a reserve on Kawa Bay of Kawnipi Lake in the heart of modern Quetico Provincial Park (Nelson 2009). At the time of its signing, Treaty 3 permitted continued subsistence activities by all the participating First Nations, across their ceded territory. Between 1867 and 1875 disease reduced the Bois Forte population 34% from 1,029 individuals to only 697. These population losses were likely mirrored north of the Lac La Croix region with a measles epidemic across northwest Ontario in 1871.

From 1880 to 1900 the Bois Forte population held steady with slightly over 800 individuals. Despite the influx of Euro-American settlers and the cultural influence of boomtowns like Tower and Rainy Lake City, the Bois Forte continued their traditional subsistence practices, maintaining settlements in an area from Vermilion Lake, north to

Rainy Lake, and east to Ely. In 1893, Ojibwe encampments were still observed throughout what is now Voyageurs National Park and at the mouth of the Vermilion River on Crane Lake – the same location that had been occupied by a clan of Ojibwe in 1736 (Richner 2002).

Like the Bois Forte Ojibwe of northern Minnesota, the ancestors of the present-day Lac La Croix First Nation in northwest Ontario did not strictly reside within their reserve's boundaries but moved about extensively, maintaining their seasonal rounds including movement between Lake Vermilion and Basswood Lake. For example, traveler and photographer Ernest Oberholtzer visited Lac La Croix in August of 1906 during a canoe trip through the Quetico-Superior region. He met a "number of Indians" on southeast Lac La Croix that directed him towards the Indian reservation, "fourteen miles to the northwest" (Figure 2.4). Two days later, on the return trip from Lac La Croix, Oberholtzer and his Ojibwe companion arrived on Basswood Lake to find a group of Indians he had seen on Lac La Croix earlier in the week (Oberholtzer 1906). According to one elder of the Lac La Croix First Nation, canoe travel between Lac La Croix's Indian reserve to a Bois Forte village at Basswood Lake (by way of Crooked Lake) was historically common (K. Ottertail, personal communication, August 2, 2011). The village present on Basswood Lake at the turn of the 20$^{th}$ century was likely a continuation of Ojibwe occupancy and use of the Basswood Lake area since the 1770s, and probably earlier (Lamb 1970: 103).

**Figure 2.4**: Birch bark dwelling at Neguagon Indian Reserve, 25D on the north shore of Lac La Croix, 1932. Outlet to the Namakan River is in background. Credit: U.S. National Archives.

***Ojibwe Fire Use in the Quetico-Superior***

There has been a great deal of debate over the last sixty years within the historical ecology community over the level of influence Native Americans have had on the historic fire regimes of North America. Some researchers have argued traditional aboriginal fire use was ubiquitous across the North American landscape (Dey 1954, Denevan 1992, Kay 2002). Others have argued against this ubiquity and concluded that highly localized, traditional fire use has had little ecological significance across large portions of North America (Russell 1983, Vale 2002). In some geographic regions, where ethnographic research has occurred and there is rich historical data, the traditional fire management practices of aboriginal groups are better understood and their ecological

effects can be deduced. In other regions of North America, ethnographic data is sparse and historic data is anecdotal.

The cultural anthropologist Henry T. Lewis produced a notable body of work on indigenous fire use throughout his career (e.g. Lewis & Bean 1973, Lewis & Ferguson 1988). In 1975 and 1976, Lewis conducted ethnographic research on the traditional burning practices of Cree Indians in northern Alberta's boreal forest. Lewis (1977) documented traditional fire knowledge and burning practices from 37 Indian informants who had knowledge of traditional burning practices that had been used until the 1940s. Lewis' research was unique for its time in its documentation of historic Indian fire use in a boreal forest system with fire regimes characterized by large, high-severity forest fires. Lewis found that the Cree's motive for fire use was not to mimic lightning-caused fires, but to alter the vegetation mosaic in such a way that it reduced the negative impacts of catastrophic, lightning-caused fires upon their traditional subsistence strategies.

While it would be presumptuous to claim that the traditional fire use by the Cree in northern Alberta would be the same as Bois Forte historic fire use practices in the Quetico-Superior region, Lewis' ethnographic research makes it clear that boreal hunter-gatherer cultures were highly capable of using fire to assure the predictable abundance of favored vegetation types in areas of traditional use. This possibility does have important implications for the probability of historic fire use by other boreal hunter-gatherer cultures, like the Bois Forte Ojibwe in northeast Minnesota.

More recent ethnographic research related to traditional fire knowledge and use has been conducted in northwest Ontario with Ojibwe informants from the

Iskatweizaagegan No. 39 First Nation at Shoal Lake (Berkes & Davidson-Hunt 2006) and the Pikangikum First Nation on the Berens River (Miller & Davidson-Hunt 2010). This research is highly complimentary to Lewis' fire ethnography in northern Alberta as it makes evident the essential similarities in traditional fire use between Cree and Ojibwe cultural groups living hundreds of miles apart. Because both of the Indian communities are located in northwest Ontario and the research has been carried out with Ojibwe informants, it is particularly useful for inferring probable historic Ojibwe fire use practices for the Quetico-Superior region. Berkes and Davidson-Hunt (2006) interviewed Shoal Lake elders and found that fire was used historically in diverse ways to maintain early stages of plant succession at particular places on the landscape. Motives for controlled fire use include the clearance of brush from campsites and promontories, to thin the forest understory in oak stands, and the creation/maintenance of blueberry patches. Miller and Davidson-Hunt's (2010) ethno-ecological research with Pikangikum elders yielded striking similarities to the Shoal Lake Ojibwe's traditional fire use practices. The Ojibwe of the Pikangikum Lake area used controlled burns in the spring and autumn to maintain campsites, stimulate new plant growth in marshes, to clear gardens, and to maintain trails and portages. Of 30 interviewed elders, only one mentioned the use of controlled burns to maintain berry patches. The similarities and potential differences among geographically disparate but culturally similar Ojibwe communities suggests that while regional landscape ecology can provide universal incentives for intentional burning, local traditional knowledge and community history may significantly affect actual fire use practices from one community to another.

My search of the fur trade literature for information pertaining to Ojibwe fire use in the Quetico-Superior region has, for this study, been a largely fruitless task. The only rewarding historical text with references to aboriginal fire use are the 1823 journals of Dr. John J. Bigsby who appears to have been fascinated by forest fires, and a keen observer of their ecological effects during his travels across the Upper Great Lakes. Bigsby was part of the 1822-1824 joint US/British Boundary Commission and, as a well-educated physician and geologist, he was fastidious in narrating the landscapes of his travels. As a scientist and the appointed British secretary for the Boundary Commission, he likely had few incentives to embellish his travel accounts.

Mention of burned areas along heavily used travel routes and of Indian fire use in several sections of Bigsby's travelogue suggests humans may have been a reasonably common cause of fires by at least the 1820s. For instance, during Bigsby's westward trip across northern Lake Superior, he observed the "peculiar wildness and gloom" of "recent conflagrations" along the lakeside highlands of Ontario's Dog River where "the Indians [Ojibwe] burn[ed] large tracts of pine barrens in order to favour the growth of very useful autumnal fruits" (Bigsby 1850: 207). On a short side trip up the Namakan River from Sand Point Lake, Bigsby and his group spent the night where Lac La Croix empties into the Namakan River at what is now within the Neguagon Indian Reserve on northern Lac La Croix. Near their encampment "in a wood close by, which had *lately been fired*" (italics added for emphasis) he found a "beautiful tomahawk-hatchet" presumably left behind by those responsible for the recent fire (pg. 259). As Bigsby travelled further west to Lake of the Woods he briefly described the vegetation at Rat Portage, a prominent fur

trade portage leading from the north end of Lake of the Woods into the Winnipeg River. Here he observed "a grassy swamp, the portage lying between two eminences, naked but for burnt pines, a few cypress trees, and poplars" (pg. 303). On the east-central side of Lake of the Woods, near what Bigsby describes as "the promontory", his group found and traded with "a party of Indians gathering black bilberries (*Vaccinium canadense*)" which were "incredibly abundant" throughout the Border Lakes country (pg. 313). That night Bigsby's party encamped on a small wooded island across from the promontory. He wrote of the highland, "although the west end of the promontory is well wooded, towards its middle it becomes naked, and is often purposely fired by the Indians" (pg. 315). By the time of Bigsby's visit, the Indians he refers to were likely Saulteaux Ojibwe who had, like the Bois Forte Ojibwe, migrated west from the Sault St. Marie region of eastern Lake Superior roughly a century earlier. Bigsby's 1823 descriptions of localized fires in heavily-used areas of the Minnesota-Ontario border, while anecdotal, corroborates the knowledge provided in more recent fire ethnographies (Berkes & Davidson-Hunt 2006, Miller & Davidson-Hunt 2010) with the Saulteux Ojibwe First Nations in northwest Ontario.

I personally consulted with three elders of the Bois Forte Ojibwe to determine if any parallels exist between the previously discussed fire ethnographies conducted with the Saulteaux Ojibwe of northwest Ontario and traditional knowledge of Bois Forte fire use. At this time, formal ethnographic research on traditional fire knowledge has not been conducted with the Minnesota Bois Forte. My discussions with three Bois Forte elders yielded general information pertaining to historic Ojibwe fire use for vegetation

management along with several specific examples. The Bois Forte, even into the 1950s, were using fire to reduce grass and other fine fuels in community areas. One informant recalled from her youth (1950s) that the entire Nett Lake community (west of Lake Vermilion) would gather on spring evenings and burn the grass along trails and near buildings to reduce ticks and other pests. She clarified by saying the Nett Lakers burned any area that could be maintained or enhanced by fire but were very careful. Controlled fires were not taken lightly and were carried out with large groups of people to help. The fires were lit ceremonially with tobacco offerings and prayers given to reduce undue harm caused by the flames (R. Berens, personal communication, Spring 2011).

Along with Nett Lake, there is some traditional memory of fire use by the Bois Forte at Lake Vermilion. Like at Nett Lake, meadows and openings on the shores of Lake Vermilion were burned to reduce ticks and other insects. A second informant mentioned that, prior to fire suppression, the numerous islands on Lake Vermilion (there are over 350 islands on the lake) were burned by the Bois Forte to enhance the growth of blueberries. She said that her mother and grandmother, while paddling by canoe across Lake Vermilion to reach Trout Lake (north of Lake Vermilion), would stop along the way to burn certain islands. She explained that several islands were purposefully burned each year, on a rotational basis, to ensure consistent, local berry yields over time (P. Boshey, personal communication, June 16, 2012). This activity reflects traditional knowledge of blueberry ecology where frequent light spring fires can be used to 'prune' bushes and ensures high annual yields (Penney et al. 1997). Based on the knowledge of the first informant, these maintained berry patches would not have been communal, but

claimed by a single family for continual use, up to a century or more (R. Berens, personal communication, Spring 2011).

My first informant emphasized that traditional fire use practices would have been highly variable from one Ojibwe community to another. Oral traditions and spiritual reasoning behind particular methods of traditional fire use differ, therefore generalizing regional fire use practices based on tradition at a specific locality may lead to erroneous conclusions (R. Berens, personal communication, Spring 2011). Still, there have historically been, and remain, strong kinship ties between the Bois Forte Ojibwe and the Lac La Croix First Nation (LLCFN). There are several surnames common among members of the Minnesota's Bois Forte and Lac La Croix Indian communities including Ottertail and Jourdain. As late as the 1950s, one hundred canoes from Lac La Croix would travel to Nett Lake for an annual powwow (R. Berens, personal communication, Spring 2011). One elder of the Lac La Croix Indian community firmly declared there really is no cultural difference between Minnesota's Bois Forte and Ontario's LLCFN community (K. Ottertail, personal communication, August 2, 2011). Given these strong community ties, it is possible that the traditional fire use practices at Lake Vermilion and Nett Lake extended to other parts of the Quetico-Superior in earlier times, with controlled burns common in the vicinity of seasonal encampments and villages throughout Bois Forte traditional territory. This would be one explanation for the references to historic Ojibwe fire use on Washington Island's American Point on Basswood Lake and the area's "rocky ridges…covered with a variety of berries" that explorer Alexander Mackenzie described in the late 18$^{th}$ century (Lamb 1970:103).

Traditional fire use may also help explain the abundant trade of berries in the Bois Forte territory north of Lake Vermilion along the international border. For instance, west of Lac La Croix on nearby Sand Point Lake, another member of the 1823 joint border commission, Joseph Delafield mentioned "a band of Indians" carrying on a "brisk trade exchanging tobacco for blue berries, until they had filled every vessel & man's hat that wished it, in the canoe" (Delafield 1943: 436). The bountiful berries that both Delafield and Bigsby describe in their travels through the heart of the Quetico-Superior could very well be a product of large and widespread fires that occurred several years prior. However, the Bois Forte Ojibwe's active supply of furs and food stuffs to passing European canoe brigades make it possible that the purposeful firing of berry patches was an activity that had begun in the mid 1700s to provision the burgeoning fur trade along the present day International Border (Davidson-Hunt 2003).

The maintenance of berry patches is not the only explanation for increased ignitions in heavily used areas of the Quetico-Superior. Fritz et al. (1993) suggest that casual attitudes of Europeans and Indians involved in the fur trade increased anthropogenic ignitions in the Quetico-Superior region from the 1780s to the 1820s. A fur trader journal entry from Lake of the Woods speaks explicitly of setting ablaze a forested island, following the practice of the local Indians, to create a smoke signal to a nearby trading party.

In addition to intentionally set fires, tended and abandoned campfires occasionally escaped and burned adjacent vegetation. An August 1918 journal entry by forest ranger John Handberg describes an event on Little Vermilion Lake (west of Lac La Croix) that

was probably a frequent occurrence along historic travel routes before fire suppression began ca. 1910. Ranger Handberg wrote:

> I paddled up lake and found fire in on Canadian side in Brown's Bay on north end of Little Vermilion. I returned to outlet of Little Vermilion and man watching dam here told me Ottertail, an Indian, had gone up the lake yesterday, had camped night before last on this point where I found fire. It had burned pretty well down and slight rain we had last night checked it. There is no danger of it getting away. (Handberg 1918)

As mentioned earlier, the Ottertail surname is common among the Bois Forte of Minnesota and northwest Ontario's LLCFN. In fact, two of the four current members of the 2012-2013 LLCFN community council have the Ottertail surname. The man Handberg mentions as the cause of the small fire on Little Vermilion was almost certainly a member of either the Bois Forte or Lac La Croix Ojibwe communities.

Historic sources suggest in the late 1800s and early 1900s Minnesota's forest rangers struggled to prevent the burning of federal, state, and tribal lands. In 1899, the Chief Fire Warden Report for Minnesota includes a section on fire prevention on Indian lands in northern Minnesota. The report includes a transcription of a letter sent to the US Chippewa Indian agent stationed at White Earth from then acting State fire commissioner W.A. Jones. The request is as follows:

> …use your best endeavors to prevent the Indians, so far as possible, from causing forest or prairie fires on any of the reservations under your charge. To this end you should take such action…as may be necessary, carefully

> to explain to them and to all other persons who may be residing upon the reservations…the laws that have been enacted by the State of Minnesota for the protection of its forests – which the whites have to obey – and also inform them of the said Act of June 4, 1888, which provides that every person who wantonly destroys any timber upon any Indian reservation or lands of any tribe of Indians shall be punished by a fine…or be imprisoned…. (Andrews 1900)

Furthermore, the report states:

> 1. It is forbidden for any Indian willfully or maliciously to set on fire any timber, underbrush or grass, or any other combustible material upon Indian reservations, or carelessly or negligently to leave or suffer fire to burn unattended near any timber or other inflammable material.
>
> 2. Any Indian who shall build a camp fire, or other fire, in or near any forest, timber or other inflammable material upon any reservation, or shall be a party thereto, shall before breaking camp or leaving said fire, totally extinguish the same. (Andrews 1900)

Such detailed instructions coming from the Minnesota Fire Commissioner's office paints an interesting picture of the difficulty early state fire managers must have had in preventing fires on reserve lands and suggests that the Ojibwe, in some areas of northern Minnesota, were at least partially involved in traditional fire use practices around 1900.

During the 1920s, the Ash River area of what is now Voyageurs National Park

was declared by *National Geographic* magazine as the "blueberry capital of the United States" (Beatty 1965: 63). Extensive clear-cut logging and slash fires had caused a profusion of blueberries in the area and attracted large groups of Indian pickers from reserve lands. Forest Ranger Leslie Beatty recalled that "quarrels over picking grounds" resulted in competing berrying groups "setting fires to drive one another out" with "fires almost a daily occurrence" (Beatty 1965: 64). According to Beatty this was not an unusual occurrence up to the early 1930s (Beatty 1966: 62) with maliciously ignited fires being at least partially attributable to traditional views of fire use among the Bois Forte.

### *The Significance of Characterizing Ojibwe Fire Use in the Quetico-Superior*

Fire, as both a natural and cultural phenomenon, presents difficulties in distinguishing the impacts of lightning- and human-ignitions on pre-suppression fire regimes across North America. In regards to the near-boreal forest of the Quetico-Superior, there is presently very limited knowledge of the relative roles of human- and lightning-ignitions within the region's fire environment. By compiling information from ethnographies in other parts of the North American boreal forest, indirect historical references to traditional Ojibwe views of fire in the region, and presently limited oral history data from elders within the local Bois Forte Ojibwe community, a compelling case for Ojibwe augmentation of proto-historic fire regimes within the Quetico-Superior emerges. In the next chapter this traditional-cultural context is combined with tree-ring based records of fire from the BWCAW to test the possibility of human manipulation of fire frequencies over the last 300+ years.

# CHAPTER 3

## Tree-Ring Based Evidence of Anthropogenic Influence on the Fire Frequencies of Eastern Lac La Croix

### *Fire in the Quetico-Superior*

Fire has been an important disturbance agent in the forests of the Quetico-Superior for millennia (Swain 1973) with nearly all of the region's forests originating from one or more fires that have occurred since the late 1500s (Heinselman 1973). Like the true boreal forests to the north, weather conditions during the fire season, from late April to early November, control fuel moisture levels with periods of extended dryness allowing small lightning- and human-ignited fires to grow and burn over large tracts of land. The physical and reproductive adaptations of the region's early- and mid-successional tree species – such as thick, heat-resistant bark, serotinous cones, and root sprouts – allow these trees to persist and even thrive in a landscape of relatively frequent fires of varying intensities (Frelich 1995).

Despite the Boundary Waters Canoe Area Wilderness (BWCAW) and Quetico Provincial Park's current socio-political status as wilderness, the region has a long history of human presence that may have substantially altered otherwise lightning-dominated fire regimes with human-caused ignitions. Perhaps the most important way indigenous groups could have altered the Quetico-Superior's near-boreal landscape is through the use of fire and the subsequent alteration of ignition rates, locations, and fires' seasonal timing (Granstrom & Niklasson 2008). The determination of human influence on proto-historic, or pre-fire suppression, fire regimes is crucial to understand the potential effects of early

Ojibwe subsistence activities and cultural practices on the composition, structure, and heterogeneity of the region's forests prior to historic logging, fire suppression, fire exclusion, and the dramatic alteration of traditional Ojibwe land use.

### *Island-Fire History Research*

The primary focus of fire history research is to observe, analyze, and explain spatial and temporal patterns of fire events across heterogeneous landscapes with complex contributing factors. When characterizing fire regimes, tree-ring based fire histories are best used to establish conservative estimates of fire frequencies for discrete locations across landscapes. Because fire frequency is largely controlled by local fire ignition rates and fire spread (Guyette et al. 2004) fire histories conducted in island settings – actual or figurative – allow investigators to better account for fire occurrence when reporting and interpreting reconstructed fire frequencies. Case studies of fire history among forest isolates created by natural fuel breaks like lakes (Niklasson et al. 2010), shifts in fuel type (Drobyshev et al. 2004, Loope & Anderton 1998), and geological features (Arabas et al. 2006) have been used to test fire regime assumptions where forest unit insularity and size are thought to limit fire frequency and influence fire behavior and effects.

While it is generally thought that landscape fragmentation will decrease fire frequency for individual land units, results differ among studies showing that barrier type and landscape setting is important. Some fire history studies agree with theoretical assumptions of fire spread with lower fire frequencies in disjoint parcels relative to the

surrounding landscape (Grissino-Mayer 1995, Clarke 2002). Others studies report higher fire frequencies in insular forest units relative to adjacent 'mainland' units (Bergeron 1991, Murray et al. 1998, Fule et al. 2003). The presence of natural fire breaks are often not enough to predict localized fire occurrence in fragmented landscapes. Often other spatial, environmental, and cultural variables including island size (Wardle 2003), local fuel conditions (Drobyshev et al. 2010), and changes in human land use (Niklasson et al. 2010) contribute to observed fire histories – often in confounding ways.

### *The Distinctiveness of Red Pine*

Prior to Euro-American settlement, red pine comprised approximately one-third of the 22 million acres of pine forest of the Upper Great Lakes States, including Minnesota, Wisconsin, and Michigan (Gilmore & Palik 2006). Much of this acreage existed in mature and old-growth forests. From a combination of historic timber harvesting activities, catastrophic, wildfires (many attributable to human activity and fueled by logging slash), and subsequent agricultural development, red pine forests were drastically reduced to roughly 12,140 hectares (≈ 300,000 ac) in the Upper Great Lake States by the early 1900s. Today, the species has made a small comeback with roughly 809,371 hectares (≈ 2,000,000 ac) of red pine timberland in the Upper Great Lakes region (Buckman et al. 2006), the bulk of which exists as even-aged plantations planted in the 1930s and 1940s.

Red pine is considered by foresters and ecologists to be a pyrophytic, mid-successional species. The tree is shade intolerant and fast growing, capable of reaching

heights of 75 feet in 50 years with ideal site conditions (Gilmore & Palik 2006). Despite red pines' fast growth, the trees are long-lived with stand ages frequenting 200 years of age and single trees living over 400 years. Red pines' combined longevity and rot resistance makes it one of the tree species best suited for dendrochronological applications in the Upper Great Lakes. The species' fire resistance, ranked third in the northeast United States (Hauser 2008) after pitch pine (*Pinus rigida*) and chestnut oak (*Quercus prinus*), makes the tree an irreplaceable resource in tree-ring based fire history studies throughout its natural range.

Red pine is sometimes referred to as a fire-maintained sub-climax species (Hauser 2008). Of the fire-adapted tree species in the Upper Great Lakes, red pine is ecologically unique in its particular fire dependence (Ahlgren 1976). Historically, a combination of relatively frequent surface fires and more infrequent crown fires encouraged red pine persistence across the landscape. Periodic, low- to medium-intensity surface fires reduced competing vegetation and woody fuels while opening up canopy gaps for understory pine ascension. More infrequent, high-intensity surface and crown fires would eventually burn as a stand aged, resetting the successional clock, creating seedbeds of exposed mineral soil while returning full sunlight to the forest floor. If fires did not coincide with a good seed crop (masting occurs every 3-7 years), significant tree regeneration did not take place (Heinselman 1996).

Since the 1910s, red pine has been the subject of silvicultural research in the Great Lakes Region (see Gilmore & Palik (2006) for a reference list). Still, the natural development of ecological complexity within red pine stands and the tree's particular

needs for natural regeneration, as opposed to regeneration induced by silvicultural treatment, are not well understood (Buckman et al. 2006). Red pine's height, relatively straight grain, buoyancy, and rot-resistant wood made it a prime first target of early logging operations. Today, the species is the plantation pine of choice in the Upper Great Lakes due to high growth performance in dense, commercial stands and low mortality from disease and blight. Timber products produced from the species are diverse – from lumber, pulpwood and paper to fence posts, railroad ties, power poles and structural flakeboard (Buckman et al. 2006).

Beyond red pine's commercial uses, the tree has great aesthetic appeal and recreational value (Figure 3.1). The red pine was given the status of Minnesota's state tree in 1953, in part for its economic importance in Minnesota history, but also for its regal stature. Mature red pine forests are highly sought out year round for hiking, wildlife watching, cross-country skiing, and power sports. A 1965 study of BWCAW visitor use preferences found that visitors almost unanimously preferred campsites located in lakeside pine stands, largely due to the stands' open understories and visual appeal (Frissell & Duncan 1965).

Red pine has great economic, aesthetic, and cultural importance in the Upper Great Lakes. Prior to Euro-American logging and settlement, the tree was a large component of mixed pine forests across the Upper Great Lakes region. However, knowledge of the disturbance regimes important to these forests' non-mechanical establishment and development are not fully understood. Of the fire-dependent forest communities of the Quetico-Superior, red pine forests on xeric sites with quick drying,

**Figure 3.1**: An open grove of 300-year-old red pine on the south shore of Lac La Croix's Coleman Island.

fine fuels would have been the most receptive to frequent lightning- and human-ignitions prior to fire suppression (Mutch 1970). If forest resource managers are interested in ensuring the persistence of heritage stands of old-growth red pine, like those found in the unlogged portions of the Quetico-Superior, or in encouraging stand complexity and decadence in managed reserve plantations, the drivers and effects of historic fire regimes in red pine forests must be fully examined.

## STUDY AREA

### *Historical Setting*

Lac La Croix is a 13,788 hectare waterbody, the largest by surface area in the BWCAW. Located on the western fringe of Quetico Provincial Park and the BWCAW, the waters of Lac La Croix and its tributaries flow north, across the Canadian Shield through Rainy Lake, Rainy River, and Lake of the Woods, eventually reaching Hudson Bay. The historic Grand Portage and Kaministiquia River fur trade routes from western Lake Superior converge on Lac La Croix's northeast end to form the Rainy River trail to the west (Figure 2.3). The lake received its present name – translated *Lake of the Cross* – from the French fur traders that visited the area beginning in the late 17$^{th}$ century. While the lake's shape does not remotely resemble a cross, an early Ojibwe name for Lac La Croix was "Sheshibagumag sagaiigun", meaning "the lake they go every which way to get through" (Upham 2001), with the Ojibwe referencing the lake's significance as a hub of historic water-based transport. Today, the four hundred members of the Lac La Croix First Nation call the lake "Zhingwaako Zaaga'igan" – an Ojibwe name meaning "Lake of the Pines" (LLCFN 2010). The US-Canada international boundary transects the full course of the lake with the Lac La Croix First Nation reserve (Neguagon Indian Reserve, 25D) on the north shore, Quetico Provincial Park directly to the east, and Minnesota's BWCAW spanning the southern half of the lake. Voyageur's National Park lies 20 kilometers to the west.

Like many of the large, granitic lakes in the Quetico-Superior region, Lac La Croix is a maze of forested islands varying in shape, size and relief. During the 1823

international border survey of the lake, American surveyor Joseph Delafield reported difficulty establishing a middle ground for the political boundary due to a reported 450 islands strewn across the waterscape (Lass 1980). Dr. John Bigsby, a member of the British border commission also visited Lac La Croix in 1823 and describing the lake's islands as "pine-tufted with rushy sides, besides rocks innumerable" and the lake's shores "extremely capricious in their outlines, and often bare and high". Bigsby continued, "The Indians have names for most of [Lac La Croix's] localities, but we could seldom procure them" (Bigsby 1850: 256). His casual mention of Indian place names suggests the local Ojibwe were intimately familiar with the lake and its environs.

About 10,117 hectares (25,000 acres) of remnant mixed pine forests remain in northern Minnesota, most of which are located in the BWCAW (Frelich 1995). The largest concentrations of old-growth red pine (initiated in 1822 or earlier) are located "in the Lac La Croix region of the BWCAW", where "near Boulder Bay, Lady Boot Bay, Fish Stake Narrows, Coleman Island, and the other eastern islands of Lac La Croix, the Boulder River, Lake Agnes, Ge-be-on-equet Lake, and Oyster Lake" are "about 6,400 acres [2590 hectares] of more or less contiguous red and white pine groves" (Heinselman 1996: 138). These pine stands are but remnants of what once existed across the Laurentian Mixed Forest Province of the Great Lakes – St. Lawrence region and are the biological legacy of innumerable centuries of fire.

A July 5$^{th}$, 1894 *Rainy Lake Journal* excerpt gives an explicit estimate of the areas value as a timber resource with, "1,300,000,000 feet of marketable pine from "Lac La Croix and Rainy Lake and tributaries" (Nute 2004: 57), the rough equivalent of 216,667

modern logging truck loads. Extensive logging activities in the pineries of the Rainy Lake-Kabetogama area began ca. 1910 (Coffman et al. 1980) but the pine forests on the American side of Lac La Croix were largely spared the axe and saw. The lake's isolation from American logging companies' core operations and the high density of harvestable timber south of Rainy Lake and in the vicinity of Basswood Lake (Searle 1977) slowed the movement of logging operations towards the Lac La Croix region in the early 1900s.

In 1905, Minnesota Forestry Commissioner Christopher C. Andrews travelled by canoe along the international boundary through Crooked Lake and Lac La Croix. Andrews marveled at the area's grandeur and timber resources. The islands, he said "lend the chief beauty to the scenery…to denude them of timber would be of public injury, for that locality…is one of the most important in Minnesota" (Searle 1977). With Andrews as advocate, the General Land Office set aside roughly 57,060 hectares (≈ 141,000 ac) of timbered land, including the U.S. side of Lac La Croix, as a forest reserve for recreational use. This reserve was incorporated into the newly established Superior National Forest in 1909, with the support of President Theodore Roosevelt, in tandem with the creation of a large provincial forest and game reserve on the Canadian side of the border, now known as Ontario's Quetico Provincial Park. The reserve designation did not offer complete protection from timber harvest on either side of the international border. The USFS tried unsuccessfully to sell five million board feet of timber on the American side of Lac La Croix in 1939 (Searle 1977). With the exception of a ≈ 65 hectare (160 ac) parcel logged by the Virginia Rainy Lake company from 1925-1929 at the south end of Lac La Croix's Lady Boot Bay (Heinselman 1996), the American side of Lac La Croix remained uncut,

until the area received absolute protection from logging with the BWCAW Act of 1978 (Public Law 95-495). The same cannot be said for the Canadian side of the lake. Extensive logging did occur on Lac La Croix's Canadian shore. For example, portions of Quetico's Irving Island on the east side of Lac La Croix, were heavily logged sometime shortly before 1938 (Figure 3.2). Timber harvest within Quetico Provincial Park ended in 1971 (Searle 1977).

**Figure 3.2**: Logging on Lac La Croix's Irving Island (east of study area), Quetico Provincial Park ca. 1938. Credit: Minnesota Historical Society.

The development of summer homes and resorts on Lac La Croix parallels the lake's logging history. The Canadian side received some development of summer homes and fly-in resorts while there was only one development on the American side. Scala's resort was built in 1945 on eastern Lac La Croix (within the study area) and expanded in the winters of 1948 and 1949 to increase the property's value in preparation for a United

States Forest Service property buyout (L.J. Beatty, personal communication, January 27, 2012). While some local forest manipulation occurred for resort construction and the harvest of firewood, as evidenced by cut stumps observed in the field, very limited encroachment of homesteads, summer homes, and resorts during the late nineteenth and early twentieth centuries affirms the historically untrammeled character of the study area – relative to other large border lakes (e.g. Basswood and Rainy Lakes).

### *Geology and Soils*

The bedrock underlying the Lac La Croix region is part of the Vermilion Granitic Complex of the ancient Canadian Shield (Southwick & Sims 1980). Exposed, scoured, and carved by ice during the Wisconsin glaciation, the land is undulating with many hills and frequent granite outcrops with relief ranging from 6 to 40 meters and lake depths up to 50 meters. Geologists refer to the homogenous, light-pink biotite rock ubiquitous to the area as simply, Lac La Croix Granite (Southwick & Sims 1980). The La Croix region was a place of glacial erosion rather than deposition during the late Pleistocene. Consequently, soils in the area are thin and nutrient poor (Heinselman 1996). Field notes from the area's December 1879 original General Land Office survey describe the soils as "poor and entirely unfit for cultivation; 3rd rate" (USDI 2012: 189). As the Rainy Lake lobe retreated from the Boundary Waters region around 12,000 years ago, it left only a thin and broken layer of non-calcareous glacial till. This glacial till and subsequently eroded bedrock is the parent material for the soils present today (Wright 1972). The soil types I observed within the selected study area were shallow and well-drained with

assorted textures of gray to brown sandy loam. Mosses, needle beds, and other organics served as an important rooting substrate for tree seedlings and herbaceous ground cover. As would be expected, soil type and moisture levels varied based on local physiography with lakeside slopes and terraces having drier and patchier soils than adjacent flat and gently rounded uplands.

***Climate***

The climate of the Lac La Croix region is northern-continental with large seasonal shifts from long, cold winters to short and mild summers with a median 112 frost-free days (Minnesota State Climatology Office 2012). Seasonal precipitation is moderated by the fluctuating dominance of Arctic, Pacific, and Gulf air masses over the region. During the growing season, unstable sub-tropical air masses are transported from the Gulf of Mexico bringing warm temperatures, high humidity, and thunderstorms to the area. These periods of warmth and moisture are punctuated by influxes of cool and dry Arctic air that result in extended periods of atmospheric stability in late spring and early summer (Heinselman 1996).

According to Lac La Croix's 30-year weather normals from 1971-2000 (Figure 3.3) January's average minimum temperature is -22.5° C (-8.5° F) and July's average maximum temperature is 25.9° C (78.7° F). Mean annual precipitation is 70.4 cm (27.7 in) with the majority of moisture coming as rain from mid-April to late October (PRISM Climate Group 2012). The mean number of days with snow cover (≥ 25 mm) is 145 days beginning in early November and lingering until early April (Baker et al. 1982). Winters

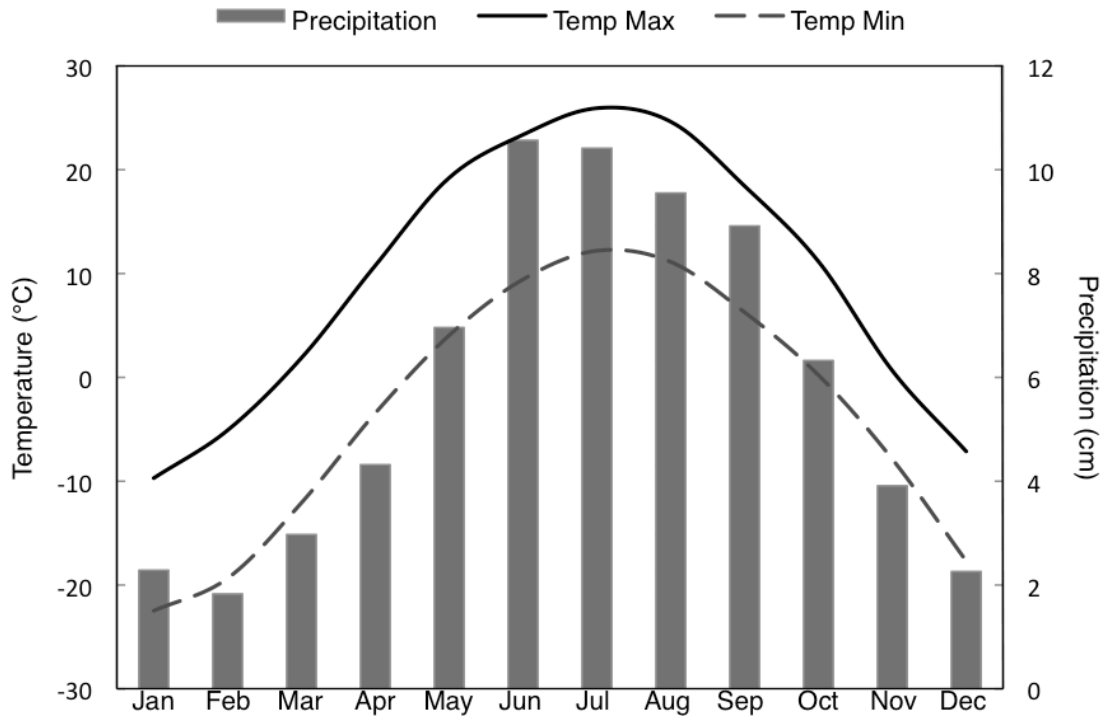



**Figure 3.3**: Climate Normals (1971-2000) for the Lac La Croix region, Minnesota. Data Credit: PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, retrieved on Jan. 30, 2013

are drier on the west side of the region than in the east while the opposite holds true for summers, with the west receiving greater precipitation from May to October. Relative to the east, the west side of the Quetico-Superior is drier on an annual basis (Kipfmueller et al. 2010). The general drying trend from east to west in the Quetico-Superior is likely attributable to higher levels of summer evapotranspiration to the west – up to 5 cm (2 in) greater in the Voyageurs National Park area than in the eastern BWCAW (Baker et al. 1979).

***Vegetation***

The forests of the Lac La Croix region are generally representative of the vegetation of the greater Quetico-Superior ecotone with a blend of northern coniferous and temperate-deciduous tree species determined by a site's physiography and disturbance history. Life history characteristics of the predominant tree species are suggestive of the significant role fires have played in the development of the region's forests. Quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), black spruce (*Picea mariana),* jack pine (*Pinus banksiana),* red pine (*Pinus resinosa*) and white pine (*Pinus strobus*) have physical and reproductive adaptations such as root sprouting, cone serotiny, self-pruned branches, and thick insulating bark that enable these trees to persist and thrive in an environment of frequent fires with varying intensity and severity (Frelich 2002). In the absence of fire, fire-intolerant species like balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), and northern white cedar (*Thuja occidentalis*) establish themselves in the understory as mid- to late-successional species.

In the Lac La Croix region, pockets of scrub red oak (*Quercus rubrus)* and northern pin oak (*Quercus ellipsoidalis)* can be found on rocky uplands and red maple (*Acer rubrum*) is a common understory component. The presence of these temperate-deciduous species, which are less common in the eastern and northern sections of the Quetico-Superior, may be explained by Lac La Croix's warmer and drier westward location and the area's well-drained, drought-prone soils.

The original 1880 General Land Office notes describe the general vegetation of

eastern Lac La Croix as dense timber with "jack pine thickets, white and norway pine, birch, aspen, fir, cedar, spruce and tamarack" with the surface of islands being "hilly and broken – burnt land – aspen and birch brush, windfall and dead timber" (USDI 2012: 189). The "burnt land" with "aspen birch brush" on central Coleman Island, just north of the study area, was likely associated with fires that swept through the area in the 1860s.

Though the forests of eastern Lac La Croix have had over 130 years to mature and change in structure, the general descriptions of forest composition provided by surveyors in 1879 remains largely accurate. Unlike other portions of the BWCAW, the conspicuous absence of historic logging on the American side of Lac La Croix and a dearth of large-scale wind events (e.g. Rich et al. 2010) and catastrophic fires, like the 37,507 hectare Pagami Creek Fire in 2011, makes Lac La Croix an indispensible reference area for researchers interested in the historical ecology of the primary-growth pine forest that were once abundant across the Upper Great Lakes.

Areas where I located and collected fire-scarred samples typically had a sparse to dense ground layer of Canada mayflower (*Maianthemum canadense*), large-leaved aster (*Aster macrophyllus*), wintergreen (*Gaultheria procumbens*), bunchberry (*Cornus canadensis*), bracken (*Pteridium aquilinum*) and an assortment of grasses, mosses, and lichens. The shrub layers varied from patchy to continuous cover of blueberry (*Vaccinium angustifolium),* juneberries *(Amerlanchier spp.)*, bush honeysuckle (*Diervilla lonicera*), beaked hazelnut (*Corylus cornuta*), common juniper (*Juniper communus),* interspersed with red maple, balsam fir, paper birch and quaking aspen saplings. The understory when present usually consisted of paper birch, red maple, mountain maple,

white pine, and balsam fir. The forest overstory was generally scattered to dense red and white pine. Fire-scarred red pine samples were found and collected in areas that I have characterized as sub-classes of Northern Dry-Bedrock Pine Woodland (FDn22), Northern Poor Dry-Mesic Mixed Woodland (FDn32), and Northern Dry-Mesic Mixed Woodland (FDn33) as defined by the Minnesota Department of Natural Resources (MN DNR 2003).

## METHODS

### *Field Reconnaissance*

In May 2011, I visited eastern Lac La Croix to conduct an initial assessment of the viability of a fire history study of the lake's islands. I scouted the American side of the lake by canoe and surveyed select islands with an observable red and white pine component on foot. I referenced Heinselman's 1973 stand-origin map for the Coleman Island 7.5' USGS Quadrangle (Figure 1.1) to locate and examine island sites with two or more reported stand-origin dates and island sites without existing fire history records. These islands were of primary interest in order to confirm the accuracy and comprehensiveness of Heinselman's (1973) stand-origin map. The general reconnaissance trip involved water and ground-based survey of island and mainland sites extending from the south end of Lac La Croix at the Boulder River to Lac La Croix's north channel near Twentyfive Island.

The full distance of lake I initially explored was 22 kilometers following the south and west periphery of the irregularly branched Coleman Island. Due to Lac La Croix's

immense size, many islands, and limited accessibility, I delineated a roughly 2,170 hectare subsection of the original search area on eastern Lac La Croix – south of Coleman Island and west of the lake's east arm – for my case study of the lake's proto-historic fire history. The study area lies centered within the Coleman Island 7.5' United States Geological Survey Quadrangle (Figure 3.4), split equally between T67N-R13W and T67N-R14W. The study area is approximately 40% water.

Between June and early August, I made four additional trips to the study area totaling twenty days of canoe and pedestrian reconnaissance and fire-scar sampling and eight days of canoe travel to and from the study area. I accessed eastern Lac La Croix from the Echo Trail by way of the Nina Moose River, Nina Moose Lake, Lake Agnes, and the Boulder River, a trip of 25 kilometers one direction.

I implemented two approaches to surveying and sampling within the study area. First, I located sampling sites by systematically paddling and walking island and mainland shorelines in search of even- and mixed-aged stands of pine. I used a study area map with real-color aerial imagery (one-meter resolution) to locate pine stands in the field and determine their approximate size and extent. Because my primary field objective was to collect data on surface fire frequencies for individual island and mainland locations, my sampling targeted areas of pure and mixed red pine – a forest type known to persist amidst frequent surface fires. Due to well-drained soils, south and west exposures, and low fuel consumption by past fires, I found that these sites are more likely to have experienced and retain material evidence of periodic surface fires. My targeted approach to pedestrian survey and sampling yielded an overwhelming majority

of my datable cross-sections.

The second sampling method I used was a grid of 32 search points placed at the geometric center of each General Land Office-delineated quarter section within the study unit (Figure 3.4). Nine of the 32 search points were located over water. Of those nine search points, five were close to land and I surveyed the nearest shoreline instead. I removed the remaining four points (6, 10, 11, 26) from the grid search. I visited and searched a total of twenty-three grid points for fire-scared material. A search radius of twenty meters was used at each grid point but the search area was generally greater when considering the area traversed to reach each visited point. Grid sampling was conducted in a good faith effort to determine if systematic reconnaissance of all forest types across the study area might have fire-scarred materials with potential for tree-ring based fire reconstructions. Only four of the twenty-three grid points I visited contained fire-scarred trees. All four of these grid points were located on the shorelines of islands or a mainland unit and would have eventually received targeted pedestrian survey. Grid points at interior locations were typically dominated by aspen and birch and had no living or dead fire-scarred pine. Due to accessibility issues (e.g. swamps, thick hazel and fir), I did not conduct searches at grid points 7, 15, 16, 19 and 21. Real color aerial imagery (one-meter resolution) was helpful in determining general forest type (red or mixed pine vs. other) at these unvisited grid points. Through aerial image interpretation I determined the five unvisited interior sites were determined to be without a current pine component, greatly decreasing the sites' potential for having well-preserved pine stumps.

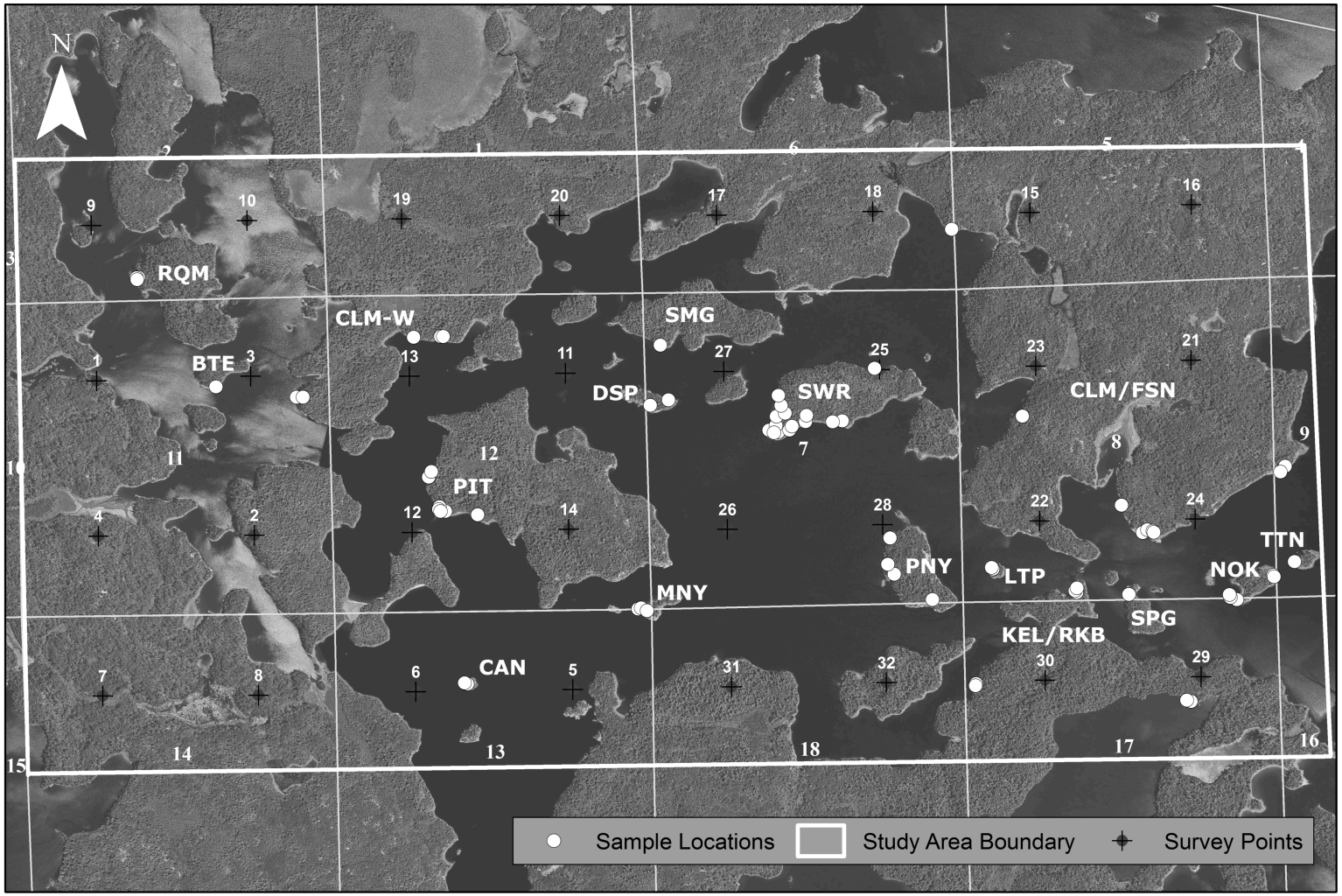



**Figure 3.4**: Study area map with a 32-point survey grid and 71 plotted sample locations.

### *Sample Collection*

Each stand of red pine I visited was thoroughly searched for evidence of past fires. I examined the bases of living, dead, downed, and remnant red, white, and jack pine for fire-induced scars and signs of occluded fire-induced wounds. For sampling purposes, I defined a fire-scar as the death of a triangular- or dome-shaped cambial section of a tree's bole occurring at ground height. Other evidence I used to confirm fire-induced cambial injury included smooth and regular wound margins, charred wood or bark within the wound, multiple healing lobes at the wound margins, and the absence of adjacent wind-thrown trees.

Current research restrictions designed to protect the wilderness character of the BWCAW prohibit the collection of full and partial cross-sections from living and standing-dead pine. As a result, my collection of full and partial tree cross-sections was limited to dead and downed pine and remnant stumps. However, I recorded the locations of heavily-scarred, living and standing-dead pine with the possibility of returning to sample them at a later date under less stringent sampling guidelines.

Many of my sampling areas had relatively high densities of remnant stumps and dead, downed trees. In these situations, I searched the whole island, or the full extent of the stand for fire-scarred material, prior to sampling, to ensure focused collection of samples with the most data potential. Remnant stumps and downed trees with evidence of multiple fire events, minimal rot, maximum annual growth rings, and the fewest number of necessary saw cuts were the first to be sampled. Whenever possible, I dispersed sample collection across the full extent of island and mainland areas to maximize

sampling coverage and to aid in the areal reconstruction of past fire events.

The overwhelming majority of remnant stumps I observed in the field were identified as red pine. Repeat cambial damage from surface fires promotes resin build-up in the lower bole of red pine. When these trees die and rot, partial stumps are left behind that are relatively resistant to decay due to their high resin content. These red pine stumps have a distinct, resinous scent when cut that distinguishes them from other types of remnant wood. Even in the absence of this distinguishing characteristic in the field, the anatomical features of red pine, as observed under magnification, allow confident verification of species type in the lab (Figure 3.5). While I observed living and dead fire-scarred white pine and jack pine in the field, their wood appears to have a significantly shorter residence time on the landscape, quickly succumbing to rot, even when fire damaged.

I harvested samples using a one-man crosscut saw and a more compact 61cm arborist handsaw. The majority of samples I collected were full, radial sections of stumps. Several full cross-sections were collected from downed trees. Partial cross-sections were preferred on occasion to reduce the size and weight of unnecessarily large samples. I carefully inspected sampled stumps and downed trees to determine the appropriate bole sampling height. While stump sampling at ground height was desirable to better estimate the decade of tree germination in the laboratory, wood erosion caused by decay, disease, insects, and heavy scarring from repeated fires made optimal bole sampling heights, on stumps and downed trees, highly variable, ranging from 0 to 120cm above ground. Often

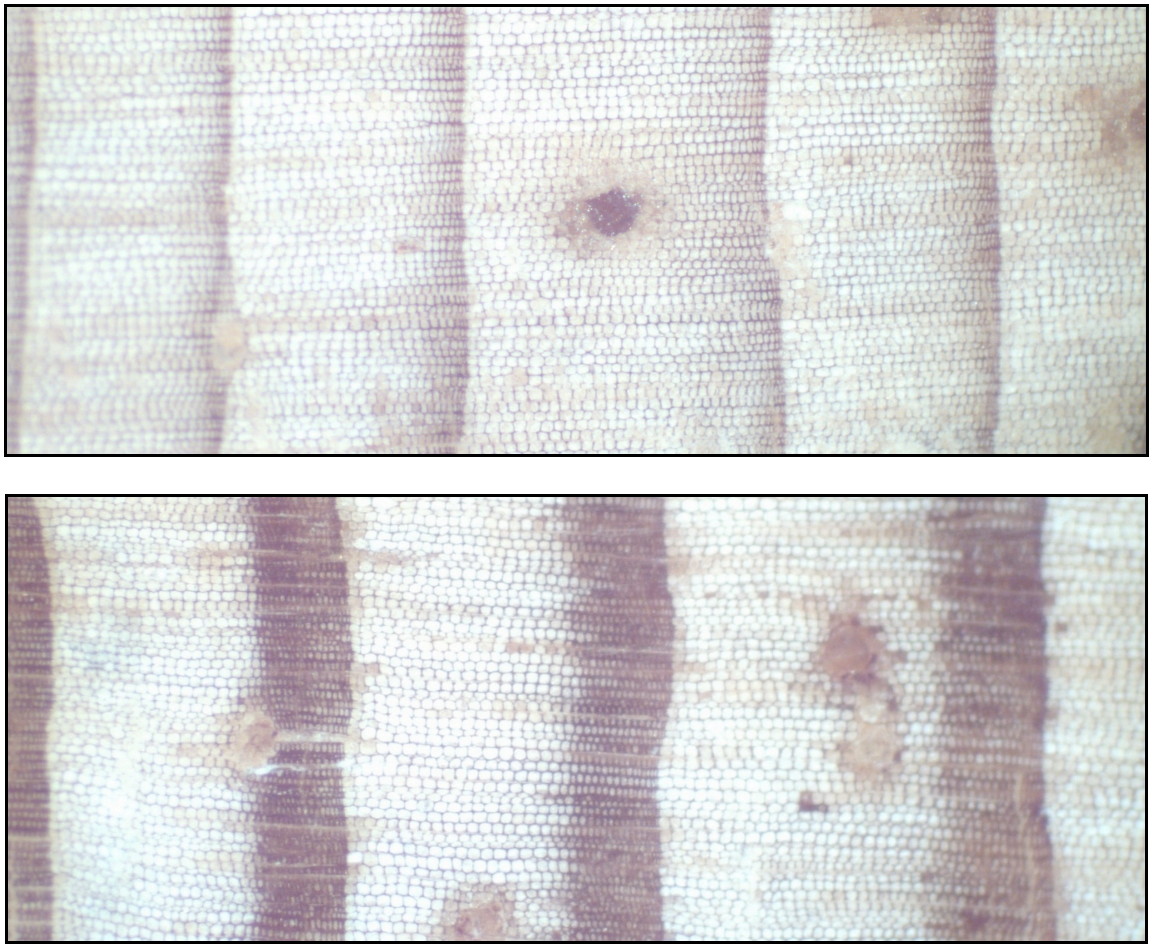


**Figure 3.5**: Radial view of white pine (top) and red pine (bottom) cellular structure under 0.63x magnification. The transition from early- to late-wood (light to dark tracheid cells) within each annual ring tends to be gradual in white pine and more abrupt in red pine.

I cut and inspected several cross-sections from a single stump before the highest quality sample with the greatest number of observable fire scars and growth rings was labeled and bound with plastic wrap (Figure 3.6). I generally cut cross-sections 15 to 20 centimeters thick to minimize breakage during sample transport. On numerous occasions heavily decayed samples were cut and discarded in the field due to an insufficient number of growth rings for use in crossdating (less than 100 years). In many instances, I was able to locate and collect an alternative fire-scarred sample nearby.

At each sample location GPS coordinates were collected, the point was plotted on a paper map, and photographs were taken of the sampled stump (Figure 3.7). Scar direction, number of observable scars, sample cutting height (from stump base), bole diameter at sample height were recorded at each site along with a narrative description of the site's physiography (e.g. vegetation, soil, slope, aspect, distance from water). Trees exhibiting the greatest number of fire scars were of primary interest and were generally sampled first. Often two or more adjacent stumps were sampled to ensure the most complete record of fire events for their location and to crossdate individual fire events among several neighboring trees, consistent with the principle of replication (Fritts and Swetnam 1989). However, the isolation of the wilderness study area, the logistics of transporting samples by canoe and portage pack, and the labor involved with fire-scar sampling by handsaw encouraged a somewhat restrained sampling approach consistent with wilderness ethics.

I also sought out long-lived, red pine trees without evidence of fire damage to construct a living-tree chronology of red pine growth for eastern Lac La Croix. I collected increment cores from selected trees using a 46cm increment borer (5.15mm core width). Red pine exhibiting old-growth characteristics were cored at least twice to extract a core terminating as near as possible to each tree's innermost ring. I initially cored each tree at its base, transitioning to sampling at chest height when rotten cores were extracted lower on the tree. I encountered rot in approximately 50% of the red pine sampled. Two unsuccessful attempts to extract solid cores did not always negate the success of a third coring attempt on a different height and aspect of the same tree's bole.

**Figure 3.6**: Cut and wrapped red pine stump sample with GPS for scale.

**Figure 3.7**: Remnant red pine stump at water's edge with an inner-ring date of 1654 and outer-ring date of 1875.

Large diameter red pine with thick, sinuous branches, low-volume crowns, and red-orange flakey bark generally exhibited the greatest number of annual rings. All tree cores collected were stored in paper straws and assigned identification codes with notes taken on the tree's location, diameter at breast height, core sampling height(s), and general tree/site characteristics.

***Laboratory Methods***

I prepared cross-sections and cores following standard dendrochronological procedures described by Stokes and Smiley (1968). Large cross-sections were frequently reduced in thickness, and sometimes width, using an industrial bandsaw. Brittle and crumbling cross-sections were mounted to a 3.2mm plywood backing with carpenter's glue. I exposed the surface of each sample with progressively finer grits of abrasive paper, beginning with a belt sander and finishing by hand until individual tracheid cells, resin ducts, and annual-ring boundaries were easily distinguishable. The belt sander was used with industry-standard grits ranging from 50 to 400 (348-23μm); hand sanding was completed with 20 and 15μm grit paper. Well-prepared, highly polished surfaces are absolutely essential in the identification of false, micro, and locally absent rings while crossdating and to determine the accurate placement of fire scars within a series of annual rings (Kipfmueller & Swetnam 2001). Poorly prepared sampled surfaces are possibly the greatest cause of error in tree-ring based studies.

With samples properly prepared, I counted the annual rings of the cross-sections, beginning at the sample's innermost ring or the tree's pith and then counting outwards

using a fine-point pencil and stereo-microscope with 6.3-40x magnification. Ten, fifty, and one hundred year sets of rings were marked with a fine-point pencil along with all annual rings recording fire events. Initially, I did not assign calendar years to individual rings because the year of death for each remnant pine sample was unknown. I inspected each fire scar carefully under high magnification (40x) to determine, with confidence, its position within the annual rings of each sample. A second dendrochronologist experienced in fire scar analysis verified the placements of many fire scars. Dormant season fires were always treated as spring fires due to the greater likelihood of human and natural fires occurring before leaf-out, based on the best knowledge available of traditional fire use practices and historic fire seasonality in northern Minnesota (Lewis 1983, Mitchell & Conzet 1927). I made this spring fire assumption to ensure consistency in assigning calendar years to dormant season scars. This assumption may be subject to change with further research.

Ring-width variability was evident when visually inspecting full cross-sections (Figure 1.4) but growth releases and suppressions from repeated fires and associated stand dynamics made it difficult to crossdate samples using the graphical method of skeleton plotting (Stokes & Smiley 1968). Instead, I measured and statistically crossdated cross-sections as floating chronologies against a regional master chronology of red pine growth. I measured each sample's growth rings to the nearest 0.001mm using a Velmex™ measuring system (Velmex Inc., Bloomfield, NY USA) and a sliding-stage micrometer mounted with a wide-berth measuring platform. The measuring bench set-up was connected to a computer running MATLAB® with a toolbox of tree-ring

measurement and analysis functions created by Dr. David Meko from the University of Arizona's Laboratory of Tree-Ring Research. I measured full cross-sections with multiple radii to account for changes in ring-curvature and to avoid rot, insect damage, and distorted growth rings caused by growth responses to cambial damage. Tree-ring measurements were exported from MATLAB® into computer program COFECHA (Holmes 1986, Grissino-Mayer 2001) where ring-widths from individual samples were compared against an existing 300+ year master chronology of red pine growth for the western BWCAW (Kipfmueller et al. 2010). I considered samples initially dated when the majority of correlation coefficients for 50-year segments of annual ring widths (with 25-year segment overlap) were greater than 0.35 and marker rings determined from the area's master chronology were determined to be properly aligned within the series following visual inspection. The ability to compare fire event dates and marker years among several samples from the same island or mainland location provided an additional opportunity to confirm the accurate dating of each sample and its recorded fires. In this study, the marker rings used for dating were very narrow, the most consistent of them being the year 1804 (Figure 1.4), which was often manifested in cross-sections as a locally-absent or micro-ring but never missing. Other useful but less consistent marker years were 1739, 1821, and a series of rings in the mid-1860s.

I set aside samples that did not date with the regional master chronology and later compared them against a new master chronology developed from the increment cores collected from old-growth pine on eastern Lac La Croix. Several problem samples that would not date satisfactorily against the regional master chronology did date against the

local master chronology. I could not date six of 77 cross-sections due to low inter-annual growth ring variability, ring distortion from fire damage, and/or insufficient chronological overlap between the master chronology and the undated remnant wood.

I frequently observed micro-scars or scarlets on samples (Figure 1.4) – generally embedded in the growth rings following a single fire event evidenced by heavy cambial damage to the tree. In most samples, I observed scarlets in pairs, and at times, in sets of up to seven. While I cannot be certain that these scarlets were not caused by repeat, low-intensity surface fires, the scars have been treated here as healing anomalies and excluded from the fire history reconstruction. Other fire history researchers have favored this cautious approach due to uncertainty and the low probability of annual fire events in a single location (C. Baisan, personal communication, 2012). I made exceptions with several samples where scarlets were treated as true fire events. To be considered true fire scars the injury had to be at least one of the following: 1) large enough to determine the scars' placement within the samples' annual rings, 2) present on both sides of the trees' scar face, and/or 3) have healing seams or calluses visible along the healing lobe of the trees' catface. This conservative approach to determining fire scars may exclude light damage caused by frequent, low-intensity surface fires.

I developed composite fire histories for thirteen island sites, three mainland sites, and for the study area as a whole. I used fire charts to visualize spatial and temporal patterns of fire occurrence across the study area. I treated each sampled island within the study area as a site, although sample clustering often made the true site size much smaller than the island itself. All three mainland sites have a greater areal coverage than the

island sites due to dispersed sampling along the lakeshore. Mainland samples were assigned to their respective sites based on proximity. Two of the three mainland sites are located on the south end of Coleman Island, but due to Coleman Island's large size (≈ 6.5 km west-east and ≈ 6.7 km north-south), I classified the sites here as a mainland units. Two of the 28 islands within the study area, including the Requiem (RQM) sample site, are not true islands as they are connected to a mainland by a narrow isthmus. For the purpose of this study, these two landforms are almost entirely surrounded by water and were treated as forest isolates.

I calculated standard fire history statistics including composite mean fire intervals (MFIs) and fire interval ranges for each of the 16 sites. The mean fire interval is an arithmetic average of fire frequency for a given area and time and was determined by taking the mean of all calculated fire intervals (the number of years between successive fires) over a given length of time. I developed composite MFIs for sites rather than single tree MFIs, due to the tendency for single trees to remain unscarred after some fire events (field and laboratory observation), thus providing a less complete record of fire for an area. I also calculated composite MFIs for combined island and mainland sites by historic time period and for the full study area over the entire recording period. The recording period is defined here as the number of years between the first and last tree-ring reconstructed fire within the area of interest, whether it is a single site, a combination of sites, or the full study area.

The primary time periods used for MFI calculations within the reconstruction include the *Early Pre-suppression Period* (1700-1799) and the *Late Pre-suppression*

*Period* (1800-1899). A continuity of Ojibwe occupation in the Lac La Croix region since at least 1736, the presence of other indigenous groups in the region prior to 1736, and the conspicuous absence of logging and Euro-American settlement on Lac La Croix before the 20th century makes the creation of pre-suppression land use periods somewhat arbitrary. For this reason, I simply divided the reconstruction prior to 1900 into three consistent, 100-year periods, which includes the core periods discussed above and an earlier *Fading Record Period (*1600-1699). I designated the last 100-year period from 1910 to present (2009) as the *Fire Suppression Period* with the formation of the Superior National Forest in 1909 and increased effectiveness in fire suppression activities from 1910 onward. Both the *Fading Record Period* (1600-1699) and the *Fire Suppression Period* (1910-2009) are difficult to statistically compare to the core portion of the record (1700-1799 and 1800-1899) due to a reduced number of recording samples over these periods of the reconstruction.

I obtained fire atlas data from the Superior National Forest for the *Fire Suppression Period* including fire year, location, cause, and size to supplement the 20th century portion of the tree-ring based fire reconstruction. Exact calendar dates (including month and day) and other details related to each suppressed fire were not available. Considering the Superior National Forest's commitment to fire suppression efforts since its inception in 1909, I have treated the SNF's fire atlas record as a reasonable proxy of fire occurrence within the study area over the last 80 years. There is a high likelihood of missing fire atlas data prior to the first logged fire year in 1929. The complete absence of fire atlas data from 1910 to 1928, despite a tree-ring reconstructed island fire occurring in

the study area in 1923, is a strong indication of the fire atlas' limitations over the earliest portion of its record.

I created fire maps with the locations of recording stumps for all fires occurring at more than one site (multi-site fire years) to visualize fire synchrony and examine each fire's potential coverage across the study area. I also compared my tree-ring reconstructed fire dates with fire years for the same area as reported by Heinselman (1973, 1996) to determine if my current, crossdated fire records corroborate his original fire and stand-origin maps.

I tested the relationship between fire occurrence within the study area and regional drought using Superposed Epoch Analysis (SEA) over a five-year window containing each reconstructed fire year, the three preceding years, and one year after. I conducted the SEA for both multi-site site fire years and for the total reconstruction of fire years across the entire study area. A tree-ring reconstruction of summer (June-August) moisture availability, the Palmer Drought Severity Index or PDSI (Palmer 1965), was obtained from the North American Drought Atlas (Cook et al. 2004) for the Lac La Croix region (grid point 197). Average deviations from normal PDSI for each year within the five-year window were calculated based on all fire events of interest and 95% bootstrap confidence intervals were calculated using a randomized Monte Carlo simulation of 1,000 iterations. An average departure from normal in any year greater than the calculated confidence intervals was used to identify a significant relationship at the 95% level between moisture availability in that year and the fire events of interest.

## RESULTS

### *Field Observations*

I visited and searched all 28 wooded islands within the study area for evidence of past fires, but samples were only collected from thirteen islands, due to the absence of remnant fire-scarred material. About half of the 15 unsampled islands had living or standing, dead trees exhibiting fire damage that were not sampled due to wilderness sampling restrictions. The remaining islands had no fire-scar evidence of past fire events – explained by either past high-severity fires eliminating previously fire-scarred trees or the complete exclusion of fire events from the site over the last three centuries.

Islands tended to have more and better-preserved fire-scarred material to sample than mainland sites and it was rare to locate fire-scarred materials in areas where red pine was not currently a primary overstory component. The amount of fire-scarred material within the study area was greatest on shorelines with the frequency and density of remnant and living fire-scarred trees tending to decline with increasing distance from shorelines. A large majority of these living and dead fire-scarred pine had scar faces oriented away from the nearest shoreline suggesting, based on the physics of fire-scar formation (Gutsell & Johnson 1996), that many fires ignited near the lakeshore and spread uphill, away from the water and into the woods. Remnant fire-scarred materials were most frequently found on the south and west aspects of island and mainland sites. The presence of fire-scarred material in these locations is likely a product of their dryness. Xeric sites tend to burn more frequently and at lower intensities (with reduced fuels) while also having lower rates of wood decay, relative to wetter sites.

It was uncommon to find pole-sized (10-30 cm diameter) red pine or other young timber with fire-induced scars. Over-mature and standing-dead red pine exhibited the greatest number of scars. This is not surprising given that a tree's increased residence time on a fire-prone landscape increases the probability of it being damaged by fire. But with many remnant red pine exhibiting fire scars at young ages (small diameters), this may also be treated as tangible evidence of reduced fire frequencies within the study area over the last 100 years. Evidence of surprisingly high surface fire frequencies prior to the *Fire Suppression Period* were observed in some areas. For example, a living red pine northwest of Fish Stake Narrows of ca. 1710 origin (estimated by increment core) exhibited 10 to 12 observable fire scars (Figure 3.8).

***Fire History Reconstruction***

A total of 71 crossdated, fire-scarred samples yielded 79 fire years from 255 dated scars over 297 years (Figure 3.9). The tree-ring record of growth derived exclusively from remnant red pine extends from 1590 to 2010 with the first fire reconstructed fire year recorded in 1636 and the last in 1933 (Figure 3.10). Fifty-three fires were reconstructed on islands and 36 within mainland units. The most reliable portion of the record (n>50) begins in the early 1720s and extending to the early 1860s (Figure 3.11). Nine of 71 dated cross-sections had outer-ring dates between 1815 and 1849 suggesting a stump residence time of 100+ years, even when accounting for the decay and loss of the remnant pines' sapwood. Eighteen of the reconstructed fires burned at least two disjoint sites. Three of these 18 multi-site fires – 1682, 1739, and 1752 – burned three to five sites

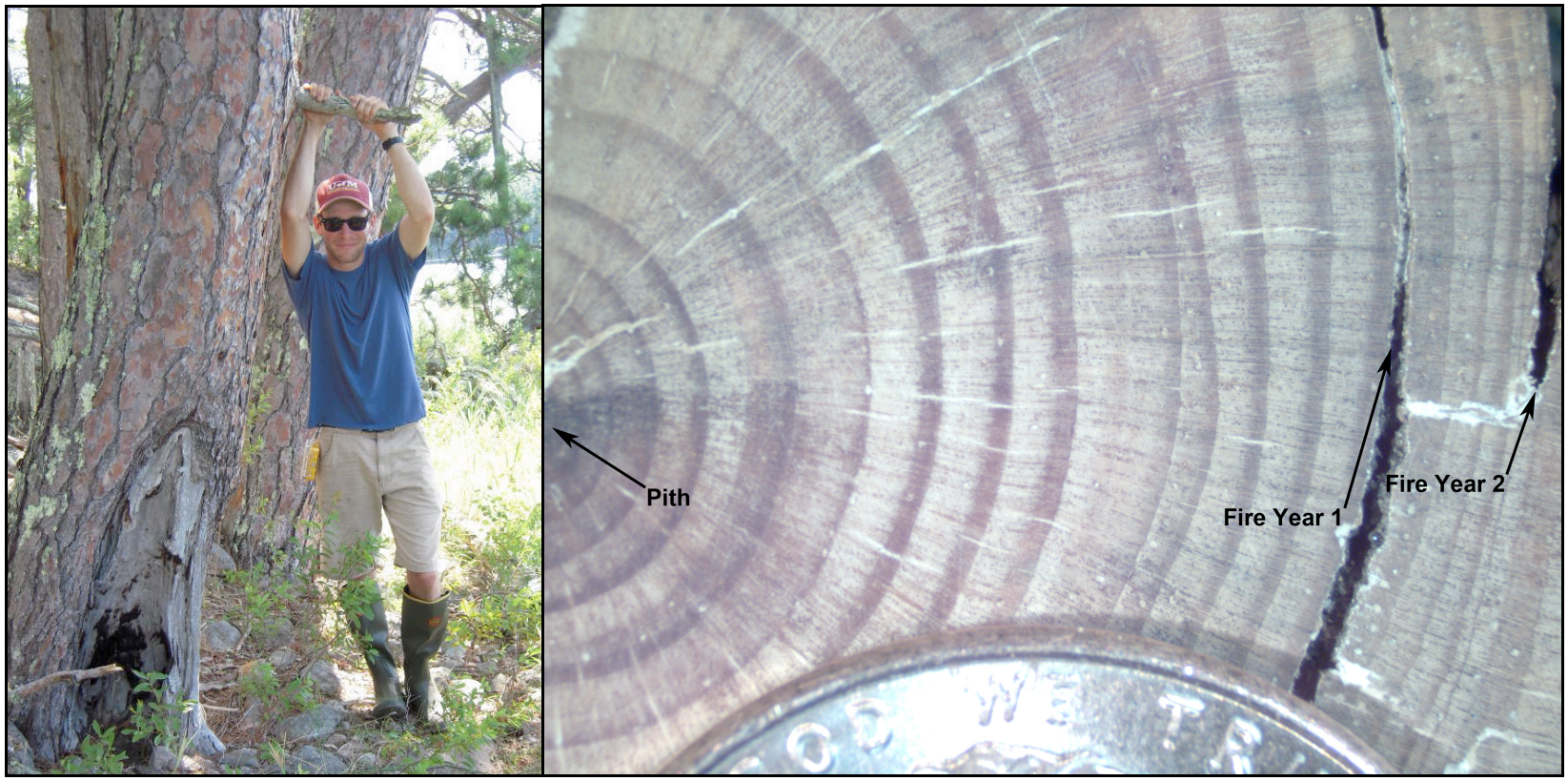



**Figure 3.8**: Evidence of frequent, non-lethal surface fires. Left: A living red pine with 10-12 observable fire scars with an estimated pith date of 1728 at chest height. Right: Undated stump sample found adjacent to the above tree with 16 years from pith to the first fire year and 20 years from pith to the second fire.

**Figure 3.9**: A radial view of a fully-prepared and crossdated red pine stump sample, including eight fire years (left) and the sample as found in the field (right).

(Figures 3.12-3.14). The other multi-site fires burned in 1712, 1749, 1758, 1759, 1784, 1820, 1825, 1846, 1849, 1865, 1871, 1891, 1896, 1901 and 1909. Despite 18 multi-site fires, fire chart and map visualization of the area's reconstruction shows fires have been predominately asynchronous and patchy throughout the majority of the fire reconstruction.

Median point and site fire return intervals provide the best measure of central tendency for the right-skewed fire return interval distribution (Figure 3.15). The point MFI for the study area is 34.1 years based on 184 intervals from 71 crossdated samples

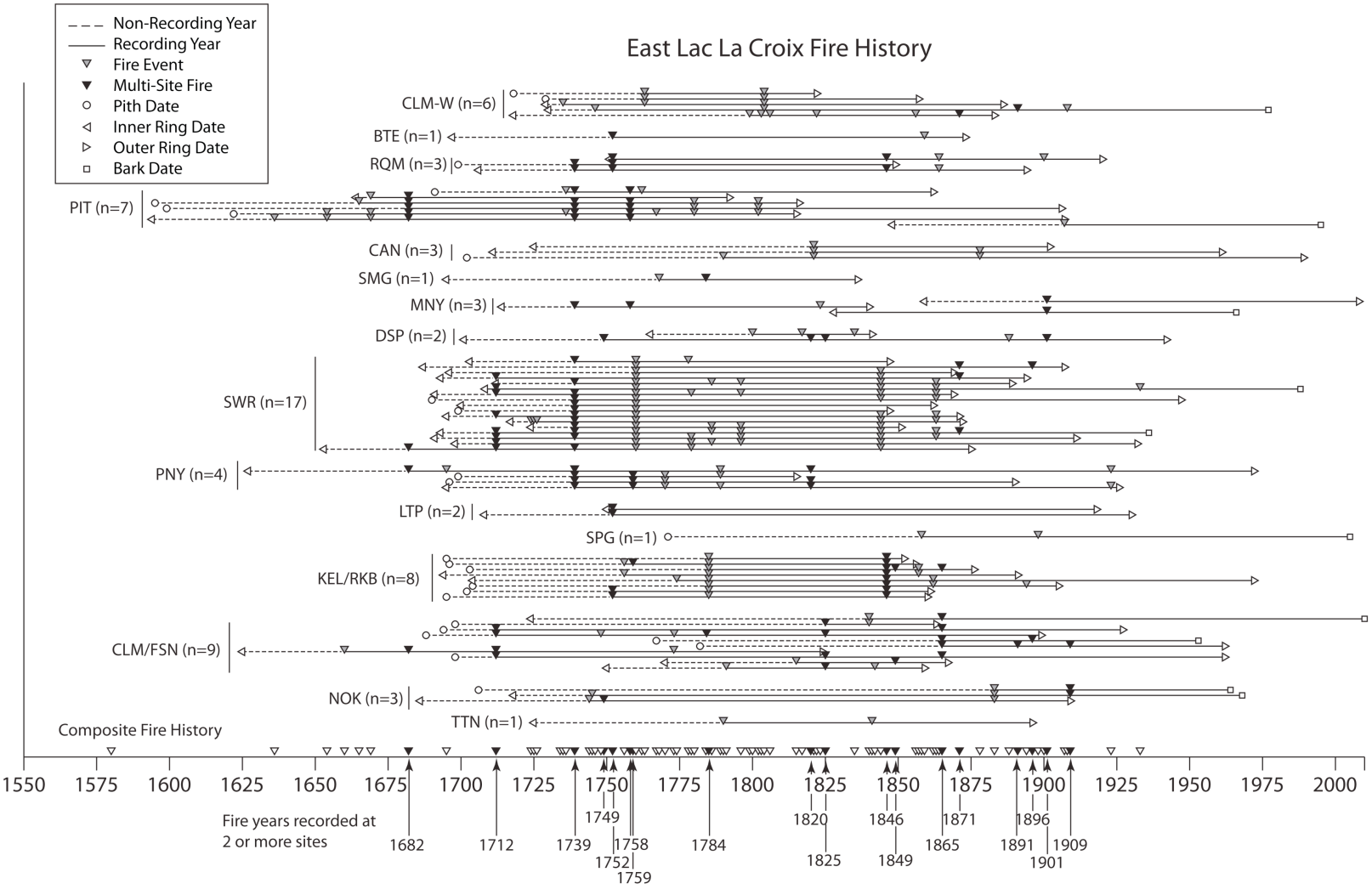



**Figure 3.10**: Fire history chart for all dated samples and sites.

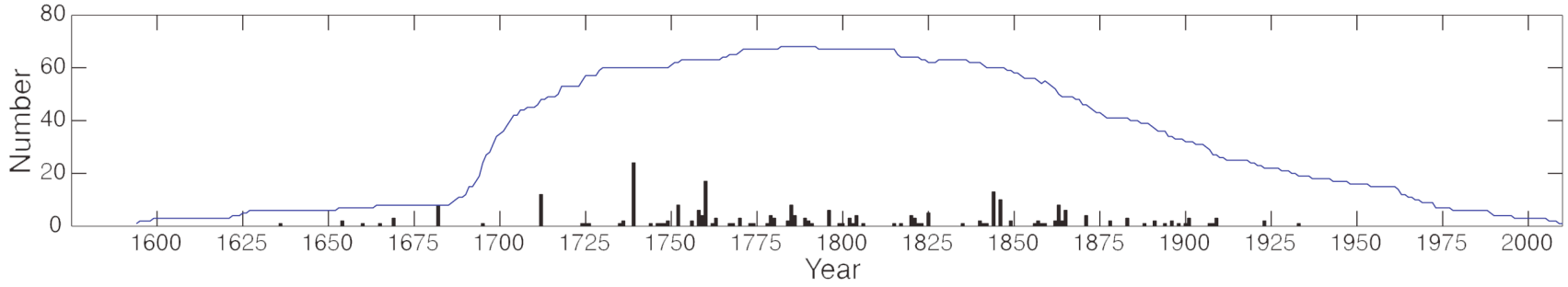



**Figure 3.11**: Sample depth (line) and number of samples scarred (bars) for the full study area. The number of scarred samples is not always the best indication of wide-spread fire events due to clustered sampling within study area.

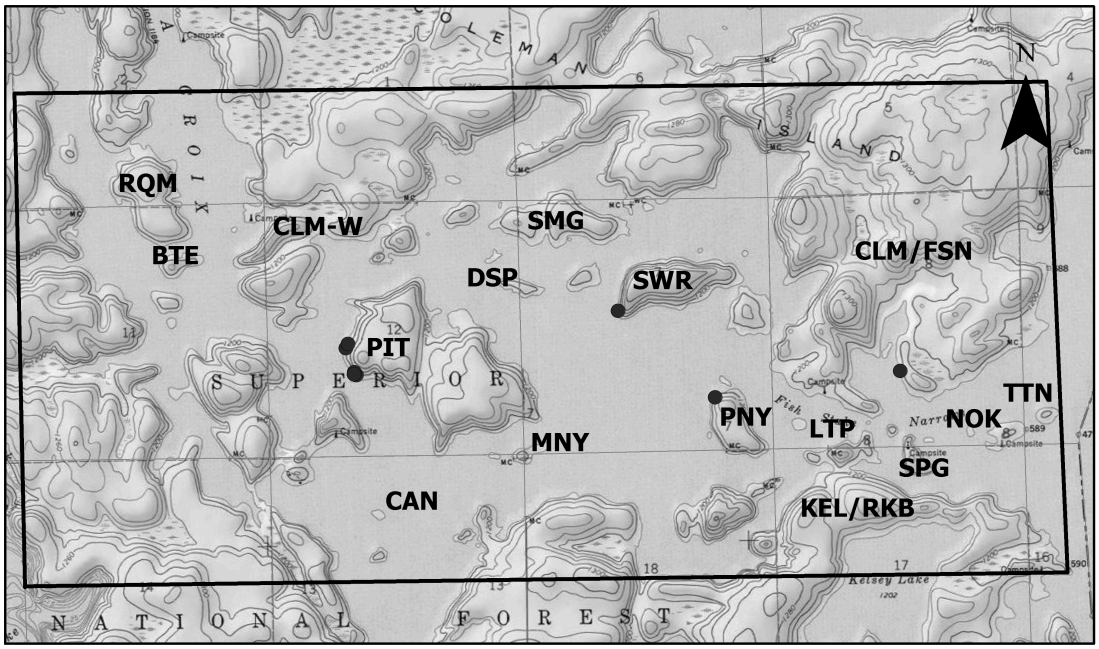



**Figure 3.12**: Point locations of each sample recording the 1682 fire with island/mainland site codes in bold text. See Figure 3.3 for all sample locations.

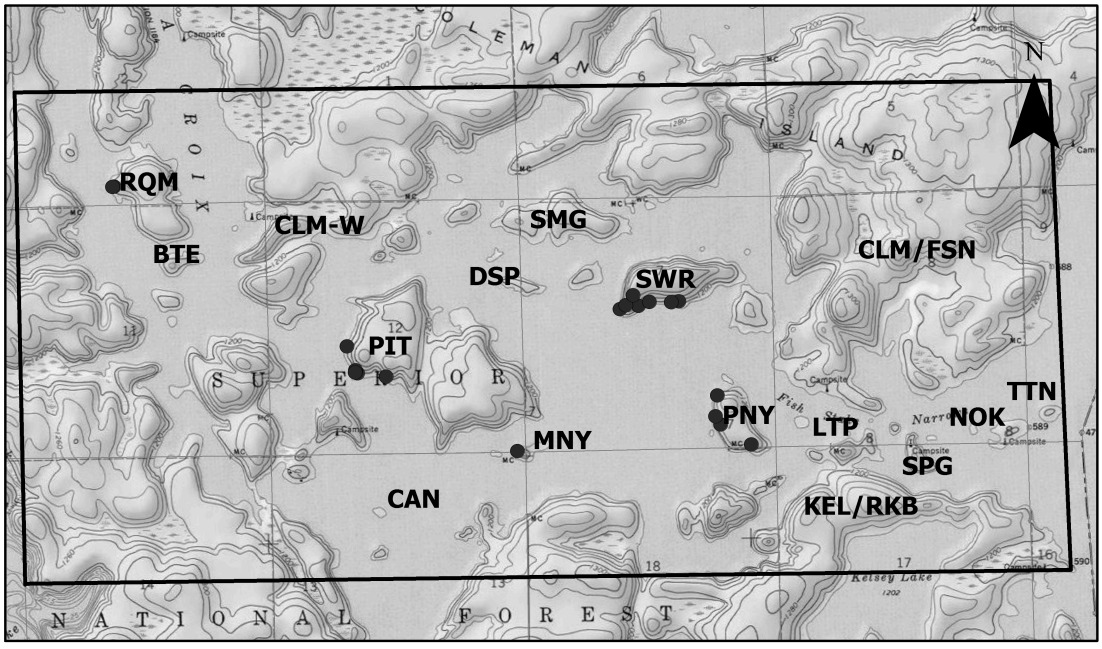



**Figure 3.13**: Point locations of each sample recording the 1739 fire with island/mainland site codes in bold text. See Figure 3.3 for all sample locations.

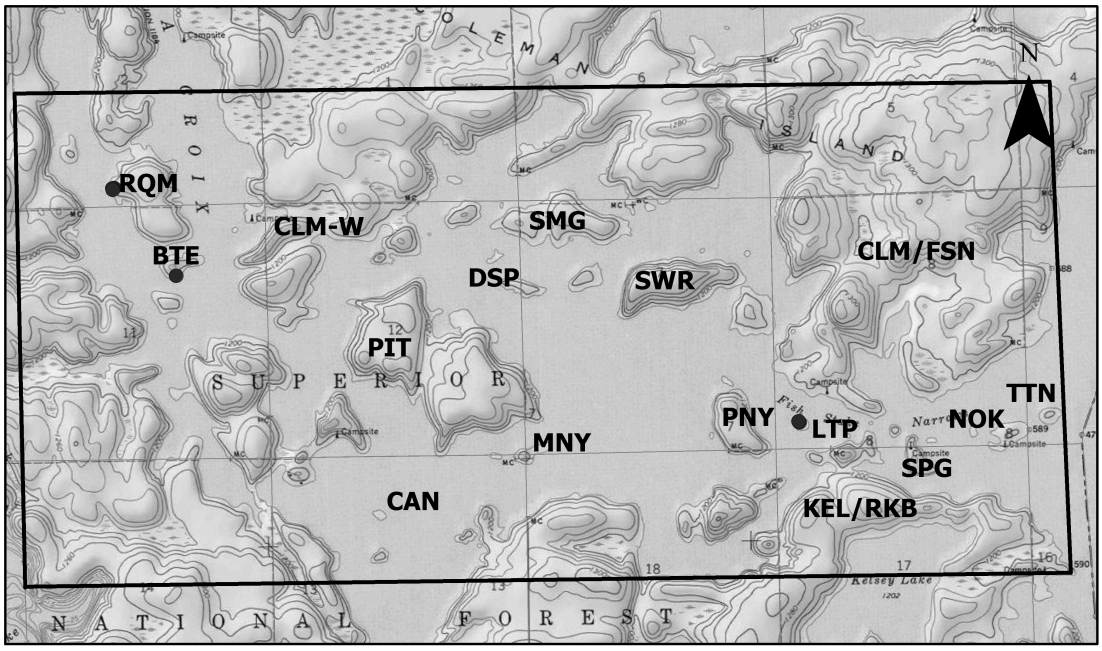



**Figure 3.14**: Point locations of each sample recording the 1752 fire with island/mainland site codes in bold text. See Figure 3.3 for all sample locations.

with a median fire-free interval of 22 years. The site MFI for the full study area is 24.3 years based on 89 fire-free intervals from 15 sample sites with a median fire-free interval of 17 years.

Composite fire chronologies were developed for 16 sites across the study area including 13 island and three mainland units (Figure 3.16). The composite mean fire interval (MFI) for the approximately 2,170 ha. study area from 1636 to 1933 is 3.8 years with site MFIs ranging from 14.2 years to 107 years over their respective recording periods (Tables 1 & 2). The mainland sites' MFIs were the lowest, ranging from 14.2 to 16.6 years, however several small island sites had MFIs similar to the larger mainland

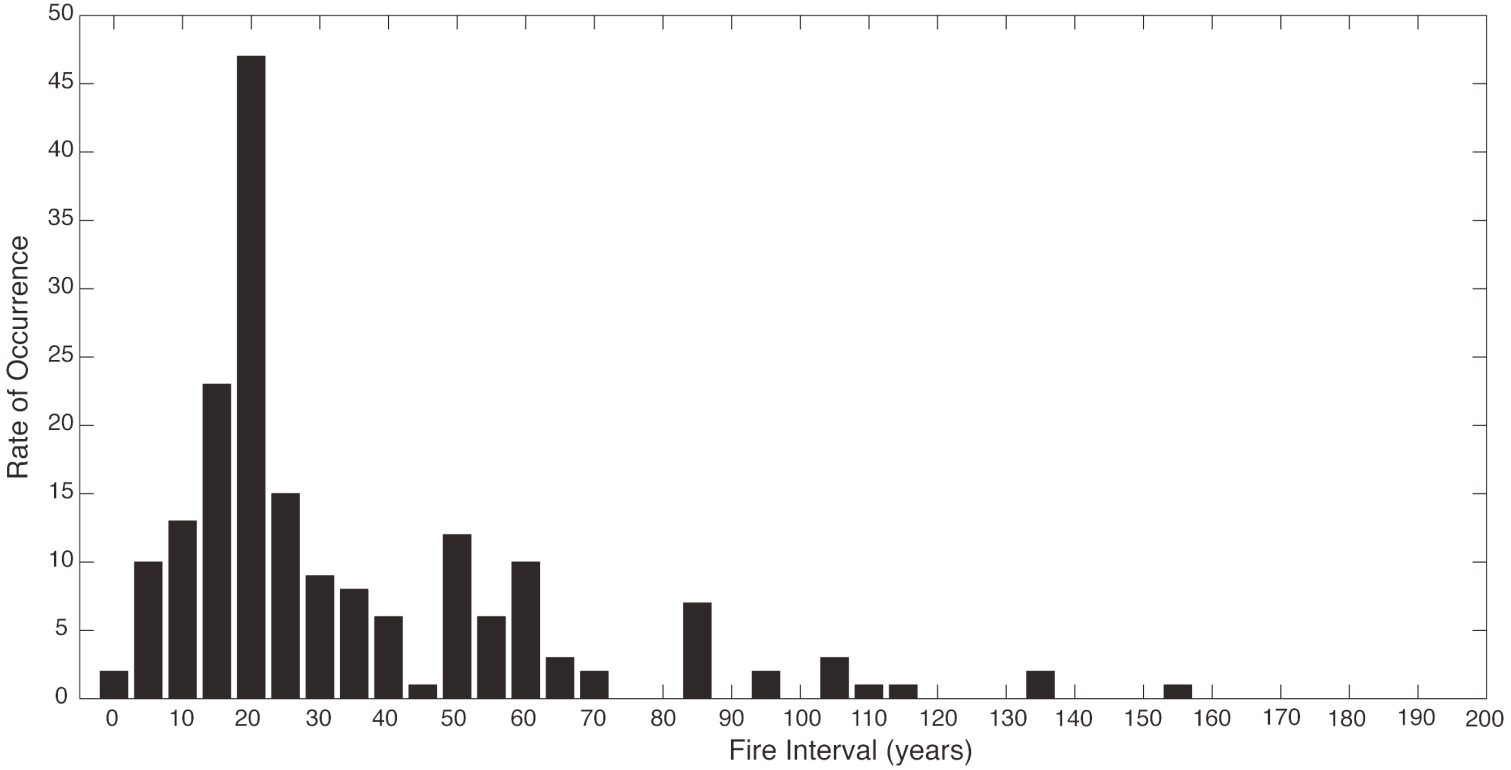



**Figure 3.15**: Fire interval distribution chart with each bar representing a five-year range of fire intervals. For instance, the largest bar represents the number of intervals in the 20-24 year range.

units. Shower Island (SWR) exhibited a MFI of 17.9 years over a 1682 to 1933 recording period. Pit Island (PIT) exhibited a MFI of 16.6 years over a 1636 to 1802 recording period. Disappointment Island (DSP) exhibited a MFI of 21.7 years between the years 1749 and 1901. However, only 10 of the 36 fire years recorded within mainland units also burned an island site leaving 43 fire years unique to a combined 13 island sites. The composite MFI for all the island sites was 5.7 years from 1636 to 1933 with the composite MFI for the mainland units being 7.1 years from 1660 to 1909.

The mean fire return intervals (MFIs) for the full study area during the *Early*-(1700-1799) and *Late Pre-Suppression Periods* (1800 to 1899) are 3.4 and 2.9 years (Table 2) with 33 and 35 fires respectively recorded for each period. If mainland fires are excluded from the calculations and a composite MFI for only the island sites is used, the MFI is 4.8 years for the *Early Pre-Suppression Period* (1700 to 1799) and 4.9 years for the *Late Pre-Suppression Period* (1800 to 1899).

My current fire reconstruction shows greater spatial and temporal complexity in the fire history record of eastern Lac La Croix than previously demonstrated by Heinselman (1973; 1996). Heinselman mapped nine stand-replacing fire events within the study area (Figure 3.16). With one exception (the year 1681), all of Heinselman's recorded fire years are present within my current fire reconstruction, although Heinselman's mapped and the current, reconstructed fire locations do not always coincide. For instance, Heinselman mapped 1864 as a widespread fire event within the study area while samples show that fires burned at different sites across the area in 1862, 1863, 1864, and 1865. The 1681 fire year recorded by Heinselman is represented in the

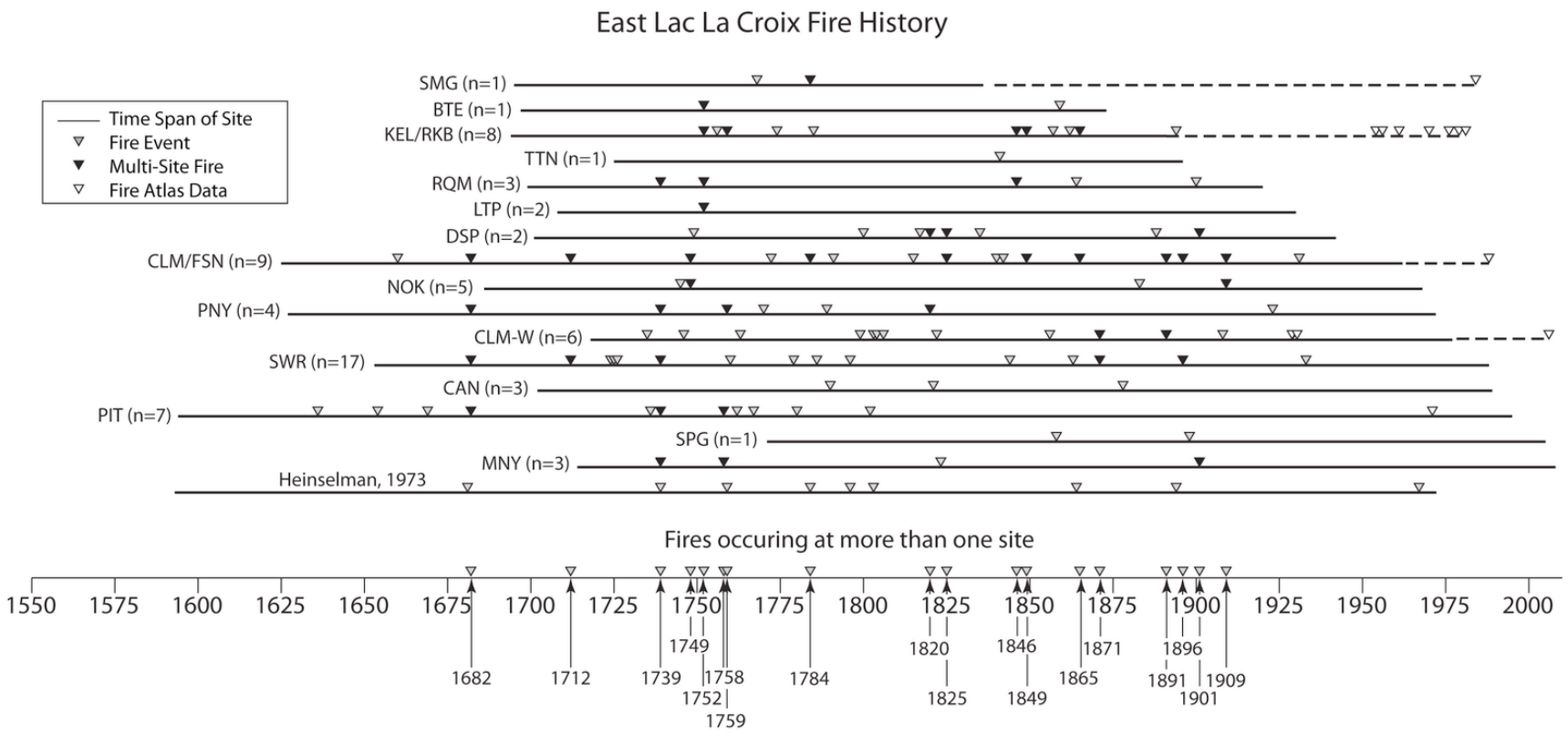



**Figure 3.16**: Composite fire chronologies for all 16 sites within the study area including three mainland sites – KEL/RKB, CLM/FSN, and CLM.

**Table 1:** East Lac La Croix Fire History Data by Island and Mainland Site

| *Site Code* | *Site Name* | *No. of Samples* | *Earliest Recording Year* | *Last Recording Year* | *First Fire Yr.* | *Last Fire Yr.* | *No. of Recorded Fires* | *Mean Fire Interval* | *Fire Free Interval Range (min- max)* |
|---|---|---|---|---|---|---|---|---|---|
| SMG | Smudge Island | 1 | 1695 | 1836 | 1768 | 1784 | 2 | 16 | --- |
| BTE | Butte Island | 1 | 1697 | 1862 | 1752 | 1859 | 2 | 107 | --- |
| KEL/ RKB* | Kelsey Lake & Rock Knob* | 8 | 1694 | 1972 | 1752 | 1865 | 11 | 14.2 | 4-61 |
| TTN | Teton Island | 1 | 1725 | 1896 | 1790 | 1841 | 2 | 51 | --- |
| RQM | Requiem Island | 3 | 1699 | 1920 | 1739 | 1900 | 5 | 40.3 | 13-94 |
| LTP | Little Pine Island | 2 | 1708 | 1918 | 1752 | 1752 | 1 | --- | --- |
| DSP | Disappointment Island | 2 | 1701 | 1942 | 1749 | 1901 | 8 | 21.7 | 3-53 |
| CLM/FSN* | Coleman Island East & Fish Stake Narrows* | 10 | 1625 | 2010 | 1660 | 1909 | 16 | 16.6 | 2-36 |
| NOK | Nook Island | 3 | 1686 | 1968 | 1744 | 1909 | 5 | 54 | 2-134 |
| PNY | Penny Island | 4 | 1627 | 1972 | 1682 | 1923 | 7 | 40.2 | 11-103 |
| CLM-W* | Coleman Island West* | 5 | 1718 | 1977 | 1735 | 1908 | 12 | 15.7 | 1-36 |
| SWR | Shower Island | 17 | 1653 | 1988 | 1682 | 1933 | 15 | 17.9 | 1-48 |
| CAN | Can Island | 3 | 1702 | 1989 | 1790 | 1878 | 3 | 44 | 31-57 |
| PIT | Pit Island | 7 | 1594 | 1995 | 1636 | 1802 | 11 | 16.6 | 3-54 |
| SPG | Sponge Island | 1 | 1771 | 2005 | 1858 | 1898 | 2 | 40 | --- |
| MNY | Money Island | 3 | 1828 | 2008 | 1739 | 1901 | 4 | 54 | 18-78 |

* ‘mainland’ site

**Table 2:** Mean fire intervals (in years) in the LLC study area by site type and time period. The full recording period is from 1636-1933 with the full tree-ring record spanning from 1590-2010.

| Site Type | | | | | |
|---|---|---|---|---|---|
| | *Full* | *Fading Record (1600-1699)* | *Early Pre-Suppression (1700-1799)* | *Late Pre-Suppression (1800-1899)* | *Fire Suppression (1910-2009)* |
| All Sites | 3.8 | 11.5 | 3.4 | 2.9 | 10 |
| Mainland | 7.1 | NA | 8.4 | 5.4 | NA |
| Island | 5.7 | 15.3 | 4.8 | 4.9 | 10 |
| | | | | | |
| Two Sample K-S tests of significant differences between the interval distributions ($p < 0.05$) | | | | | |
| Mainland vs. Island | SIG | Not tested | NS | NS | Not tested |

reconstruction as a multi-site, dormant-season fire in 1682 on all recording samples. The 1755-1759 fires Heinselman mapped are represented in the reconstruction as fires in 1756, 1758, 1759, and 1760 with both 1758 and 1759 being multi-site fires.

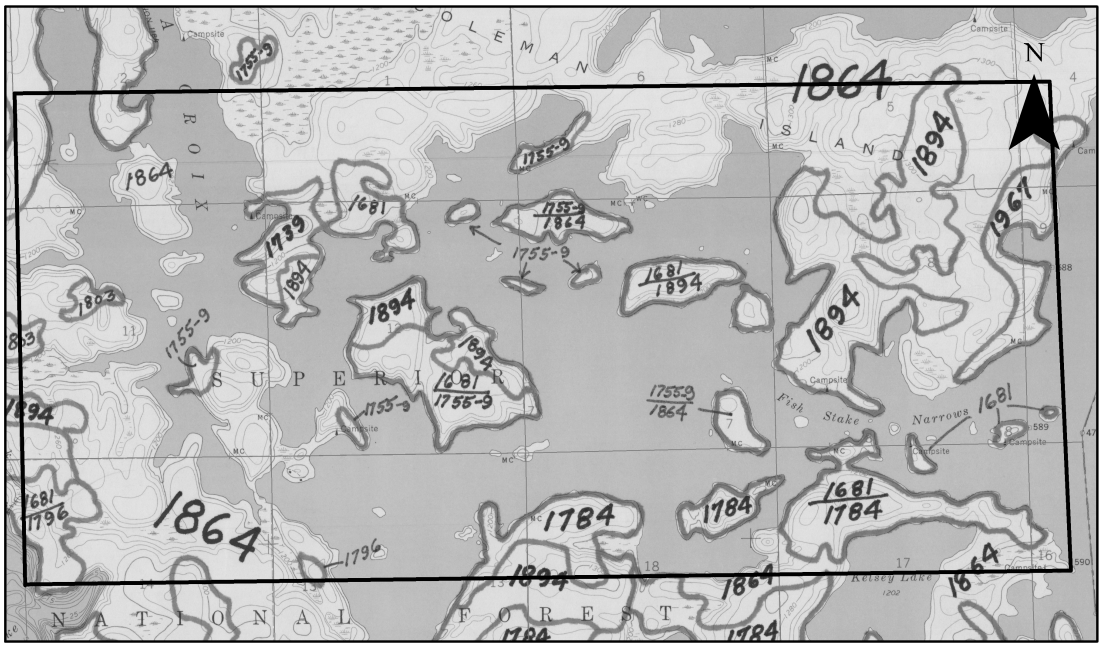



**Figure 3.17**: Heinselman (1973; 1996) fire year and stand-origin map for study area.

### *Fire-Climate Relationships*

When taken as a whole, the reconstructed fire years within the study area are not significantly associated with regional dryness. Based on Superposed Epoch Analysis, there is no significant association ($p > 0.05$) between summer drought, as represented by tree-ring reconstructed PDSI, and the occurrence of fire within this fire history dataset or in the three years preceding the fire year. This summer moisture and fire relationship remains consistent when conducting the SEA with just 18 multi-site fire years (Figure 3.18) and the study area's complete record of 79 fire years (Figure 3.19). Tree-ring reconstructed, summer PDSI values for the 18 multi-site fire years range from -2.5 (moderate-severely dry) in 1682 to +1.6 (mild-moderately wet) in 1901 with a mean of -0.4. The three largest fires within the fire reconstruction, as determined by the number of recording sites, are 1682, 1739, and 1752 with PDSI of -2.5, -1.4, and +0.2 respectively.

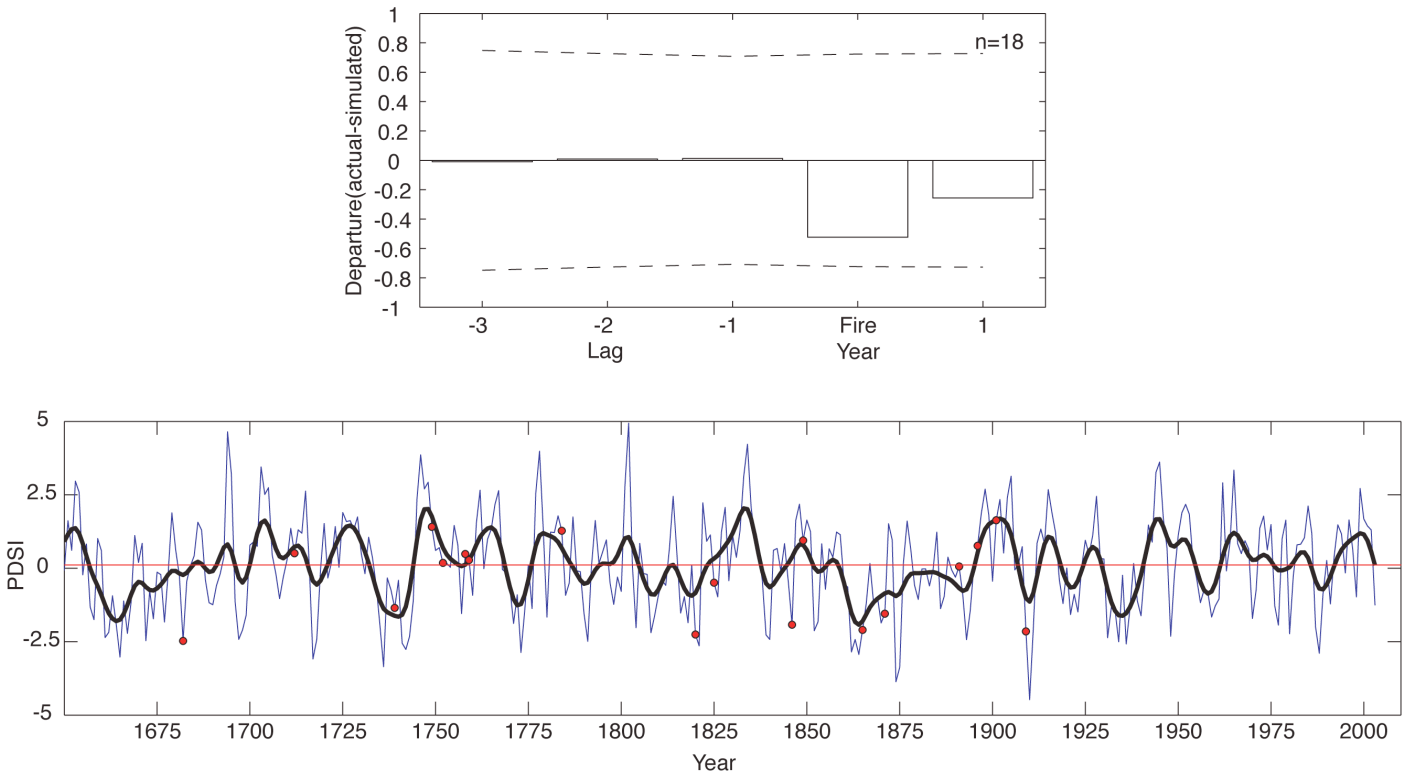



**Figure 3.18**: Superposed Epoch Analysis (SEA) of tree-ring reconstructed fires (dots) and PDSI (line) for the study area's 18 multi-site fire years. Positive PDSI is wet and negative PDSI is dry.

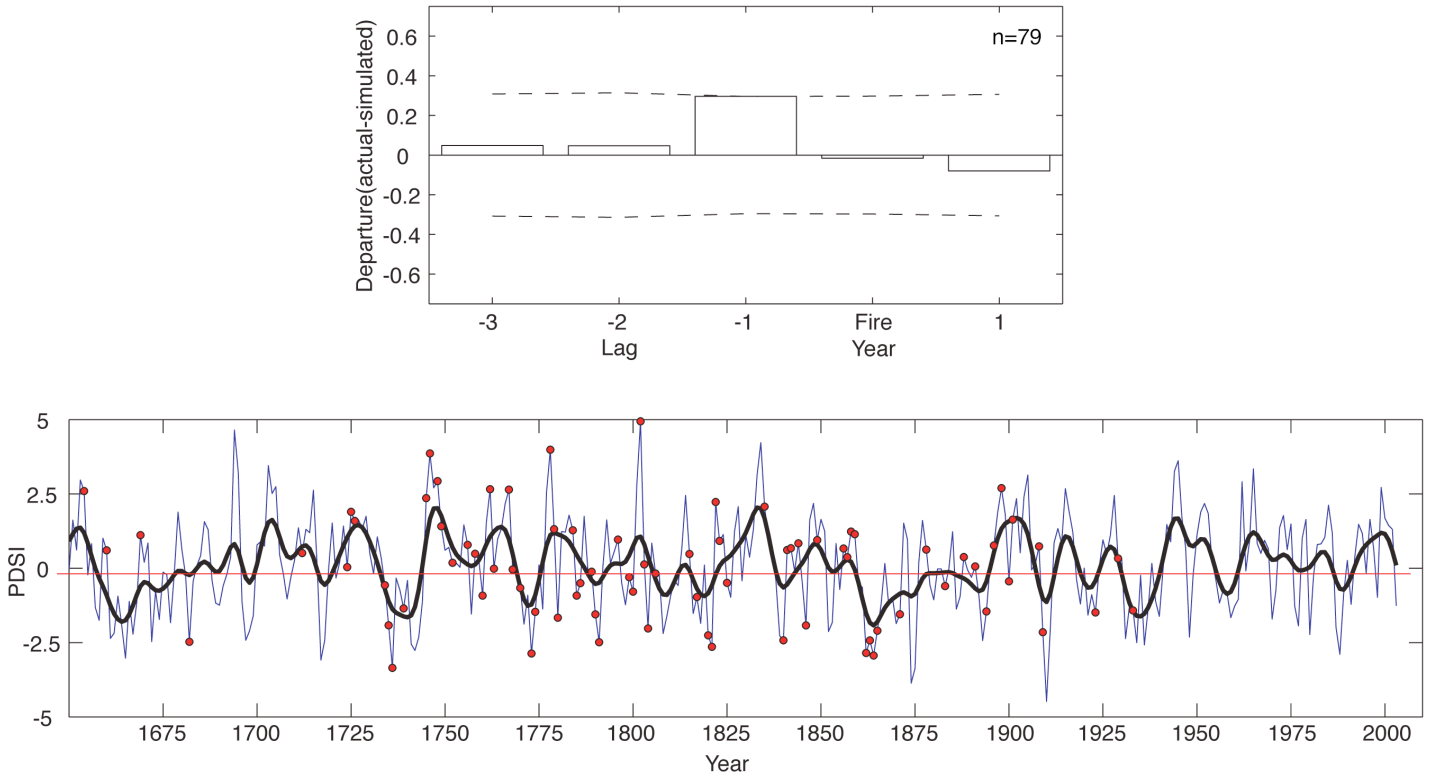



**Figure 3.19**: Superposed Epoch Analysis (SEA) of tree-ring reconstructed fire years (dots) and PDSI (line) for the study area's complete record of 79 fires. The growing season prior to each fire year tends to be wetter (PDSI > 0) than normal.

## DISCUSSION

### *Fire Regime Characteristics*

The mean fire return intervals observed on eastern Lac La Croix are similar to MFIs reported in the literature for other red pine forests in the Upper Great Lakes. The mean site fire return interval for this portion of eastern Lac La Croix is 24.3 years at the site level with a range from 1 to 134 years. Fire occurred somewhere within the study area every 3.8 years. These estimates of fire occurrence are comparable to the 22-year site MFI and full study area MFI of 8.8 years Frissell (1973) reported for the mixed-pine stands of Itasca State Park (with 32 fires between 1650-1922) and the MFI of 26.1 years Clark (1990) reported for Itasca State Park (between 1700-1920). Lac La Croix's mean fire return interval is higher than the MFI of 19.4 years that Loope and Anderton (1998) reported for select coastal pine stands along Lake Superior's south coast yet is in agreement with the observed fire return interval range of 25-35 years reported by Drobyshev et al. (2004) for Seney National Wildlife Refuge in Michigan's Upper Peninsula. Fire frequencies on eastern Lac La Croix are in agreement with Heinselman's (1981) reported fire frequencies for the mixed pine stands of the greater BWCAW with non-lethal surface fires occurring on an average of every 36 years with a fire interval range from 1-100+ years. In general, MFI comparisons among study areas should not be relied upon heavily due to differences in sampling design, study area size, and even MFI calculations.

The abundance of mature, fire-scarred red pine exhibiting multiple wounds across the study area reflects the occurrence of frequent, non-lethal surface fires at many island

and mainland sites – many of which were of limited spatial extent. The number of reconstructed surface fires (79 events) within the study area is much greater than the number of stand-replacing fires (9 events) as reported by Heinselman (1973, 1996) (Figure 3.20) and indicates the potential need for greater refinement of the BWCAW's current historic fire record. The frequent, low severity surface fires and observed structural complexity of many sampled red pine stands on eastern Lac La Croix are congruent with the recently quantified mixed-age structure of other virgin red pine stands in northern Minnesota (Fraver & Palik 2012).

### *The Case for Human Ignitions: Interpretation of Fire Frequencies and Fire-Climate Relationships*

Based on Superior National Forest fire atlas data for the study area, fire frequencies recorded on islands and some mainland sites during the 1700s and 1800s are difficult to explain by modern rates of lightning-ignition alone (Table 3). As would be expected, reconstructed MFIs for the three mainland sites in the study area are smaller than many of the island MFIs (Table 1) due to a larger sample area and a greater chance of fire spread from outside the study area. However, several islands within the study area, namely SWR, DSP, and PIT have MFIs similar to the mainland units. This is contrary to what would be expected given the size and insularity of these forest isolates (Heinselman 1996: 72). By removing known human-caused ignitions from the modern fire record (7 of the 20 recorded fires; Table 3), an initial proxy of 20th century lightning-fire occurrence for the islands can be estimated and includes a decline in fire occurrence over

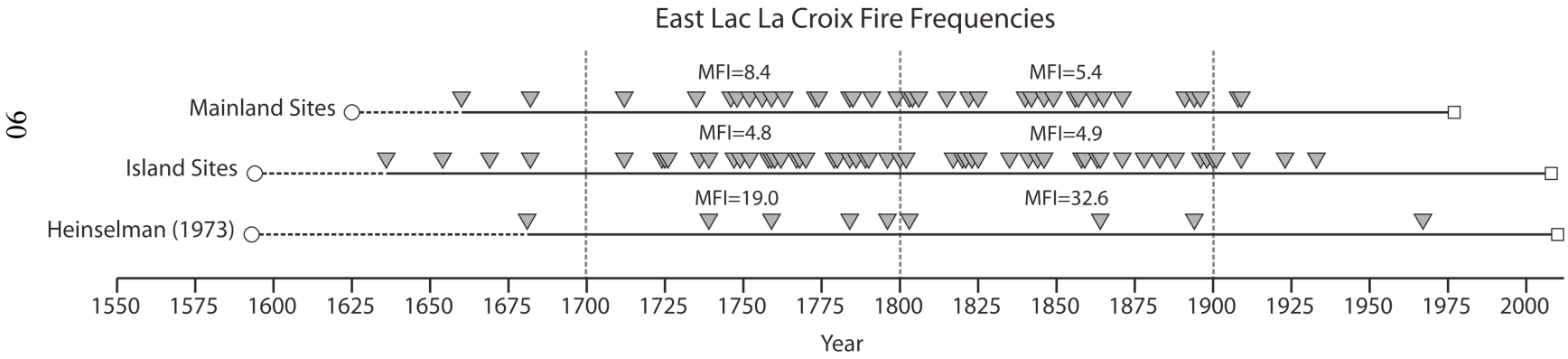



**Figure 3.20**: Composite fire histories for mainland and island sites relative to fire years as reported by Heinselman (1973, 1996).

the last 80 years. Only two of the thirteen lightning-ignited fires located and suppressed by the Superior National Forest from 1929 to 2012 occurred in island settings. Because the islands within the study area have wide, natural fire-breaks that limit fire spread, the decline in island fires in the 20$^{th}$ century cannot be attributed solely to a lower occurrence of fire spread from mainland to island areas (caused by mainland fire spotting). A decline in localized, island ignitions must be at least partially responsible. As an example, fifteen fire events were recorded on Shower Island between 1682 and 1933 with an MFI of 17.9 years, followed by a fire-free interval of 79 years from 1934 to 2012. The same conclusions may be drawn for several other islands within the study area including Disappointment, Pit, and Penny Islands with pre-suppression MFIs of 21.7, 16.6, and 40.2 years respectively over their site-specific recording periods.

Some fire history researchers have explained high lake-island fire frequencies in the boreal forest of Quebec based on the combination of biotic and abiotic factors affecting island fire environments. Bergeron (1991) attributed high fire ignition rates on the islands of Lake Duparquet, Quebec to island size, elevation, and isolation increasing the probability of lightning strikes and subsequent ignition of receptive fuels in dry woodlands. Drobyshev et al. (2010) further explained the phenomenon of high island ignition rates on Lake Duparquet with variations in local fire weather and higher probabilities of lightning strike occurrence on islands. Both studies discount humans as a potential ignition source. In contrast, Niklasson et al. (2010) suggested island fire frequencies shifts in a lake environment in southeast Sweden had been caused by changes

**Table 3:** Modern fire atlas data for study area from the Superior National Forest with 20 total recorded fires from 1929-2012 including seven human-caused and 13 lightning-caused fires. Only two of the 13 lightning-ignited fires occurred in island settings.

| *Fire Year* | *Cause* | *Location* | *Site Code (if applicable)* | *Acreage* | *Management Action* |
|---|---|---|---|---|---|
| 1929 | Lightning | Mainland | CLM-W | 2 | Suppressed |
| 1931 | Lightning | Mainland | CLM-W | 4 | Suppressed |
| 1931 | Human | Island | -- | <0.25 | Suppressed |
| 1932* | Human | Island | SWR | 2 | Suppressed |
| 1933 | Human | Mainland | KEL | <0.25 | Suppressed |
| 1938 | Human | Mainland | CLM-W | <0.25 | Suppressed |
| 1940 | Human | Island | -- | 2 | Suppressed |
| 1954 | Lightning | Mainland | -- | <0.25 | Suppressed |
| 1956 | Lightning | Mainland | KEL | <0.25 | Suppressed |
| 1961 | Lightning | Mainland | KEL | <0.25 | Suppressed |
| 1961 | Human | Island | SPG | <0.25 | Suppressed |
| 1967 | Human | Mainland | CLM/FSN | 116 | Suppressed |
| 1970 | Lightning | Mainland | -- | <0.25 | Suppressed |
| 1971 | Lightning | Island | PIT | <0.25 | Suppressed |
| 1976 | Lightning | Mainland | -- | <0.25 | Suppressed |
| 1979 | Lightning | Mainland | KEL | <0.25 | Suppressed |
| 1981 | Lightning | Mainland | -- | <0.25 | Suppressed |
| 1984 | Lightning | Island | SMG | <0.25 | Suppressed |
| 1988 | Lightning | Mainland | CLM/FSN | 0.5 | Suppressed |
| 2006 | Lightning | Mainland | CLM-W | 19 | Wildfire Use |

*1932 is represented in the fire reconstruction as 1933 due to ring-width interpretation of a fire scar at the location of the fire. The 1932 date is thought to be a transcription error in the atlas data and is treated here as a 1933 fire when calculating fire frequencies for the island

in human land use where, prior to Sweden's fire suppression era (ca. 1860), islands had higher fire frequencies relative to mainland sites due to the cultural practice of island pasture maintenance by swidden – the agricultural approach to clearing land with controlled fires. While it is possible island micro-climate conditions create forest isolates more receptive to lightning ignitions, given the cultural context for Lac La Croix (provided in Chapter II), it is quite reasonable to consider Ojibwe use of the study area

prior to ca. 1910 fire suppression period as one explanation for the 53 island fires reconstructed within the study area between 1633 and 1933. If island micro-climates increase the potential occurrence of lightning-ignited fires (e.g. Drobyshev et al. 2010), they also increase the possibility of purposeful and accidental human ignitions – given that humans are present.

Lightning-dominated fire regimes in boreal forests are characterized by a modest number of drought and wind-enhanced fires burning large areas (Johnson 1992). These fires occur in the summer months (June-July-August) when convective thunderstorms storms and lightning coincide with extended periods of moisture deficiency and dry fuels (Latham & Williams 2001). Summer fires in the Quetico-Superior require longer periods of dryness and more severe fire weather with large summer fires only occurring during periods of notable drought. On the other hand, spring and late autumn fires are much less dependent on drought than summer fires with fine dead fuels acting, before green-up and after leaf-fall, as a receptive carrier of surface fires after only several days of drying (Heinselman 1996). In the early and late parts of the fire season, from late April to early June and from late September to October, the likelihood of lightning-caused fires is very low with fire occurrence during these periods usually attributable to human activities.

The limited association between summer moisture deficiency (negative PDSI) and fire events within the study area suggests that lightning-caused summer fires associated with drought may have been historically overwhelmed by spring and late autumn fires less dependent upon extended periods of dryness. Frequent spring fires within the study area may explain the possible connection between fire events and above normal moisture

(positive PDSI) in the antecedent growing season (Figure 3.19). Increased plant productivity, as determined by previous summer moisture availability, would have ensured a receptive bed of abundant surface fuels the following spring. The potential dominance of frequent spring and autumn surface fires outside of the summer lightning season, juxtaposed to more infrequent and large fire events associated with summer drought, may also explain the patchy and commonly asynchronous fire record for the area. Some fire history researchers have suggested smaller, lower intensity fires would be one of the products of intentional human fire use in boreal ecosystems (e.g. Granstrom & Niklasson 2008).

The tenuous relationship between fire occurrence and severe drought within the study area is surprising given that moderate to severe drought has been implicated as a significant fire driver in the BWCAW (Heinselman 1996) and many other North American forests (e.g. Kipfmueller & Swetnam 2000). There are other potential explanations unrelated to ignition sources that may help explain the low coherence between drought and fire events. First, the seasonal timing of annual red pine growth is not well understood making the inaccurate assignment of dormant season fires within the fire reconstruction a possibility. Second, fire records developed from a concentrated network of fire-scarred samples may be unable to detect regional, climatically-driven fire events. It is possible that the occurrence of frequent surface fires within a localized area may be less dependent on drought than severe stand-replacing fire events detectable at the regional level. These possibilities have been considered but are not the most plausible explanation given the cultural history of the study area. Sample replication and careful

fire-scar analysis have greatly minimized fire event dating errors within this reconstruction. Expansion of the Quetico-Superior's fire scar network may help elucidate the effects of study area size and concentrated sample collection on the detection of widespread fire events with strong climatic associations.

### *Limitations to Detecting Ojibwe Fire Use in the Quetico-Superior*

With the exception of fire in mixed and pure red pine forests, the Quetico-Superior's high-severity fire regimes are a limiting factor to the development of comprehensive fire histories over large areas of the Quetico-Superior. The Quetico-Superior is a near-boreal forest with a fire regime generally characterized by expansive and intense crown and surface fires with high tree mortality that occur approximately every 100 years (Heinselman 1996). Because these fires tend to kill rather than scar the trees they burn, accurate spatial reconstructions of fires in these landscapes are often limited to the last stand-replacing fire that burned in the area (Niklasson & Granstrom 2000) with the accuracy of these reconstructions decreasing over time. This makes the broad spatial development of tree-ring based fire records spanning long periods of cultural change very challenging and sometimes impossible.

On eastern Lac La Croix, where humans were likely a proto-historic ignition source, evidence of annual and bi-annual fires has been observed. It is possible that in other parts of the Quetico-Superior surface fires have been historically frequent but are undetectable in the fire-scar record due to a combination of low-intensity burning and tree-resistance to scarring. Fire-scars form as lesions created by the over-heating of

cambial tissue on a portion of a tree's base and are the result of several variables including the fire environment, fire behavior, and each tree's physiological sensitivity to fire (Gill 1974). It is generally thought that once a tree is scarred, it becomes more susceptible to future fire damage. In this study, the detection of areas with frequent surface fires was of primary interest, and sampling was conducted at sites with a red pine component where environmental conditions would permit frequent lightning- or human-ignited fires.

Seasonality, frequency, intensity and size make human-ignited fires ecologically different than lightning fires, and for these reasons there is, in many places, a scarcity of tree-ring data available for analysis (Lewis 1982). Areas that burn frequently in near-boreal systems have less fuel, limiting the potential for surface fires to ignite, carry and damage a tree's growth tissue. On the other hand, areas that burn frequently may also increase the chance of sample loss due to the death of trees and the consumption of coarse woody debris. In either of these situations, fires may have occurred quite frequently at particular locations but be undetectable in the tree-ring based fire record. Therefore, it is important that the fire reconstruction presented here is viewed as a conservative measure of past fire events as it likely underestimates the true frequency of proto-historic fires within the study area. As other fire researchers have emphasized (e.g. Veblen 2003), the absence of fire scars is not the same as the absence of fires.

Human influence on the Quetico-Superior's pre-modern fire regimes could manifest itself in a number of ways including fires' frequency, spatial distribution, seasonality, intensity, and severity (Granstrom & Niklasson 2008). In this study, fire

frequencies, spatial patterns of fire, and fire-climate relationships have been merged to make inferences on human input into pre-suppression fire regimes. Development of fire records for areas thought to be of limited human use during the pre-modern era would help clarify fire regime differences between areas of high and low proto-historic human presence. As a pilot study focusing on a relatively small portion of the Quetico-Superior landscape, it is unlikely that the findings for this portion of eastern Lac La Croix can be accurately extrapolated to extensive portions of the Quetico-Superior landscape.

### *Fire Seasonality*

Seasonality is an important fire regime attribute that many tree-ring researchers have extracted from fire-scarred samples to detect anthropogenic influence on fire regimes (e.g. Niklasson & Drakenberg 2001). Typically, fire scars are assigned one of five intra-annual positions within a growth ring from dormant season fires – before growth initiation to late-wood fires – at the very end of the growing season (Kaye & Swetnam 1999). In regions where the phenology of tree-growth is well understood, like the American Southwest (Fritts 1976), the intra-annual position of fire scars has been used to determine the seasonal timing of fire events, make inferences of fire causation, and observe temporal shifts in fire season (Grissino-Mayer & Swetnam 2000). Intra-annual fire scar position has also been used with red pine in the Upper Great Lakes to relate fire season to area burned (Drobyshev et al. 2004). Fire seasonality can be useful in understanding historic fire regimes but the methods of determining intra-annual fire scar position are easier in theory than in practice in the BWCAW. While it is sometimes

possible (Figure 3.21), the extraction of fire seasonality information from BWCAW red pine datasets is challenging. First, the intra-annual scar position is difficult to accurately determine for many samples due to compressed rings, dormant season scars, insect galleries, concentrated resin near scars, and cracked wood (Figure 1.4). Second, even when accurate intra-annual scar placement is possible, the phenology of red pine growth in the Quetico-Superior region is not well understood, making linkages of intra-annual fire scar positions to calendar months difficult and speculative.

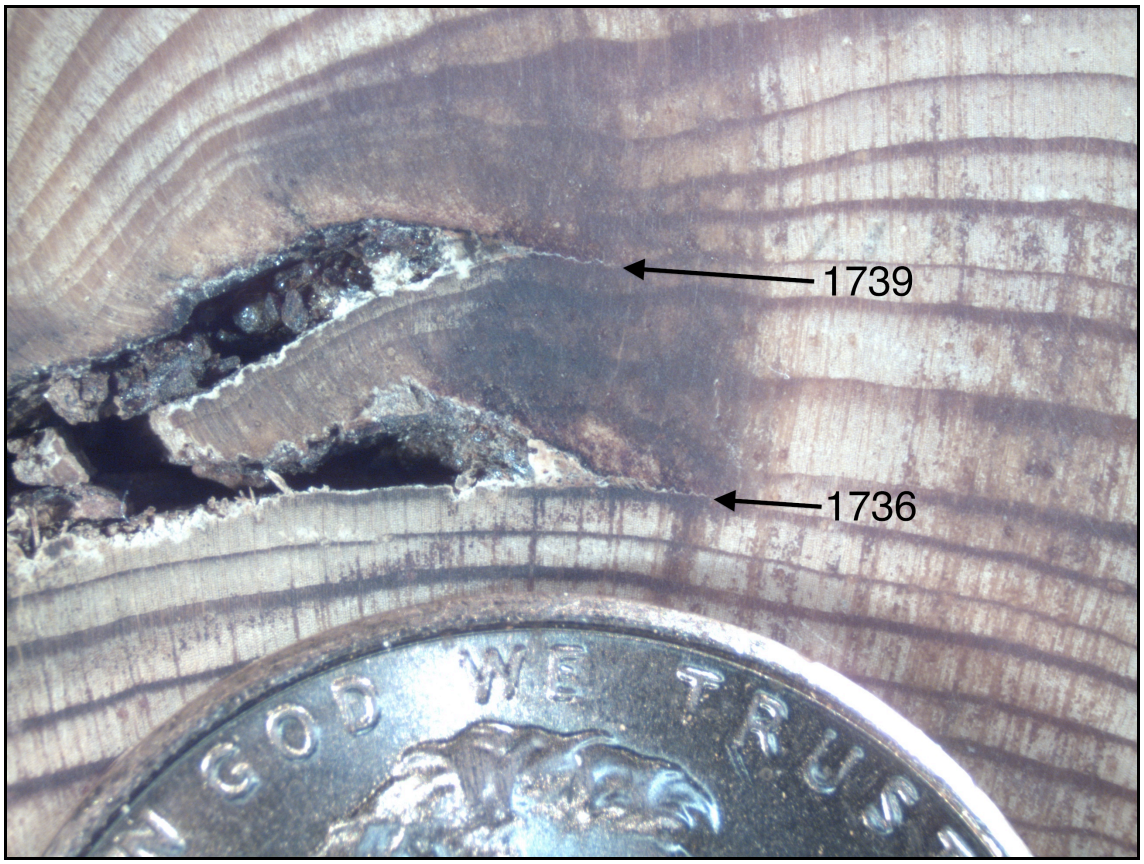



**Figure 3.21**: Image of an early-season 1736 fire followed by a late-season 1739 fire. Proper surface preparation and magnification makes the accurate intra-annual placement of fire-scars possible – but not consistently.

Previous tree phenology research in northern Minnesota by Ahlgren (1957) illustrates the challenge of deriving accurate fire seasonality data from intra-annual fire-scar positions in red pine. Ahlgren's five year study of nineteen native tree species within the BWCAW determined that red pine stem expansion began when maximum daily temperatures were above 21ºC and daytime lows were above freezing. Cambial activity, as determined by stem swelling, began between May 3rd and May 20th and ended between July 30th and September 7th. While it is important to note that stem expansion (caused by temperature and precipitation fluctuations) is not the same as wood production, the study does shows there is significant variability in the seasonal timing of red pine cambial activity and subsequently, radial growth increment, over just a five-year period in the BWCAW. Core samples collected from mature, live red pine on Lac La Croix over the summer of 2011 indicate that early-wood development in these trees did not begin until early-mid July with cores collected as late as June 26th without any indication of a 2011 annual ring.

The varying phenology of red pine wood production alone currently limits the utility of intra-annual fire scar positions as a proxy for fire seasonality, in the Quetico-Superior region, and perhaps elsewhere. If red pine in the western BWCAW typically begin wood production by early July, what would normally be considered an 'early-season fire' based on fire-scar placement would actually be a mid-summer fire in late June. These issues of interpretation are the same for 'latewood fires' and 'dormant-season fires' as it remains unclear when red pines in northern Minnesota terminate annual wood production.

Based on the variable phenology of red pine annual growth, I did not use the red pine samples collected for this study to reconstruct fire seasonality. Interpreting fire-scar seasonality requires several other assumptions beyond the annual consistency of stem growth over decades and centuries. The first assumption is that the seasonal timing of stem growth between young and old red pine is similar. The second is that red pines in dramatically different forest settings have similar seasonal timing in stem growth. The third assumption is that annual variations in growing season temperature and precipitation have little effect on the seasonal timing of wood production. Given what is known (and unknown) about variability in red pine annual growth, these assumptions represent important limitations to the interpretation of intra-annual fire scar positions. A regionally-focused, site- and age-specific study of red pine radial growth and phenology over several years might permit confident use of tree-ring derived fire seasonality data in future studies (e.g. useful quantification and analysis of inter-annual variability in dormant season and growing season fire occurrence). True cambial productivity, rather than stem swelling, could be studied by abandoning dendrometers in exchange for repeated, low-impact stem sampling with punch corers (Forster et al. 2000).

### *The Efficacy of Fire-Scar Sampling Methods*

Permission to conduct this study was graciously provided to me by Superior National Forest wilderness managers with the stipulation that sample collection be restricted to the use of increment cores of live trees and radial sections gathered from dead/downed trees. This is standard practice for tree-ring based research in the BWCAW

as wilderness managers seek to protect the aesthetic and audible qualities of the area throughout all their wilderness management activities. Fortunately, within my selected study area, there was a surprising abundance of dead, fire-scarred red pine, sometimes found as preserved stumps, that could be sampled by hand saw. Tree rot, wildfire, insects, and weathering did reduce the number, distribution, and quality of this remnant wood, but a rich reconstruction of fires across the study area for the 1700s and 1800s was still achieved with 71 samples. However, the sampling restrictions applied to this study limit the interpretation of the project's results, particularly in assessing the impacts of fire suppression over the last hundred years.

Dead wood is inherently prone to natural decay. In the Quetico-Superior region, high moisture and frequent fires limits the residence time of coarse woody debris across the landscape. These natural factors contribute to the 'fading record' problem frequently discussed in the tree-ring literature (e.g. Swetnam et al. 1999), where the oldest and most useful samples for tree-ring based ecological reconstructions are the most scarce, effectively limiting the time depth of tree-ring based fire records. By working exclusively with remnant wood, the fading record problem still remains but also prominently reduces the number of recording samples over the 20$^{th}$ century (Figure 3.11). Because red pine is a long-lived species and few forest disturbances have caused recent red pine mortality within the study area, there were a limited number of samples collected from pine with growth records spanning the 1900s to the present. This two-way fading record produced an abnormally shaped sample depth curve (Figure 3.11) that makes true temporal shifts in fire frequency over the last three centuries more difficult to detect within the study area.

Without other lines of evidence, the high frequency of fire observable in the 1700s and 1800s could be as much a product of greater sample depth for these centuries as changing land use practices over the 1900s (e.g. fire suppression). Fortunately, Superior National Forest fire atlas data for the *Fire Suppression Era* (beginning ca. 1910) is available to supplement the tree-ring record over the last hundred years.

Sampling restrictions also impact the spatial distribution of reconstructed fires across the study area. Inspection of sample locations across the study area map shows that many samples are clustered within small site areas leaving large portions of the study area without fire data (Figure 3.4). Part of this clustering is unavoidable, as it is a natural product of differential wood preservation from site to site. Xeric sites with historically low to moderate fire intensity (e.g. shorelines and islands) tend to have a greater abundance of remnant wood available for sampling relative to mesic sites and landforms susceptible to high intensity fire events. Still, in other parts of the study area there are fire-scarred trees present but they exist as live or, more commonly, as standing dead pine. There are a number of island and mainland locations across the study area where standing, dead red pine with observable fire data were located but were not sampled. Observable fire records on the boles of these trees range from one to six events and would be highly useful in improving the density and depth of samples across the study area – both to minimize error and to improve the fine-scale resolution of the existing sample network (Dieterich & Swetnam 1984). The sampling of standing dead trees would yield better quality samples that would extend fire event records further into the 20$^{th}$ century and ensure the accurate and comprehensive reconstruction of fire events across

the area of focus.

The increment core sampling of live, fire-scarred trees and standing dead trees was proposed as a way to overcome the sampling bias produced by the exclusive sampling of remnant pine. This method of tree sampling is preferred for the collection of dendrochronological samples in designated wilderness and natural areas due to the unobtrusive nature of the techniques, relative to the collection of full and partial cross-sections. Increment core sampling has proven somewhat useful in conducting past fire history research in coniferous forests (Barrett & Arno 1988). Advanced increment core methods for fire history reconstruction include combining various boring techniques including scar, face, and back boring to determine tree age, annually date individual fires, and calculate fire frequency (Barrett & Arno 1988). These sampling approaches allow for the *estimation* of fire years and the calculation of point fire frequencies from the number of fire intervals contained within trees' first and last recorded fire scars. Still, these increment borer methods are highly limiting.

Through field tests and lab analysis of red pine cross-sections, it was determined that increment borer sampling methods are inadequate for complete, precise, dendrochronological fire reconstructions required for this study. First, it has been frequently observed that the most complete fire record is not always detectable solely by the inspection of a tree's catface. Fire-scars occurring early in the lifespan of a tree and small scars caused by low-intensity surface fires can quickly heal over and be obscured from view. When sampling by increment borer, these fire events are not accounted for. Second, the variability and complexity of red pines' growth response to fire damage (e.g.

compressed or distorted rings) makes the collection of cores usable in dendrochronological analysis more difficult.

Unlike core samples, cross-sections allow complete inspection of ring margins to minimize dating errors caused by locally absent and false rings and permit adjustments when measuring ring-widths to avoid distorted rings. Third, mature red pines within the BWCAW commonly have heavy bole rot making the coring and collection of useful increment cores difficult or impossible. Increment core samples would have been useful in collecting fire dates from trees recording single fire events but the focus during sample collection was to gather the most comprehensive record of fire for each stand visited. To accurately determine two or more fire dates from a fire-scarred tree numerous cores must be carefully collected (Sheppard et al. 1988). Based on personal field trials this approach to sampling was determined to be unviable due to its inefficiency and high potential for dating error.

### *Implications for 21st Century Wilderness Fire Management*

By 1993, ecologist Miron Heinselman wrote "no management action is more urgent than restoring natural fire regimes" to the forests of the Boundary Waters region (Heinselman 1996: 258). Nearly twenty years later, the same conclusion can be drawn from my fire history study, but for different reasons. Past and present forest fire research endeavors illustrate that, relative to the *Pre-Suppression Period*s (1700-1899), there has been a glaring decline in fire occurrence within the BWCAW over the 20th century that has serious implications for the sustained protection of the region's old-growth pine

forests. Heinselman's fire history research, while wide-ranging, emphasized, for practical reasons the significance of large-scale, stand-replacing fires on the forest mosaic of the Boundary Waters region. (Fine-scale analysis of surface fires across a large area like the BWCAW would have expanded and prolonged what was already an impressive seven-year undertaking.) In the early 1990s, roughly eighty years of fire suppression and exclusion had effectively limited the spread of lightning-ignited fires within and into the BWCAW, decreasing landscape heterogeneity and increasing combustible fuels. My fire reconstruction on eastern Lac La Croix illustrates a significant decline in forest fire occurrence in the area since the 1930s, but it cannot be attributed solely to effective wildland fire suppression or forest fragmentation (and subsequent fire exclusion). The removal of the Bois Forte Ojibwe from much of their historic territory and a decline in traditional subsistence practices in the early 20$^{th}$ century may have contributed to an ecologically significant decline in fire occurrence, as made evident by a roughly sevenfold decrease in island fire occurrence on eastern Lac La Croix, from the *Late Pre-Suppression Period's* twenty-one tree-ring reconstructed fires to the *Fire Suppression Period's* three suppressed lightning fires. Reintroduction of frequent, low-intensity surface fires to heritage stands of extant primary growth mixed pine forest is necessary to decrease stand susceptibility to high-intensity fire events and to ensure the continued presence of some old-growth pine stnads across the Quetico-Superior landscape.

Human-enhanced, global climate change has been acknowledged as a real and imminent threat to diverse social and ecological resources (IPCC 2007). Increases in greenhouse gas emissions from human activities are anticipated to cause unprecedented

shifts in global temperature, precipitation, and seasonality with associated changes in wildfire occurrence (Westerling et al. 2006). In the Quetico-Superior region, models suggest average summer temperature will increase by 3ºC and summer precipitation will subtly decrease, up to 4% by 2069 (Galatowitsch et al. 2010). Temperature is the key driver of wildfire occurrence in the boreal forest by increasing evapotranspiration rates and decreasing fuel moisture (Flannigan et al. 2005). Warming may also lengthen the fire season (Westerling et al. 2006), increase lightning activity and ignitions (Price & Rind 1994), and the frequency of blocking ridges contributing to large-scale fire events (Lupo et al. 1997). The large and severe fires the BWCAW has experienced in the last decade, including the 2011 Pagami Creek, 2007 Ham Lake, and 2006 Cavity Lake fires (totaling ≈ 79,700 hectares) may be partially associated with recent climatic shifts. This spike in area burned over the last several years corresponds with the findings of Gillet et al. (2004) who attributed an increase in Canada's area burned over the last four decades to recent human-induced climate shifts. More frequent, high-severity fires have the potential to reduce red pine abundance across the Quetico-Superior lansdscape (Flannigan 1993) and replace pure and mixed pine forests with southerly vegetation types such as oak savanna (Frelich & Reich 2010). Coupling these anticipated changes in fire occurrence with shifts in forest structure and fuel loads caused by decades of fire suppression and exclusion, the remaining primary-growth forests of the Quetico-Superior are at high risk of being lost to a wide-spread, high-severity fire event.

As warming continues, the development of appropriate climate change adaption strategies and the mitigation of warming's deleterious effects may be the greatest

challenge for natural area managers this century (Cole & Yung 2010). Fire management policies and practices in the Quetico-Superior region, particularly within wilderness areas, will need to be adjusted to respond to anticipated changes in fire occurrence and fire behavior caused by global climate change. In the coming years, proto-historic fire data produced from studies such as this will be useful in developing strategies for increasing ecological integrity and resilience of focus areas within the region.

While large, stand replacing fires are part of the Quetico-Superior's historic range of variability, increased prescribed and wildland fire use across the landscape would be useful in maintaining and protecting portions of old-growth forest from destruction in wide-spread, high-severity fires. Because the region's old-growth pine forests are ecologically rare (Frelich 1995) and have high social value, these forest types may be given priority when triaging current and future best management actions. Island stands of virgin red pine that were historically maintained by frequent surface fires could be the first targets for new wilderness prescribed fire activities as many of these sites have ecologically and aesthetically valuable pine stands and natural fire breaks already exist.

The BWCAW has long been a testing ground for new and innovative approaches to wilderness management (Helland 2004). With this in mind, wilderness administrators, fire managers, and inter-disciplinary research groups ought to redouble efforts to more thoroughly explore the fire history of the Quetico-Superior region and open discussions on the efficacy of more active fire management within priority forest areas of the Boundary Waters wilderness. In an era of unprecedented changes to ecosystems, knowledge of proto-historic human influence over past fire regimes will be of great use in

making wilderness fire management decisions that are not only ecologically sound, but also honor the 1964 Wilderness Act's intent to preserve "wilderness character" (Public Law 88-577) while progressing with our present society's evolving perceptions of wilderness.

## CONCLUSION

Fire has shaped the composition, structure, and distribution of forests across the Quetico-Superior landscape. Large wilderness areas like Minnesota's Boundary Waters Canoe Area Wilderness (BWCAW) contain remnants of old-growth red pine forests that provide unparalleled opportunities to observe, record, and analyze the pre-suppression fire frequencies that once had great influence on the region's landscape heterogeneity, stand complexity, and species diversity. Although fire history research in the Quetico-Superior region is not a novel endeavor, this pilot fire history project has sought to address a knowledge gap regarding the relative role of human- and lightning-ignitions in their contribution to fire regimes within the Quetico-Superior over the last three centuries. The understanding of proto-historic fire ignitions is necessary to explain the distribution, frequency, and locations of past mixed-severity surface fires and to properly guide future fire management decisions within the region.

Spatially explicit and annually resolved records of mixed-severity surface fires were developed with dendrochronological methods using 71 red pine stump cross-sections across a naturally fragmented lake-island environment. Seventy-nine fires were detected between 1590 and 2010 with the first recorded fire in 1636 and the last in 1933.

Sixty-one of the fires were recorded at single sites with the other 18 detected at 2-5 disjoint sites. In the same area, from 1929 to 2012, thirteen lightning-ignited fires were detected and suppressed by the Superior National Forest. Only two of these fires occurred on islands compared to the 53 tree-ring reconstructed fires detected over the 297-year recording period. When comparing the conservative, tree-ring reconstructed estimate of pre-modern fire occurrence and the nearly 100% complete modern lightning-caused fire record (from 1929-2012), there is a noticeable change in the distribution and frequency of fires within the study area.

By combining information from available North American boreal forest fire ethnographies, direct and indirect historical references to traditional Ojibwe attitudes towards fire, and presently limited oral history data from elders within the Bois Forte community, a compelling case for Ojibwe augmentation of historic fire regimes within the Quetico-Superior region emerges. Given the cultural history of Lac La Croix, and other international Border Lakes in the Quetico-Superior, it can be reasonably inferred that the high proto-historic island fire frequencies observed on eastern Lac La Croix are at least partially attributable to human influence on fire ignition rates. Fires' patchiness, common temporal asynchrony, and insignificant association with summer drought ($p > 0.05$) all suggest human influence upon the area's fire regimes. If humans were significant contributors to proto-historic fire frequencies in high-use areas of the Quetico-Superior, prescribed wilderness fire in these particular places is a management action that would help restore and maintain the region's historic fidelity and ecological integrity.

Similar complexity in proto-historic fire records may be detectable on other high-

use lakes in the Quetico-Superior region and should be explored. Calibration studies of red pine fire scar formation and red pine phenology will aid in the development and interpretation of these future, tree-ring based fire reconstructions. Also, merging future fire reconstructions with ethno-historical data developed in partnership with local Ojibwe communities may be useful in elucidating the details of traditional fire use practices and the extent of their ecological effects within the Quetico-Superior.

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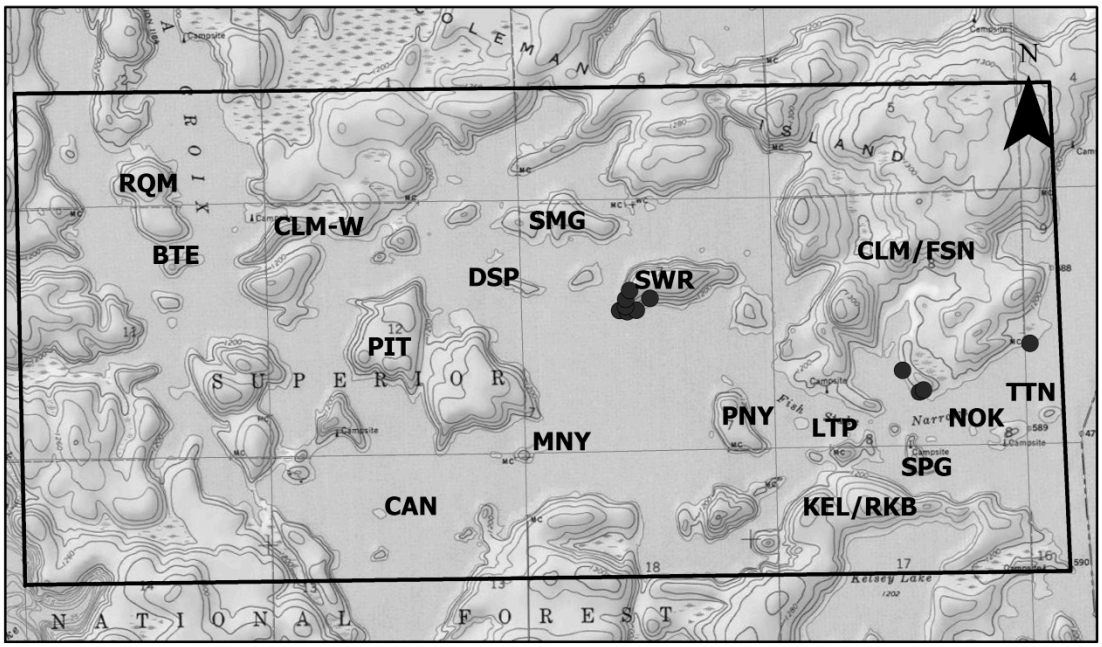
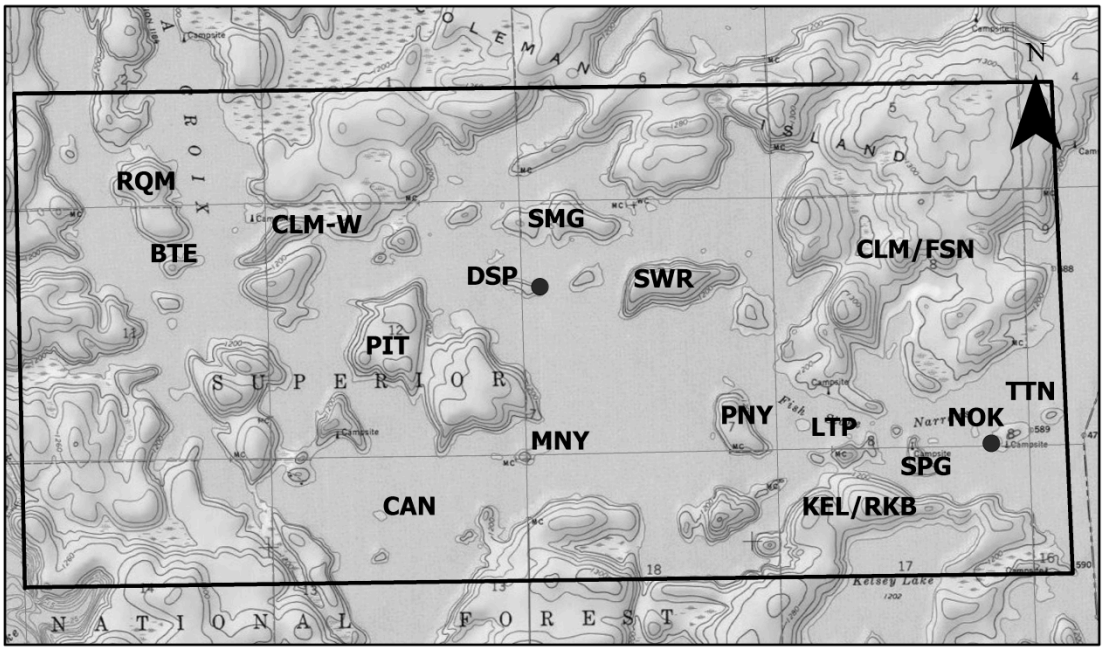
## APPENDICES

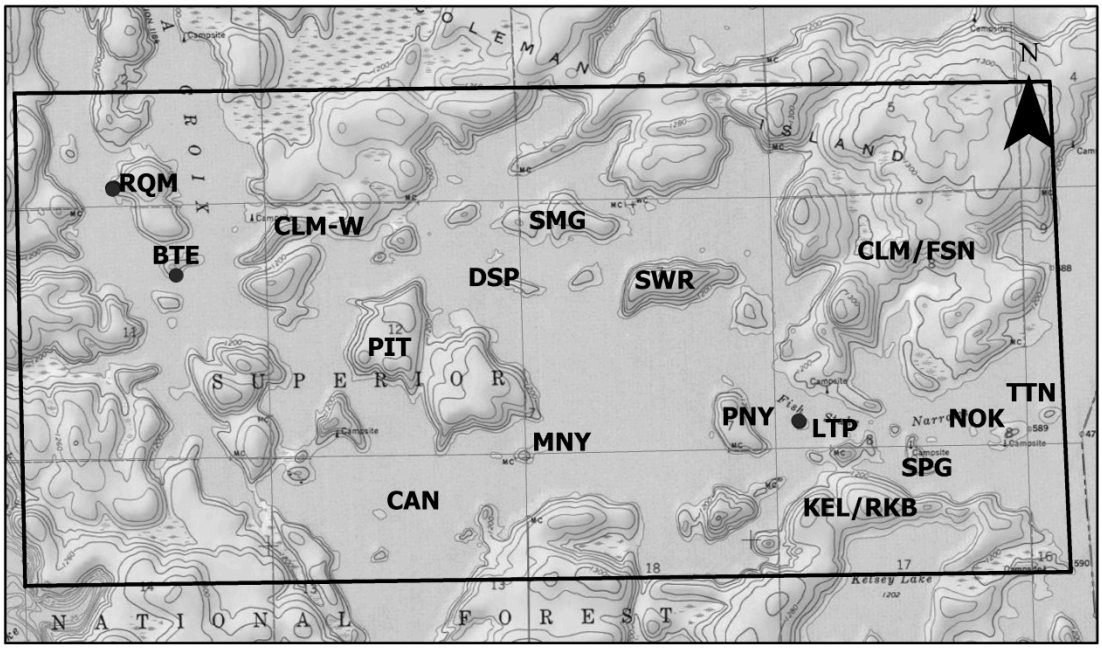
***Appendix I*** – Point recording tree locations for 15 reconstructed, multi-site fires with island/mainland site codes in bold text. See Figure 3.3 for all sample locations.



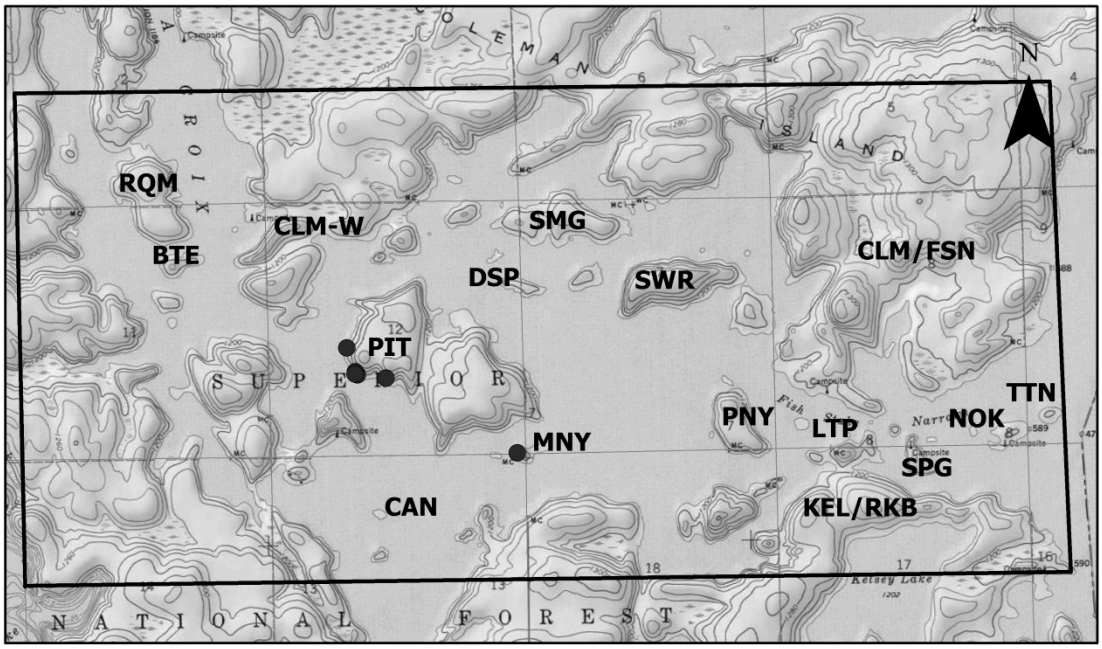

Locations of the 1712 fire's recording trees



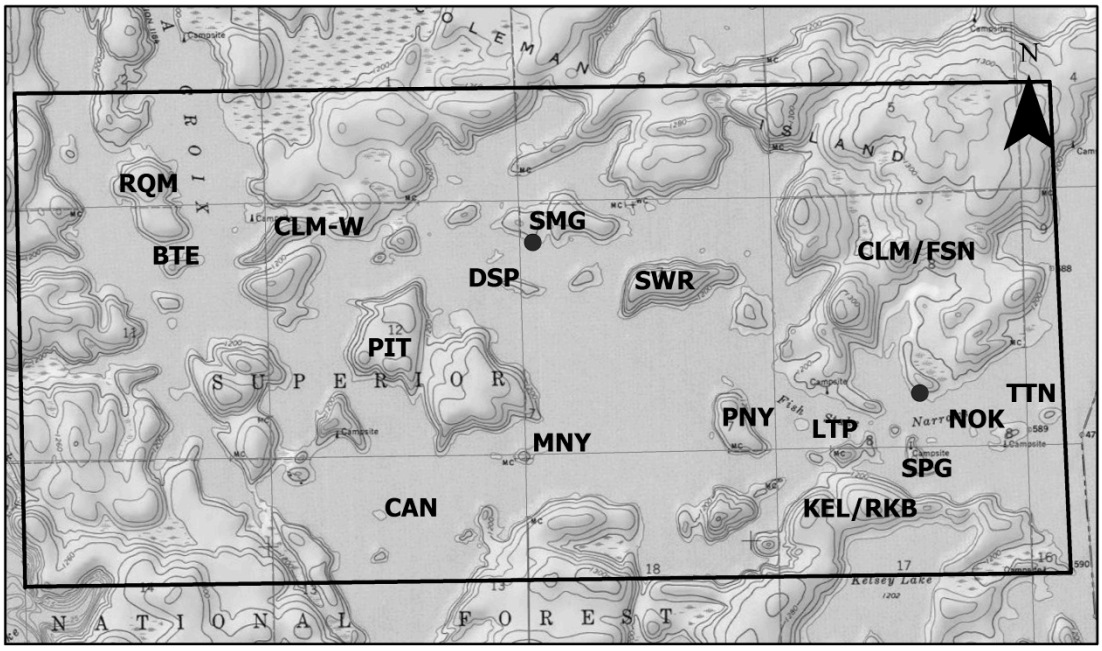

Locations of the 1749 fire's recording trees



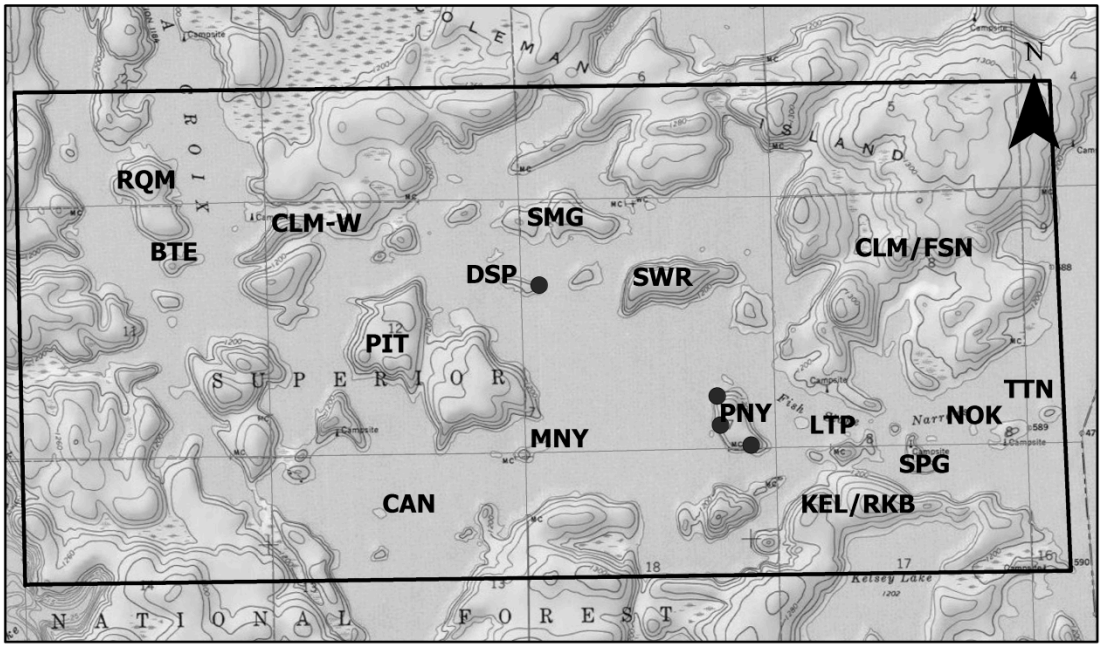

Locations of the 1758 fire's recording trees



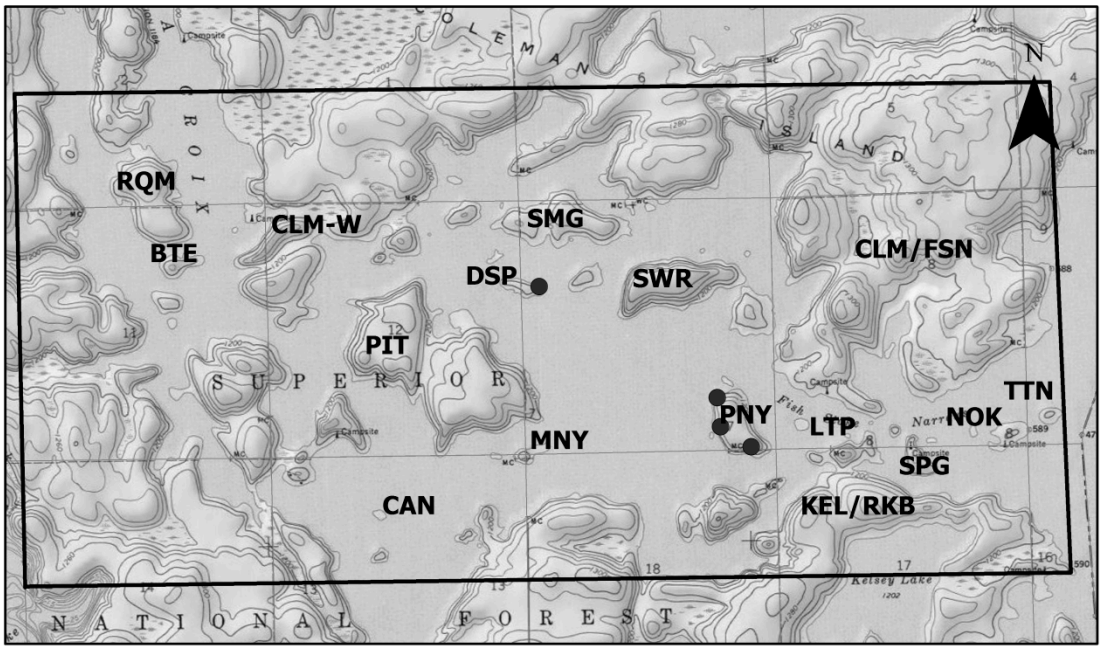

Locations of the 1759 fire's recording trees



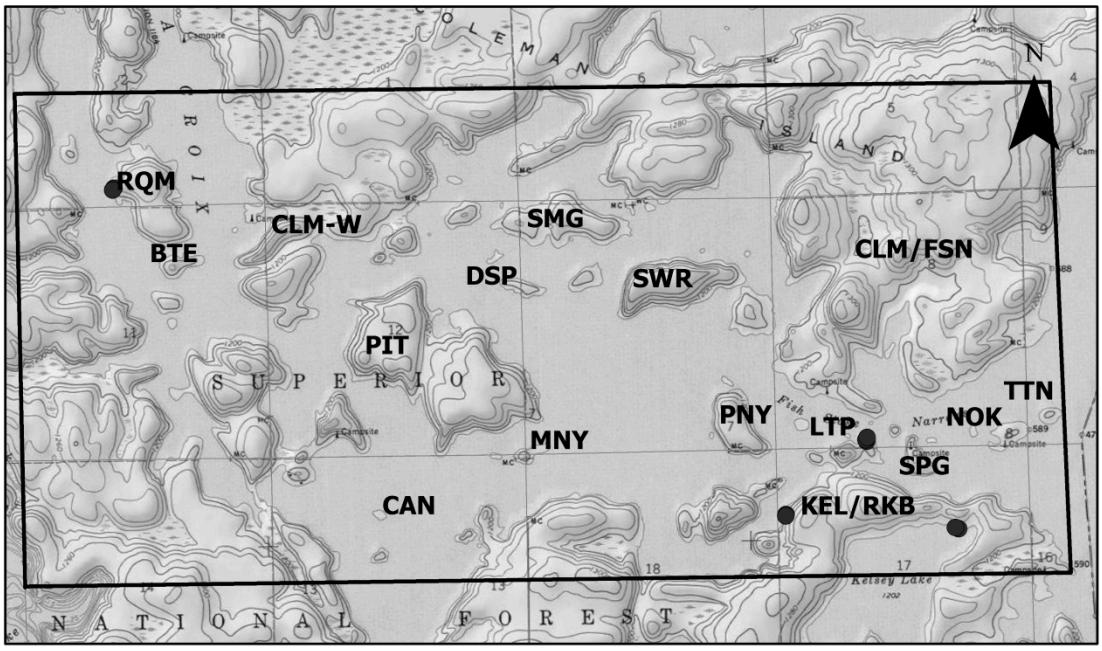

Locations of the 1784 fire's recording trees



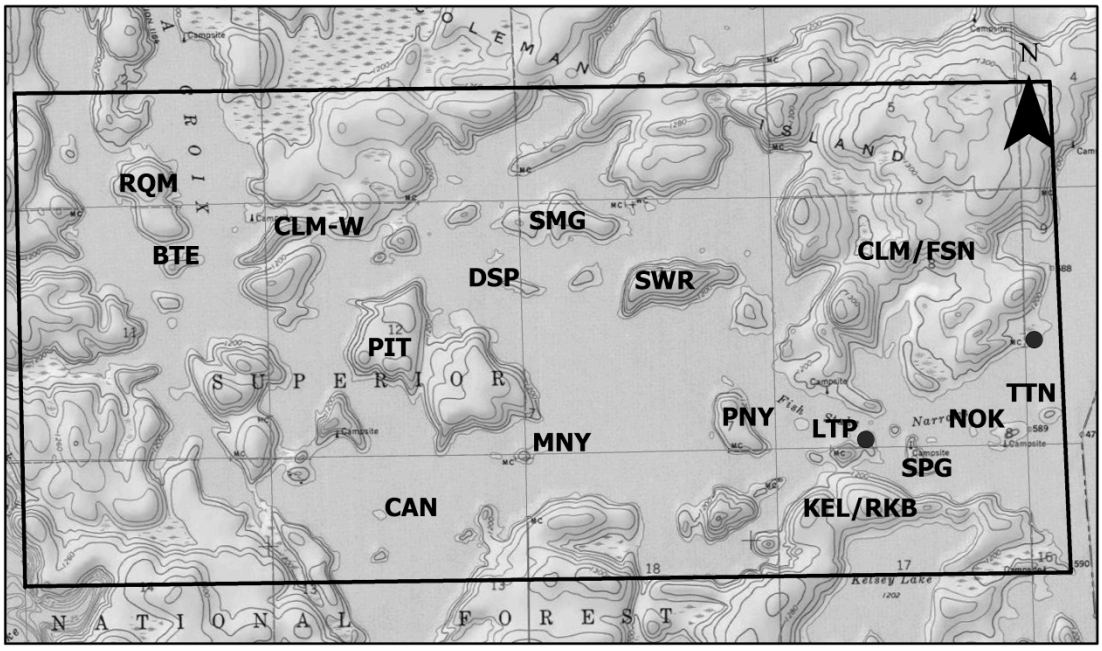

Locations of the 1820 fire's recording trees



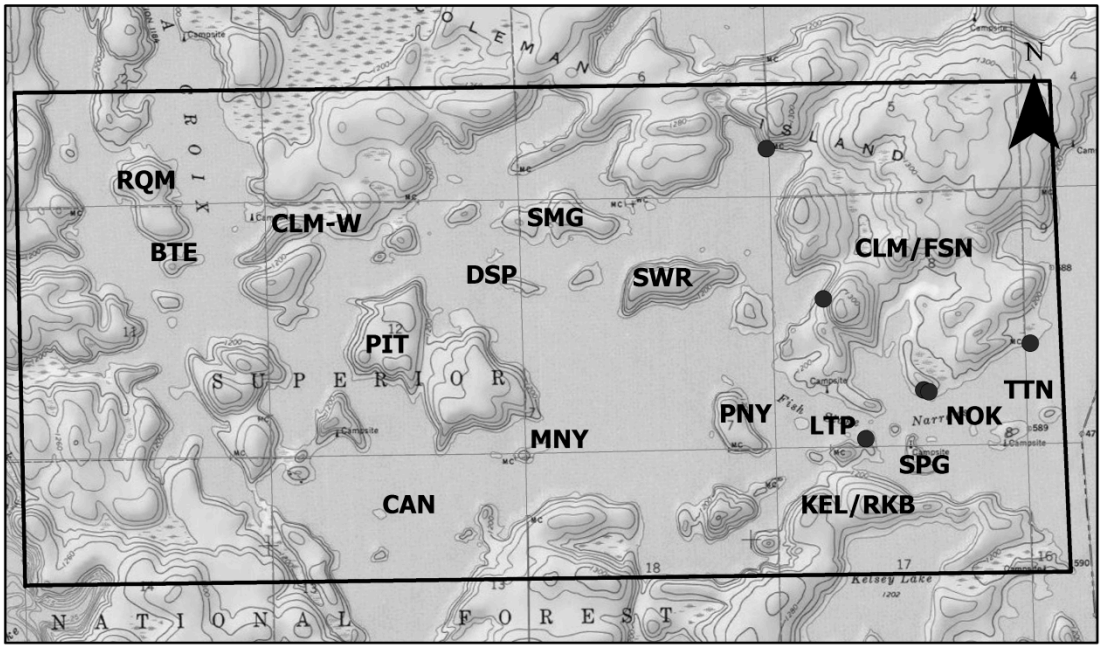

Locations of the 1825 fire's recording trees



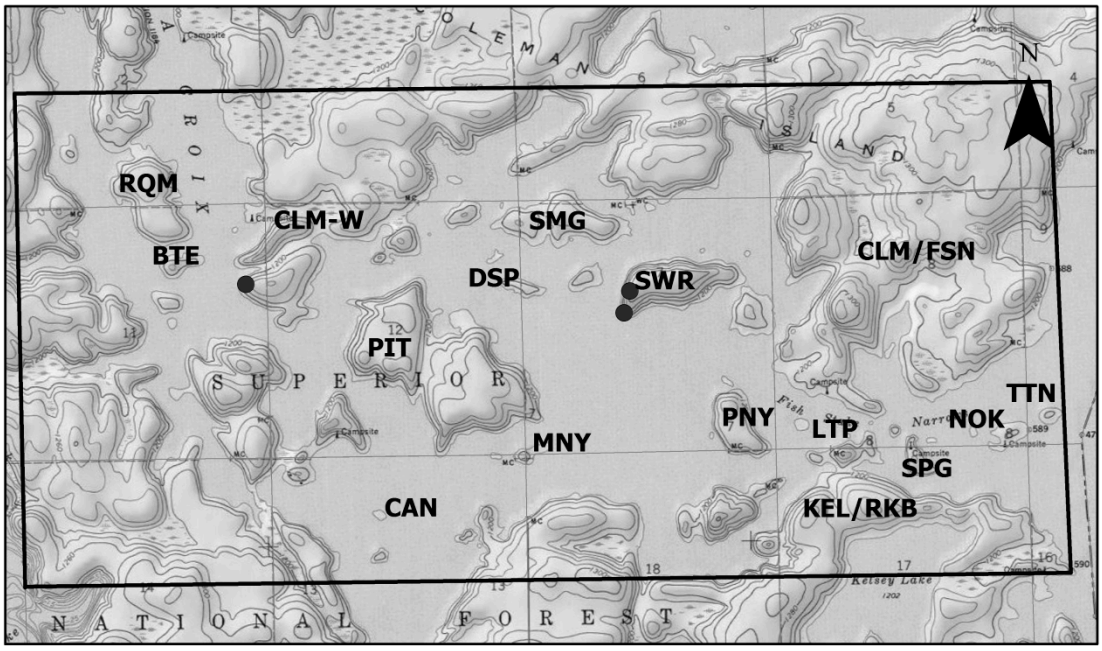

Locations of the 1846 fire's recording trees



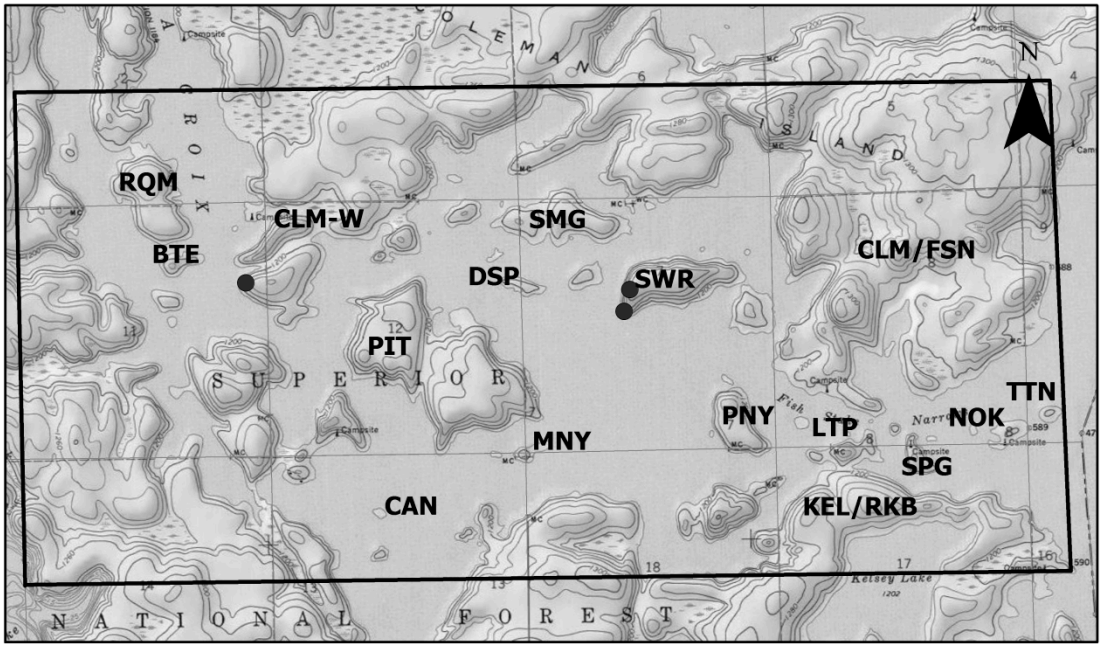

Locations of the 1849 fire's recording trees



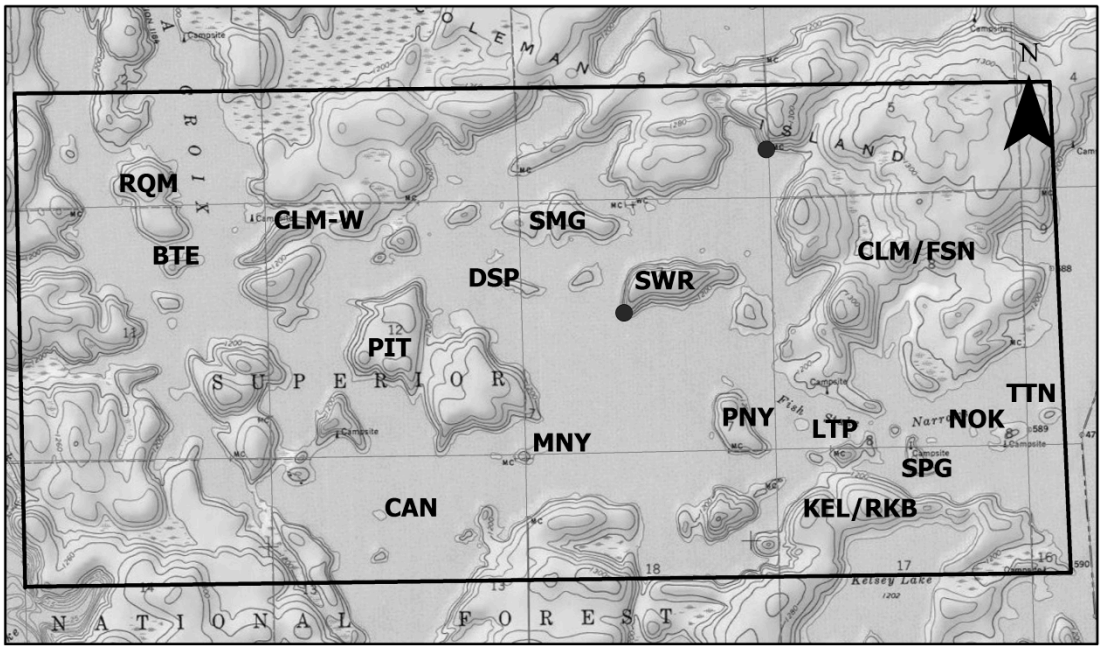

Locations of the 1865 fire's recording trees



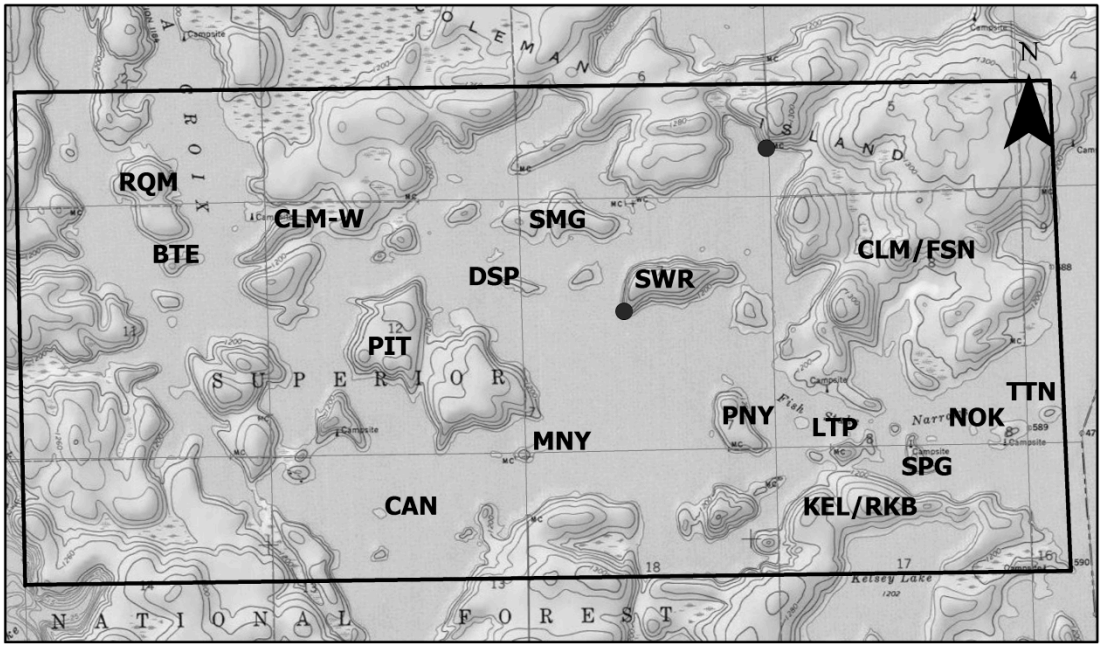

Locations of the 1871 fire's recording trees



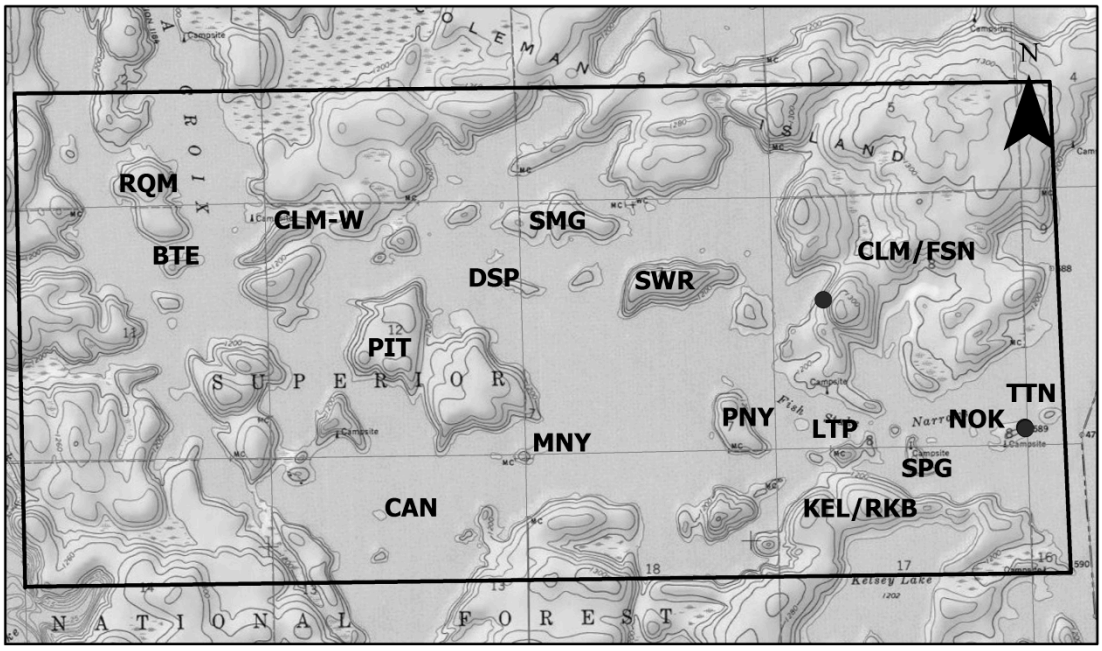

Locations of the 1891 fire's recording trees




Locations of the 1896 fire's recording trees




Locations of the 1901 fire's recording trees




Locations of the 1909 fire's recording tree

***Appendix II*** – Table: Series length and fire years for all crossdated samples (p = pith, b = bark)

| *Sample ID* | *Inner Ring* | *Outer Ring* | *Fire Year 1* | *Fire Year 2* | *Fire Year 3* | *Fire Year 4* | *Fire Year 5* | *Fire Year 6* | *Fire Year 7* | *Fire Year 8* |
|---|---|---|---|---|---|---|---|---|---|---|
| TTN001 | 1725 | 1896 | 1790 | 1841 | | | | | | |
| NOK001 | -- | -- | | | | | | | | |
| NOK002 | -- | -- | | | | | | | | |
| NOK003 | 1686 | 1909 | 1744 | 1749 | 1883 | | | | | |
| NOK004 | 1718 | 1968b | 1747 | 1883 | 1909 | | | | | |
| NOK005 | 1706p | 1964b | 1883 | 1909 | | | | | | |
| CLM001E | 1750 | 1859 | 1791 | 1825 | 1842 | | | | | |
| CLM002E | 1770 | 1867 | 1815 | 1849 | | | | | | |
| CLM003E | 1698p | 1962 | 1712 | 1825 | 1865 | | | | | |
| CLM004E | 1625 | 1824 | 1660 | 1682 | 1712 | 1773 | | | | |
| CLM005E | 1782p | 1962 | 1865 | 1891 | 1909 | | | | | |
| CLM006E | 1767p | 1953b | 1865 | 1896 | | | | | | |
| FSN001 | 1688p | 1899 | 1712 | 1748 | 1773 | 1784 | 1825 | | | |
| FSN002 | 1694p | 1927 | 1712 | 1865 | | | | | | |
| FSN003 | 1698p | 1863 | 1825 | 1840 | | | | | | |
| FSN004 | 1724 | 2010b | 1840 | 1865 | | | | | | |
| KEL001 | 1695p | 1860 | 1752 | 1785 | 1846 | | | | | |
| KEL002 | 1702p | 1861 | 1752 | 1785 | 1846 | | | | | |
| KEL003 | 1704p | 1905 | 1785 | 1846 | 1862 | 1894 | | | | |
| KEL004 | 1704 | 1972 | 1774 | 1785 | 1846 | 1862 | | | | |
| RKB001 | 1694 | 1891 | 1756 | 1785 | | 1846 | 1857 | | | |
| RKB002 | 1703p | 1876 | 1785 | 1846 | 1849 | 1857 | 1865 | | | |
| RKB003 | 1696p | 1856 | 1756 | 1759 | 1785 | 1846 | | | | |
| RKB004 | 1695p | 1852 | 1785 | 1846 | | | | | | |
| SPG001 | 1771p | 2005b | 1858 | 1898 | | | | | | |
| LTP001 | 1708 | 1930 | 1752 | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LTP003 | 1753 | 1918 | 1752 | | | | | | | |
| PNY001 | 1695 | 1922 | 1739 | 1759 | 1770 | 1789 | 1820 | 1923 | | |
| PNY002 | 1696p | 1890 | 1739 | 1759 | 1770 | 1820 | | | | |
| PNY003 | 1699p | 1815 | 1739 | 1759 | 1770 | 1789 | | | | |
| PNY004 | 1627 | 1972 | 1682 | 1695 | 1739 | 1789 | 1820 | 1923 | | |
| SWR001 | 1653 | 1875 | 1682 | 1712 | 1739 | 1760 | 1779 | 1844 | | |
| SWR002 | 1698 | 1932 | 1712 | 1760 | 1779 | 1786 | 1796 | 1844 | | |
| SWRXX1 | 1691 | 1911 | 1712 | 1739 | 1760 | 1779 | 1796 | 1844 | 1863 | |
| SWR003 | 1693 | 1936b | 1712 | 1739 | 1760 | 1786 | 1796 | 1844 | 1863 | 1871 |
| SWR004 | 1724 | 1851 | 1739 | 1760 | 1786 | 1796 | 1844 | | | |
| SWR005 | 1717 | 1872 | 1724 | 1725 | 1726 | 1739 | 1760 | 1844 | 1863 | |
| SWR006 | 1695 | 1871 | 1712 | 1739 | 1760 | 1844 | 1863 | | | |
| SWR007 | 1699p | 1847 | 1739 | 1760 | | | | | | |
| SWR008 | 1700 | 1862 | 1739 | 1760 | | | | | | |
| SWR009 | 1690p | 1947 | 1739 | 1760 | 1844 | 1863 | | | | |
| SWR010 | 1691 | 1869 | 1712 | 1739 | 1760 | 1779 | 1796 | 1844 | 1863 | |
| SWR011 | 1712 | 1988b | 1712 | 1760 | 1844 | 1863 | 1933 | | | |
| SWR012 | 1712 | 1889 | 1739 | 1760 | 1786 | 1796 | 1844 | 1863 | | |
| SWR013 | 1693 | 1894 | 1712 | 1760 | 1844 | 1871 | | | | |
| SWR014 | -- | -- | | | | | | | | |
| SWR015 | 1696 | 1869 | 1760 | 1844 | | | | | | |
| SWR016 | 1687 | 1907 | 1760 | 1871 | 1896 | | | | | |
| SWRXX2 | 1703 | 1847 | 1739 | 1760 | 1779 | | | | | |
| DSP001 | 1701 | 1942 | 1749 | | 1820 | 1825 | 1888 | 1901 | | |
| DSP002 | 1765 | 1841 | 1800 | 1817 | 1835 | | | | | |
| MNY001B | 1828 | 1966b | 1901 | | | | | | | |
| MNY002 | 1714 | 1840 | 1739 | 1758 | 1823 | | | | | |
| MNY003 | 1859 | 2008 | 1901 | | | | | | | |
| SMG001 | 1695p | 1836 | 1768 | 1784 | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CAN001 | 1702p | 1989 | 1790 | 1821 | 1878 | | | | | |
| CAN002 | 1711 | 1961 | 1821 | 1878 | | | | | | |
| CAN003 | 1725 | 1902 | 1821 | | | | | | | |
| PIT001 | 1848 | 1995b | 1907 | | | | | | | |
| PIT002 | 1594 | 1907 | 1636 | 1654 | 1669 | 1682 | 1739 | 1758 | | |
| PIT003 | 1622p | 1815 | 1654 | 1669 | 1682 | 1736 | 1739 | 1758 | 1767 | 1780 |
| PIT004 | 1599p | 1906 | 1682 | 1739 | 1758 | 1780 | 1802 | | | |
| PIT005 | -- | -- | | | | | | | | |
| PIT006 | 1595p | 1816 | 1665 | 1682 | 1739 | 1758 | 1780 | 1802 | | |
| PIT007 | 1664 | 1792 | 1669 | 1682 | | | | | | |
| PIT008 | -- | -- | | | | | | | | |
| PIT009 | 1691p | 1862 | 1736 | 1739 | 1758 | 1762 | | | | |
| RQM001 | 1706 | 1894 | 1739 | 1752 | 1846 | 1864 | | | | |
| RQM002 | 1699p | 1849 | 1739 | 1752 | | | | | | |
| RQM003 | 1751 | 1920 | 1752 | 1846 | 1864 | 1900 | | | | |
| BTE001 | 1697 | 1873 | 1752 | 1859 | | | | | | |
| CLM007W | 1718 | 1883 | 1799 | 1803 | 1806 | 1822 | 1856 | 1871 | | |
| CLM008W | -- | -- | | | | | | | | |
| CLM009W | 1730 | 1977b | 1746 | 1804 | 1891 | 1908 | | | | |
| CLM010AW | 1729 | 1886 | 1735 | 1763 | 1804 | | | | | |
| CLM010BW | 1729p | 1857 | 1763 | 1804 | | | | | | |
| CLM011W | 1718p | 1822 | 1763 | 1804 | | | | | | |