A TREE-RING FIRE HISTORY OF THE UPPER BOIS BRULE RIVER, NORTHWEST WISCONSIN

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ABSTRACT

The Bois Brule River is a 44-mile-long, northward flowing Wisconsin waterway. From 1650 – 1830 the river served as part of a popular fur trade route, used by the Ojibwe, the British, and the French, that connected Lake Superior to the Mississippi River. The route eventually reached such prominence that it was termed "The Historic Highway".

I developed fire histories at three discrete sites along the Upper Bois Brule River in Northwest Wisconsin in order to (A) determine the rate of historic fire along the Upper Bois Brule River, (B) provide fire history information within the context of changes in Native American and European American land use, (C) investigate the influence of seasonal drought patterns on fire occurrence and (D) provide crucial and necessary baseline information to be used in land management decision-making.

The fire history is comprised of 60 fire scarred trees, 344 individual fire scars and 68 unique fire years. The mean fire interval ranged from 15.7 – 22.4 and the mean fire interval for the entire region was 5.1. The rate of fires began to slow in the early 1900s, before eventually ceasing in 1918. There was no consistent relationship between fire events and regional climate patterns when each site was considered individually. When all fire years were considered in aggregate there was a significant relationship between the event year and regional drought.

Results suggest that lighting, as a lone ignition source, cannot fully explain the reconstructed fire regime. It seems likely that human land use activities may have influenced the rate of fire along the Upper Bois Brule River. These findings have

important implications for future land management and can be used as a guide to achieve site specific goals.

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CHAPTER 1

Research Rationale and Study Overview

FIRE AS A PROCESS IN THE GREAT LAKE STATES

Fire is a natural disturbance that influences both the regeneration and mortality of many tree species in the northern forests of the Great Lake States (Frelich 2002). Some species have adapted traits that enable their survival or regeneration, during or after a fire. For example, red pine (*Pinus resinosa*) has evolved relatively thick, fire resistant bark, that protects the tree species from low intensity surface fires. Red pine is also a self-pruning species, reducing the chances of surfaces fires spreading into the canopy. Additionally, red pine is a shade intolerant species that requires a mineral seed bed for germination (Gilmore & Palik 2006). Jack pine (*Pinus banksiana*), a fire adapted species that is early successional, regenerates via serotinous cones. The serotinous cones open in response to intense heat, allowing the species to regenerate quickly post fire.

Other species like aspen and paper birch are not necessarily fire dependent per se, but are more so fire adapted, with mechanisms to regenerate quickly after a fire. Aspen's roots are underground and are largely unaffected by the heat of a fire, allowing the species to sprout new stems from their root collar post disturbance. Paper birch (*Betula papyrifera*) can rapidly regenerate in areas recently effected by fire because their lightweight seeds have a large dispersal range and quickly geminate when reaching cleared areas. Because fire is a key component in the regeneration of many individual species, the disturbance also increases the species diversity of the forest as a whole.

Fire interacts with landscape features, fuel conditions and weather to create a spatially heterogeneous disturbance (i.e. some areas burn and some areas do not). The forest is then defined by a mosaic of patches with different characteristics and ages since last disturbance. Some of these patches may have been recently burned, thus containing early successional species and some may have not been disturbed in 100 plus years, thus containing late successional, shade tolerant species. The patchwork nature of the forest, in differing stages of recovery since the most recent fire, increases the overall diversity of an area (Heinselman 1973a). Without fire, forests would eventually be dominated largely by late successional species, which would decrease the species diversity as a whole. Fires also provide a means of reproduction for trees, which creates an opportunity for adaptation through natural selection and thus an opportunity to increase the overall resilience of the stand or forest (Frelich and Reich 2009). In the Great Lake States, the regeneration of many species and the diversity of forest ecosystems is dependent on fire as a fairly frequent disturbance. Thus, these communities have experienced major, consequential shifts in composition since the advent of effective fire suppression, which began circa 1935 in this region (Paulson et al. 2016).

When fire suppression was enacted as policy in the early 20th century, fire was primarily considered a serious threat to future timber and infrastructure (Leopold 1920). Additionally, from an ecological standpoint, fire was viewed as a disruptive disturbance that delayed the future development and eventual dominance and persistence of the "climax" community (Clements 1916). Succession was later accepted to be much more complex than originally presented (Gleason 1926), and was gradually accepted as an important agent of change.

Fire exclusion, a reduction of local ignition sources not caused by lightning, may have also contributed to the decreased rate of fire throughout the 20th century. The removal of Native American groups from the area, who were thought to use fire as a land management tool, may have altered the rate of fire and subsequent local ecosystem conditions (Loope and Anderton 1998, Anderton 1999).

Throughout the past century, the combination of fire exclusion and suppression has led to an increase in shade tolerant species, as well as an overall decline of fire dependent species diversity (Paulson et al. 2016). While these ecological changes were gradual, they had a spatially large footprint and did not go unnoticed by researchers. Over the last several decades, forest ecologists began to recognize the adverse effects of fire suppression and have more directly advocated for the restoration of fire as a critical natural process.

In 1973, Heinselman and Frissell documented the past rate of large, stand replacing fire and the ecological changes associated with the absence of fire in the Boundary Water Canoe Area Wilderness and Itasca State Park, respectively (Heinselman 1973a, Frissell 1973). Both, called for the restoration of fire in order to restore the ecological integrity of the natural areas in an issue of *Quaternary Research* entitled “The ecological role of fire in natural conifer forests of Western and North America”. While the public and government’s understanding of fire as a natural disturbance has grown since 1973, researchers still presently advocate for the restoration of fire to fire dependent ecological communities, since little has changed in nearly 50 years (e.g., Johnson et al. 2016; Kipfmueller et al. 2017).

SEPERATING THE ROLE OF LIGHTNING IGNITIONS VERSUS HUMAN IGITIONS

Land managers are becoming increasingly interested in using the past rate of fire as a guide to restore fire dependent communities that may be entirely absent or fading from the landscape (Swetnam et al. 1999). With this in mind, some land managers have allowed naturally ignited lightning fires to continue to burn, as long as they do not pose risks to human life or structures in the area. However, this tactic alone will not necessarily fully restore the process that shaped ecosystems of the past. The target overstory composition (typically representing composition prior to widespread EuroAmerican influence and fire suppression), which may be what many land managers seek to maintain, may have been produced by a combination of both lightning and anthropogenic induced ignition sources (e.g. Kipfmueller 2017). Thus, when land managers allow lightning fires to burn, they are in fact only restoring a portion of the past fire regime, which may not fully meet the criteria or conditions they are attempting promote. This particular issue is somewhat controversial and speculative, but increasing numbers of fire histories are showing that Native American burning, particularly in the Upper Great Lakes, likely augmented the natural fire regime (Johnson et al. 2016; Kipfmueller et al. 2017, Guyette et al. 2016, Muzika et al. 2015, Sands and Abrams 2011, Dorney and Dorney 1989).

Native Americans have a rich history of using fire as a tool to alter their surrounding landscape (Stewart 2014, Williams 1994). Historical documentation and ethnographic studies show that the Ojibwe, a group of Native Americans who inhabited portions of Wisconsin and Minnesota beginning in the early 18th century, used fire to regenerate blueberries and to clear understory brush from campsites, trails and portages (Anderton 1999, Miller and Davidson-Hunt 2010).

It is difficult if not impossible to determine those individual fires ignited by humans and those caused by lightning, which can prove to be a complication if land managers are seeking to only restore the lightning fire regime. Additionally, lightning fires alone may have not created the current overstory forest conditions, which are an vestige of pre-settlement activities. Thus, land managers may consider restoring the additional human induced fires to management plans to better maintain the past landscape characteristics. Researchers can only make broad inferences regarding how often lightning fires would naturally occur, and examine the number of "additional fires", which become attributed to human ignition sources. Land managers can then use these fire histories, site specific records, and current forest conditions as a guide to managing the landscape for the targeted ecological conditions, which may be within or outside the historical range of variability.

GOALS OF THE STUDY

My work expands the understanding of fire as an agent of disturbance in Upper Great Lakes forests by reconstructing fire histories in three sites: (1) Brule River Properties, (2) Cedar Island Estate, and (3) The Brule River Historic Portage. The study sites presented here, all located along the Upper Bois Brule River in Northwest Wisconsin, were initially selected because they contained abundant evidence of past fire, either fire scarred stumps or snags. Additionally, two of the three study sites contain old, overstory red pine, which is relatively rare in the Great Lake States outside of wilderness areas, since much of the pine forest was logged in the late 19th and early 20th centuries (Peterson & Ronnander 2017). Fire-scarred remnant stumps, paired with old overstory trees found along the Upper Bois Brule River, present a unique opportunity to understand a portion of the landscape's environmental history. Through the means of dendrochronology and the technique of crossdating, past fire occurrence can be estimated by dating fire-scar lesions preserved in the annual rings of stumps, logs, and trees. Crossdating is the pattern matching of wide and narrow tree-rings amongst many samples (Douglass 1941, Stokes and Smiley 1968). This methodology enables researchers to link the growth patterns found in the living trees to the same patterns found in the remnant stumps. This procedure enables the determination of the exact calendar year for each tree ring that contains a fire scar, enabling the reconstruction of fires far into the past.

Here, I reconstruct the past rate of fire along the Upper Bois Brule River as a potential guide to restore the process that generated red pine's past structural and compositional condition. I evaluate the relationship between regional climate patterns and the fire regime via Superposed Epoch Analysis. Additionally, I bring to light the importance of land management practices on fire adapted landscapes. Lastly, historians and archaeologists know the Ojibwe used the Upper Bois Brule River as a travel path during 18th and 19th century, with communities situated near the waterway. My research seeks to better understand how the Ojibwe's use of fire may have altered the former and present ecological communities, and I make comparisons between the fire histories of the three sites to identify potential differences that might be explained by differential land use patterns.

CHAPTER 2

Research Setting

EARLY HISTORY OF THE OJIBWE IN WISCONSIN

Numerous Native American groups inhabited Northwest Wisconsin. Most notably, in the late 1600s and early 1700s the Ojibwe arrived to the area, settling in permanent and semi-permanent communities. While several Native American groups temporarily inhabited the region prior to the arrival of the Ojibwe, little information exists regarding these groups, their movements, or their cultural history. Here, I focus on the history of the Ojibwe people whose presence was fairly well documented by explorers, traders, and missionaries, and whose presence temporally overlaps with the tree-ring evidence of fire in this region.

Circa 1400 A.D the Ojibwe began to move westward in order to flee the attacking Iroquois, a Native American group whose original homeland was located in present-day New York State. The Iroquois expanded their territory West and South, eventually pushing the Ojibwe to the area around Sault Sainte Marie, Michigan. Some Ojibwe settled in Michigan, while others continued to expand westward. Eventually, those that continued westward reached and settled on a small grouping of islands north of mainland Wisconsin, with their primary village site located on present day Madeline Island, which is situated adjacent to the Apostle Islands (O'Donnell 1944).

The Ojibwe would frequently venture onto the mainland for hunting and gathering expeditions, and also had semi-permanent encampments on the mainland area. This practice eventually became a source of conflict, as they were using hunting territory claimed by other mainland Native American groups. The mainland groups included the

Dakota (also known as the Sioux) and the Fox. After multiple battles, the Ojibwe eventually staked their claim on the northern mainland of Wisconsin in the mid 1700s (Jenks 1901, O'Donnell 1944).

One benefit that came with the expanded territory, was access to the Bois Brule River, which the Ojibwe called ‘Misakota’. The name of the river ‘Misakota’ (or Wisacoda) is thought to mean ‘burnt pines’ (Jerrard 2011: 5). The Ojibwe were well known for their ability to swiftly travel the river using birch bark canoes. The canoes were constructed of a cedar wood frame and a birch bark shell tied together with small roots and sealed with sap (Warren 1970).

The Ojibwe had two main, large communities near the northern portion of the Bois Brule River. One community was located in what is now present-day Duluth, MN and the other community was located on Madeline Island, an island situated adjacent to the Apostle Islands in Lake Superior. The Ojibwe also had a series of encampments south of the Brule River, stretched along the St. Croix River, where the Ojibwe frequently gathered wild rice (Arrowsmith 1802, Jenks 1901). A map produced by Arrowsmith identifies the Bois Brule River as the “passage into the country of the Wild Rice Indians” (Jenks 1901). It seems likely that the Ojibwe frequently used the Bois Brule River as a travel path, connecting the northern and southern communities, prior to the fur trade era.

Pierre-Esprit Radisson and Medard Chouart Des Groseilliers were the first fur traders to visit Wisconsin, in about 1651 (“Radisson, Pierre-Esprit,” n.d.). Eventually, the two returned to Montreal and spread the news of furs and a southbound flowing river. The new and growing economy attracted French and British fur traders, as well as missionaries. Native Americans would trade pelts to Euro-Americans for guns, knives and other basic goods. Wisconsin's economy was centered around the fur trade from 1650 to 1850. Eventually the fur trade economy began to dwindle in the 1830s due to overhunting and political turmoil, causing the fur trade market to shift elsewhere.

FUR TRADER ACCOUNTS AND THE HISTORIC HIGHWAY

The Ojibwe's territory encompassed the Bois Brule River, but they were not the only group to use the waterway. Many travelers and traders sought to use the river during the fur trade era because it was a part of the quickest path between the Mississippi River and Lake Superior. The headwaters of the Brule River are connected to the St. Croix River via a two-mile trail called the 'Historic Portage'. The Bois Brule River flows northward and drains into Lake Superior, while the St. Croix River flows southward and is a tributary of the Mississippi river. The path eventually became so popular that it was termed the 'Historic Highway' (Figure 1).

Daniel Greysolon Sieur du Lhut, a French military officer, was the first white man of record to use the historic portage and travel the Brule River in 1680. He wrote:

> '…where after having cut down some trees and broken about one hundred beaver dams, I went up said river, and then made a carry of a half a league to reach a lake, which emptied into a fine river, which brought me to the Mississippi…' (Jerrard 2011:13).

Here, Sieur du Lhut, writes about the Historic Highway: paddling up the beaver dam filled Brule river, traversing the Historic Portage, reaching Upper St. Croix Lake, flowing down the fine St. Croix river and eventually reaching the Mississippi. Many traders and voyagers travelled the same route after Sieur du Lhut, including Michel Curot, who camped near the historic portage in 1803-4 and wrote:

> 'After leaving the upper pool of the Brule, the present Editor and his fellow voyagers ascended for about fifty yards to a narrow plateau composed of a sand hill covered with recently burned timber, carpeted with blueberry and hazel bushes, from which rose a maze of slender blackened trunks. The portage path led southwestward through this forest for about two miles, in which there were two steep hills to be overcome by the burden bearers. Now and then the trail led through thick standing timber, the ground carpeted with pine needles; and occasionally over a little bench, on which were frequently seen the remains of an Indian camp. The landing at the St. Croix end of the portage was swampy' (Curot 1911).

In addition to the remnants of Native American camps that Curot noted along the portage, historical text indicates that there were multiple Ojibwe camps scattered along the Bois Brule River. There was a Native American village on the island located in Upper St. Croix lake, which also served as a resting spot for early travelers (Curot 1911). There were also encampments located further North, near the present-day town of Brule. In 1886, Edward N. Saunders noted a Native American village situated about 3.5 miles south of the Brule train station (Jerrard 2011: 85). The encampment was composed of a dozen cedar bark wigwams. Saunders did not recall seeing the village again on later visits after 1886. Saunders account is supported by the fact that the Ojibwe were thought to have ceased using the historic portage in 1886 (Jerrard 2011: 164).

Euro-Americans began purchasing property along the Bois Brule River from the State of Wisconsin in the 1880s, which coincides with the previously noted absence of the Ojibwe, circa 1886. The Winneboujou Club, a group of early conservationists, purchased land near the Bois Brule River in 1888 (Jerrard 2011: 84). The Cedar Island Estate, located south of the Winneboujou Club, was purchased in 1883. The land along the Bois Brule River was not only of interest to private property owners, as multiple logging companies also sought to obtain rights to the land in order to profit off the rich timber area.

LOGGING HISTORY OF NORTHWEST WISCONSIN

In 1837 the Ojibwe and Winnebago tribes reached a settlement, called the "White Pine Treaty", that allowed portions of their timber rich land to be harvested (Jerrard 2011: 68, Satz & Apfelbeck 1996: 13). The 1837 settlement was followed by an additional treaty, signed in 1842, called the "Copper Treaty", that granted the United States the timber and mining rights to the Brule River Valley and the southern shore of Lake Superior (Jerrard 2011: 68, Satz & Apfelbeck 1996: 33). In 1850, President Zachary Taylor signed an executive order ceding Ojibwe lands that were previously guaranteed in the treaties of 1837 and 1842 (Satz & Apfelbeck 1996: 55). The Ojibwe were ordered to move from their land in Wisconsin, Minnesota and the Upper Peninsula of Michigan to designate reservation lands in Minnesota. The re-settlements of 1837 and 1842, combined with the executive order signed in 1850, ensured that the United States government would be able to harvest the natural resources available in northern Wisconsin.

Logging along the Bois Brule River occurred as early as 1871. Small logging operations were situated along the Bois Brule River as logging activity increased during the 1880s. The logging boom and subsequent development peaked in the 1890s and early 1900s. Douglas county's European population increased exponentially with the growing economy, from 655 in 1880 to 13,468 in 1890 and 36,335 in 1900 to 47,422 in 1910 (Jerrard 2011: 69). The increased population and development of Douglas County coincided with the rail industry reaching the Brule River. The Northern Pacific Railroad was built in 1883 and Duluth, South Shore, and Atlantic (D.S.S.A) line was built in 1892. The Northern Pacific Railroad connected Superior to Ashland and the D.S.S.A crossed through the northern portion of the Winneboujou Club (Jerrard 2011: 69).

Northwest Wisconsin is currently comprised of federal, state, county and private land ownership, each with distinct management goals. Some forests are managed to produce uneven-aged forest conditions, while others are clear cut on a rotation ranging from 50 – 100 years. Parks and wilderness areas are maintained without extensive logging.

HISTORICAL VEGETATION OF THE BRULE RIVER WATERSHED

The Bois Brule River is a renowned trout fishing stream. The scenic river and high-quality fishing attracted many visitors throughout history. The river, which may have aided the Douglas County economy, became a cause for concern when the fish population began to decrease in the late 1930s. Shortly following the decrease, a total of $34,247 was invested from 1937 – 1941 in an attempt to restock the river (Schneberger & Hasler 1944). The investment did little to increase or maintain the fish population, which prompted the need for a scientific study that examined the local controls of the Bois Brule River fish population. The purpose of the study was stated as:

> "the evaluation of the physical, biological, and chemical characteristics of the Brule River and its watershed so that an efficient and well balanced fish management plan might be developed and placed into operation."

Researchers hypothesized that the recent logging of many forest communities may have impacted the runoff and erosion rates within and near the Bois Brule River. Thus, one portion of the study sought to examine the effects of logging by comparing forest cover conditions before and after the removal of overstory trees. N.C. Fassett, a botany professor at the University of Wisconsin, conducted the study. Fassett (1944) compared land survey notes from 1852 - 1856 to forest conditions at the time of the study (1932 – 1943), noting the changes in species composition and highlighting areas that were heavily affected by logging. The study, along with others that focused on the Bois Brule River, was published in the *Wisconsin Academy of Sciences, Arts and Letters* in 1944.

The 1852 – 1856 Brule River Watershed vegetation was derived from original government survey notes. The surveyors noted both the general forest type and the specific species that made up the ecological communities prior to the logging era. The south and southeast portion of the watershed was dominated by pine barrens, with intersecting tracts of pine forest. The northern portion of the watershed was composed of pine – hardwood and spruce – fir forests. Bog conifers are located intermittently throughout the watershed. More specifically, the southern portion of the Brule River Watershed included white pine (*Pinus strobus*), red pine (*Pinus resinosa)*, jack pine

(*Pinus banksiana*), and aspen (*Populus grandidentata*). Balsam fir (*Abies balsamea*) was mainly limited to the northern portion of the watershed and sugar maple (*Acer saccharum*) was sparsely scattered throughout the watershed.

Fassett's personal field research in 1942-43 and surveys made by the Wisconsin Land Economic Inventory in 1932 were used to produce the 1932 – 1943 Brule River Watershed vegetation conditions. The northern portion of the watershed endured substantial clear cutting. The northwest portion of the watershed was also heavily logged. Comparatively, the southwest pine barrens remained largely untouched, with only a few sections described as 'cleared'. Fassett noted that the pine barrens remained largely unchanged and were still composed of scattered jack pine and scrub oak. However, more recent studies suggest that pine barrens as a whole are decreasing in area due to fire suppression efforts (Radeloff et al. 1999).

One notable difference between the 1852 – 1856 and the 1932 – 1943 vegetation reports is the increase of lowland hardwood species. The increase of shade tolerant, hardwood species observed by Fassett serves as an important and relatively early data point in the region wide shift from pine species to hardwood species. Documentation of past vegetation communities, paired with the historic rate of fire allows researchers to evaluate landscape scale changes throughout time, which is important for 21st century land management decision making.

CHAPTER 3

A Tree-Ring Fire History of the Upper Bois Brule River, Northwest Wisconsin

INTRODUCTION

For the past 500 years, fire has been a driving component of the regeneration of many tree species in Northern Wisconsin, impacting an estimated 95% of the old growth forest (Maissurow 1941). Since the onset of fire suppression policy and extensive logging, species composition and forest structure has begun to shift in Wisconsin (Radeloff et al. 1999, Stoltman et al. 2007). Increasingly, land managers are using the historic rate of fire as a guide in order to sustain or restore past fire dependent vegetation communities (Swetnam et al. 1999). However, using the past rate of fire to regenerate forest communities does not come without its own set of unique complications. Land managers must decide if they want to restore the lightning (lightning as a lone ignition source) or anthropogenic (combination of lightning and additional anthropogenic ignition sources) fire regime. Additionally, restoring fire to a landscape is not an easy task as there are often logistical, socio-cultural, and operational constraints, such as the homogenization of fuel loads, which would make the implementation of fire a safety hazard.

Under most circumstances, the vegetation communities of an area that experiences anthropogenic caused fires, in addition to naturally occurring lightning caused fires, will be different than an area that only experiences lightning caused fires. Land managers cannot expect lightning to maintain ecological communities that were in part, produced by human ignition sources. Thus, it is crucial for land managers to consider past human land use activities as a factor when making decisions regarding desired vegetation conditions. This is especially true in areas like northwestern Wisconsin, where human land use is estimated to have shaped a large portion of the state's ecological communities (Curtis 1959).

Curtis (1959) suggested that fires set by Native Americans influenced at least 47 - 50% of the vegetation based on ecological survey data that he and his students collected from over 1000 sites throughout Wisconsin. Fires ignited by Native Americans had a wide range of ecological effects. In some cases, fires set by Native Americans modified ecological communities. In 1837, public land surveyors recorded an oak savanna in northeast Wisconsin near Green Bay. Dorney and Dorney (1989) sought to understand why an oak savanna would be present in northeast Wisconsin, as the vegetation type is much more common in southern Wisconsin. They described the oak savanna as 'unusual' as it could not be explained by the local climate, soil or topography. Dorney and Dorney (1989) deduced that the oak savanna was the product of frequent anthropogenic caused fires associated with Potawatomi and Winnebago Native Americans, who had a series of encampments near the area.

In other cases, human induced fires may have increased the abundance of fire dependent species. Sands and Abrams (2011) reconstructed fire history on the Menominee Indian Reservation in northeast Wisconsin and reported that a high rate of fire increased the abundance of aspen, pine and oak species. Sands and Abrams (2011) also downplayed the role of lightning as an ignition source, stating that lightning was responsible for only 5% of the fire events that occurred from 1927 – 2011.

While multiple studies have examined the connection between fire, Native American land use, and subsequent ecological conditions in northeast Wisconsin, only one tree-ring based fire history study has been conducted in Northwest Wisconsin (Guyette et al. 2016), where the presence of the Ojibwe is fairly well documented (Curot 1911, Jerrard 2011, Loope and Anderton 1998, O'Donnell 1944). Since the mid 1600s, the Ojibwe have occupied northwest Wisconsin as hunter-gathers, moving their encampments seasonally in order to capitalize on the resources available at the time. Ojibwe seasonal movements included a focus on maple groves to make sugar in spring, berrying and fishing in summer, gathering of wild rice in the fall, and hunting large and small game in the winter. Anderton (1999) also suggested that the Ojibwe actively used fire as a management tool to promote berry production in some portions of their territory.

In an effort to better understand the fire regime of the Upper Bois Brule River, I used tree rings to reconstruct past fire events coinciding with historical use of the area. I attempted to provide key, site specific details regarding the fire regimes of closed canopy red pine forests in northwest Wisconsin to: (A) determine the rate of historic fire along the Upper Bois Brule River, (B) provide fire history information within the context of changes in Native American and European American land use, (C) investigate the influence of seasonal drought patterns on fire occurrence and (D) provide crucial and necessary land management recommendations. I reconstructed fire at three discrete sites along the Brule River. Although these sites are in relatively close proximity, landform, current overstory composition, and past land use histories differ between sites. Comparison between these sites could yield important insight into the causal mechanisms of differences in fire regimes, if they exist, or inform the controls on fire occurrence over time.

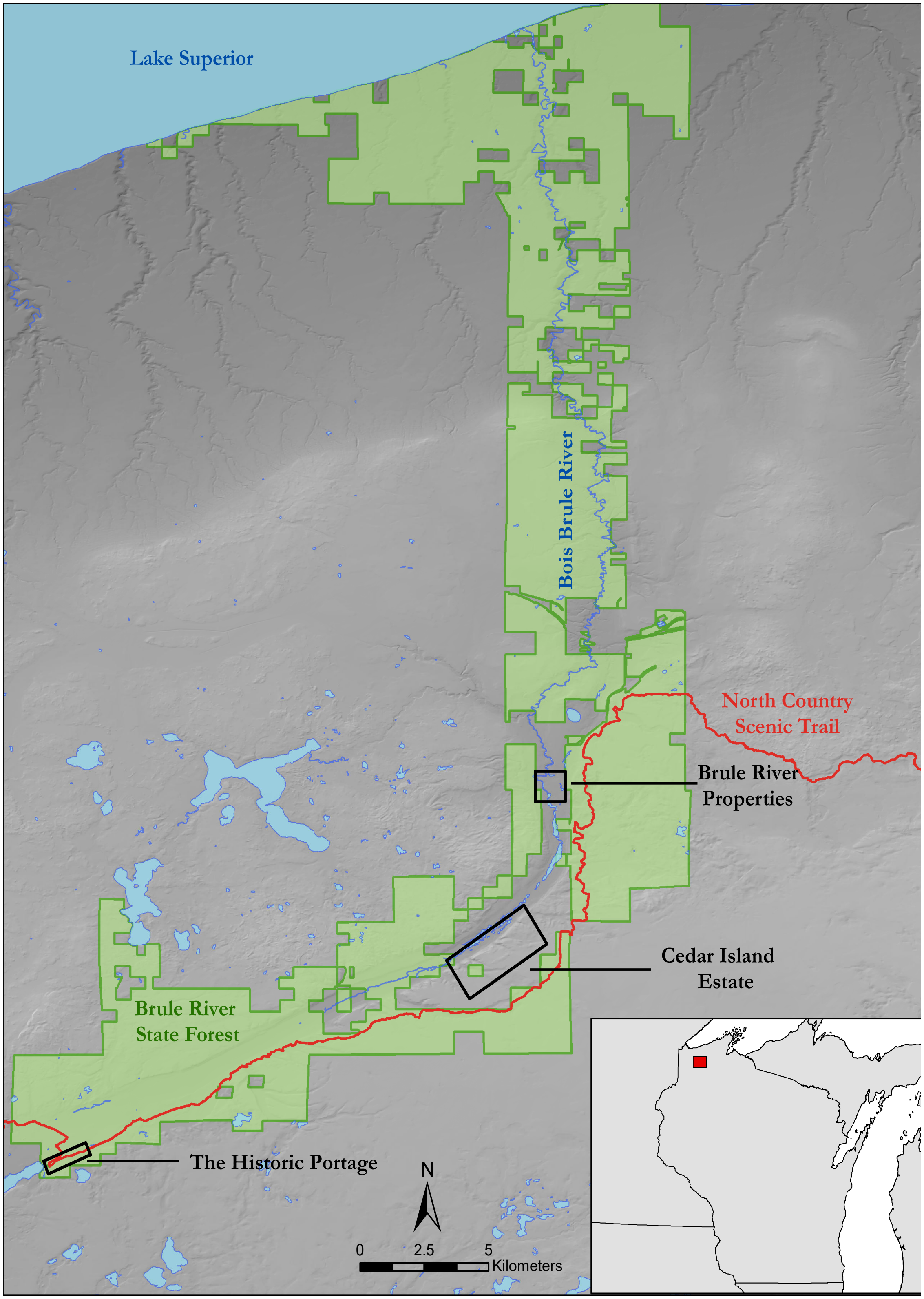

Figure 1. Study area location map situated within and around the Brule River State Forest

STUDY AREA

Geomorphology and soils

The Bois Brule River is a 44-mile-long Wisconsin waterway that begins near the Upper St. Croix Lake and flows northward, eventually reaching Lake Superior (Figure 1). Though now flowing northward and emptying into Lake Superior, the Brule River was originally a southbound flowing stream, formed from the melt water of the receding glacier that once filled the Lake Superior basin (Jerrard 2011: 5, Bean and Thompson 1944). The retreating ice sheet formed a glacial outwash system in the southern portion of the Brule River watershed. The landscape is dominated by two types of landforms, terraces and kettle lakes. The terraces formed along the glacial meltwater canals and the kettle lakes were originally outwash plains that contained a depression (Bean and Thompson 1944). Bogs and wetlands are located intermittently throughout the watershed. The melting glacier deposited a thick layer of sands in the southern portion of the Brule River Watershed, with a depth ranging from 100 – 600 feet (O'Connor 2016). These sands are relatively well drained, contain little organic material and lack sufficient nutrients (O'Connor 2016). The soils in the northern portion of the Brule River Watershed are composed of red clay (Fassett 1944).

Climate

The Brule River Watershed experiences long, cold winters and warm, short summers. January's average minimum temperature is -18.3°C. July's average maximum temperature is 26.2°C (Figure 2). The average annual precipitation is 82.5 centimeters, most of which occurs from May to October. The average annual snowfall is 210 centimeters, most of which occurs in November, December, and January. The climate of Wisconsin has remained relatively stable over the last 600 years (Gajewski et al. 1985), but temperatures have been increasing over the last several decades and there has been a decrease in summer precipitation in northern Wisconsin since the 1950s (Kucharik et al. 2010).

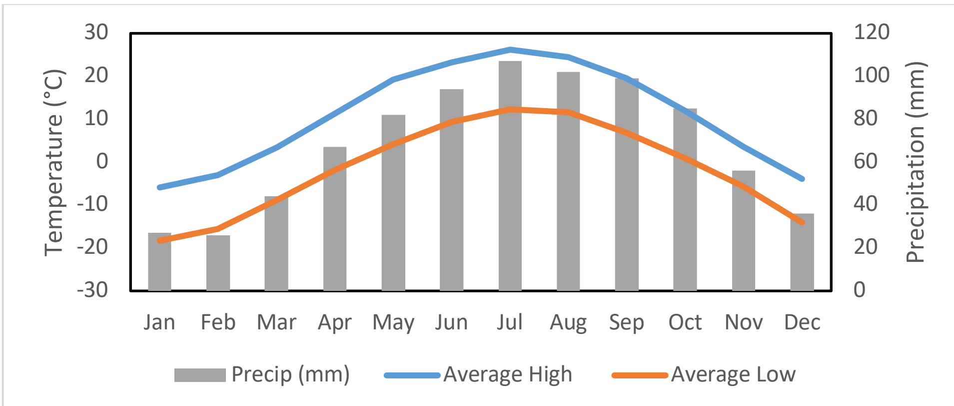

Figure 2. Climate Normals (1981 – 2010) for Lake Nebagamon, WI. Lake Nabagamon is 5 miles east of the Brule River Properties study site.

Study Site Descriptions

My efforts were primarily focused on reconstructing fire histories near the Upper Bois Brule River, in the southern portion of the watershed (Figure 1). We developed fire histories at three separate study sites within the Brule River Watershed, Brule River Properties (BRP), Cedar Island Estate (CIE), and The Historic Portage (THP) near the upper portion of the Bois Brule River (Figure 1). My study sites were limited to the areas that contained evidence of past fires, either fire-scarred stumps or standing snags. Sites are generally located along the eastern side of the Bois Brule River, with the Historic Portage being the farthest south and Brule River Properties being the furthest north. Both BRP and CIE are located on private property, while THP is located within the Brule River State Forest and is managed by the Wisconsin Department of Natural Resources.

The Brule River State Forest was established in 1936, after Fredrick Weyerhauser donated 1,618 ha of land to Wisconsin in 1907. All three study sites are located in the Northwest Sands Ecological Landscape, a Wisconsin sub division of the state's natural areas (Wisconsin Department of Natural Resources 2015). The Northwest Sands Ecological Landscape is a glacial outwash area typified by sandy soils that are well-drained and susceptible to periodic drought.

Brule River Properties

The Brule River Properties are a series of privately owned cabins that have been family-owned for several generations. The cabins are mainly used for recreation and leisure during the summer season. Currently, Brule River Properties (~ 26.5 Ha) contains a fairly extensive overstory of red pine (*Pinus resinosa)* and a sub canopy of white pine (*Pinus strobus*) and balsam fir (*Abies balsamea*) (Figure 3). There are also shade-tolerant hardwood species like sugar and red maple (*Acer sacharum and Acer rubrum*) and some smaller stands of quaking aspen (*Populus tremuloides*), particular in more mesic areas. A portion of the living red pine possess 'cat faces' that exhibit 3 - 6 scars on average, indicating that at least some fires that occurred on this landscape were non-lethal surface fires. The understory of the forest is primarily dominated by balsam fir (*Abies balsamea*) of small diameter and high stem density. The Brule River has more limited topographic relief compared to other study sites investigated.

There is some historical evidence that suggests the Brule River Properties was an Ojibwe encampment prior to 1886. Edward N. Saunders, who was travelling from the Brule train station to Ashland Lake, originally wrote about the encampment. He noted that the camp was composed of a dozen cedar bark wigwams (Jerrard 2011: 85). While the exact location is not known, he estimated that the Native American village was about 3.5 miles south of the train station in Brule. Brule River Properties is 3 miles south of the town of Brule and is just north of Ashland Lake. Edward N. Saunders noted that he did not recall seeing the village after the year 1886 (Jerrard 2011: 85). Additionally, an Ojibwe canoe maker once lived at the Brule River Properties (*personal correspondence with Robert Banks, a property owner near BRP*) and there are a number of culturally-modified peel trees found at the study site. Culturally-modified trees are thought to have been intentionally peeled and injured by Native Americans in order to produce pitch. The pitch would then be used to seal and repair birch bark canoes and for many other possible purposes (Johnson et al. 2018).

Cedar Island Estate

Cedar Island Estate is made up of a few large housing structures and a fish hatchery, situated next to a series of springs and small lakes connected to the Bois Brule River. The estate was once known as "The Summer White House" when former President Calvin Coolidge visited and temporarily moved his office to Cedar Island in the summer of 1928 (Ferrell 2017).

The Cedar Island Estate study site (~ 143 ha) is composed of four forested ravines positioned on the southeast side of the Bois Brule River (Figure 3). The overstory in the ravines sampled for fire history is dominated by red pine (*Pinus resinosa)*. The understory is dominated by white pine (*Pinus strobus)* regeneration, red maple (*Acer rubrum)*, paper birch (*Betula papyrifera*), aspen (*Populus tremuloides*) and red maple seedlings. Remnant stumps throughout the area suggested logging had occurred in the past. Logging was thought to have occurred circa 1897 (Carlson, n.d.)

The Historic Portage

The Historic Portage is a two-mile trail that connects the Bois Brule River and the St. Croix Rivers. Though only two miles long, the portage links two of the most iconic water bodies in the United States, the Mississippi River and Lake Superior. The Historic Portage joins the St. Croix, which flows southward into the Mississippi River, to the Bois Brule River, which flows northward into Lake Superior (Figure 2). The travel path was frequently used during the fur trade era, and has been called the '*Historic Highway'*. For more than 200 years, the Historic Portage was used by the Ojibwe, the Sioux, and French voyageurs alike. The first European explorer on record to use the portage was Daniel Greysolon Sieur du Lhut, a member of the French military, who crossed the trail in 1680. The Ojibwe are thought to have stopped using the passage around the year 1886 (Jerrard 2011: 164). The Historic Portage is located within the Brule River State Forest and is managed by the Wisconsin Department of Natural Resources.

The main portion of the Historic Portage study site (~ 21.1 Ha) runs along a steep, sandy ridge north of Upper St. Croix Lake (Figure 3). The overstory is composed of scattered red pine (*Pinus resinosa)*. The understory is composed of balsam fir (*Abies balsamea*), red maple (*Acer rubrum)*, big tooth aspen (*Populus grandidentata*) and paper birch (*Betula papyrifera*).

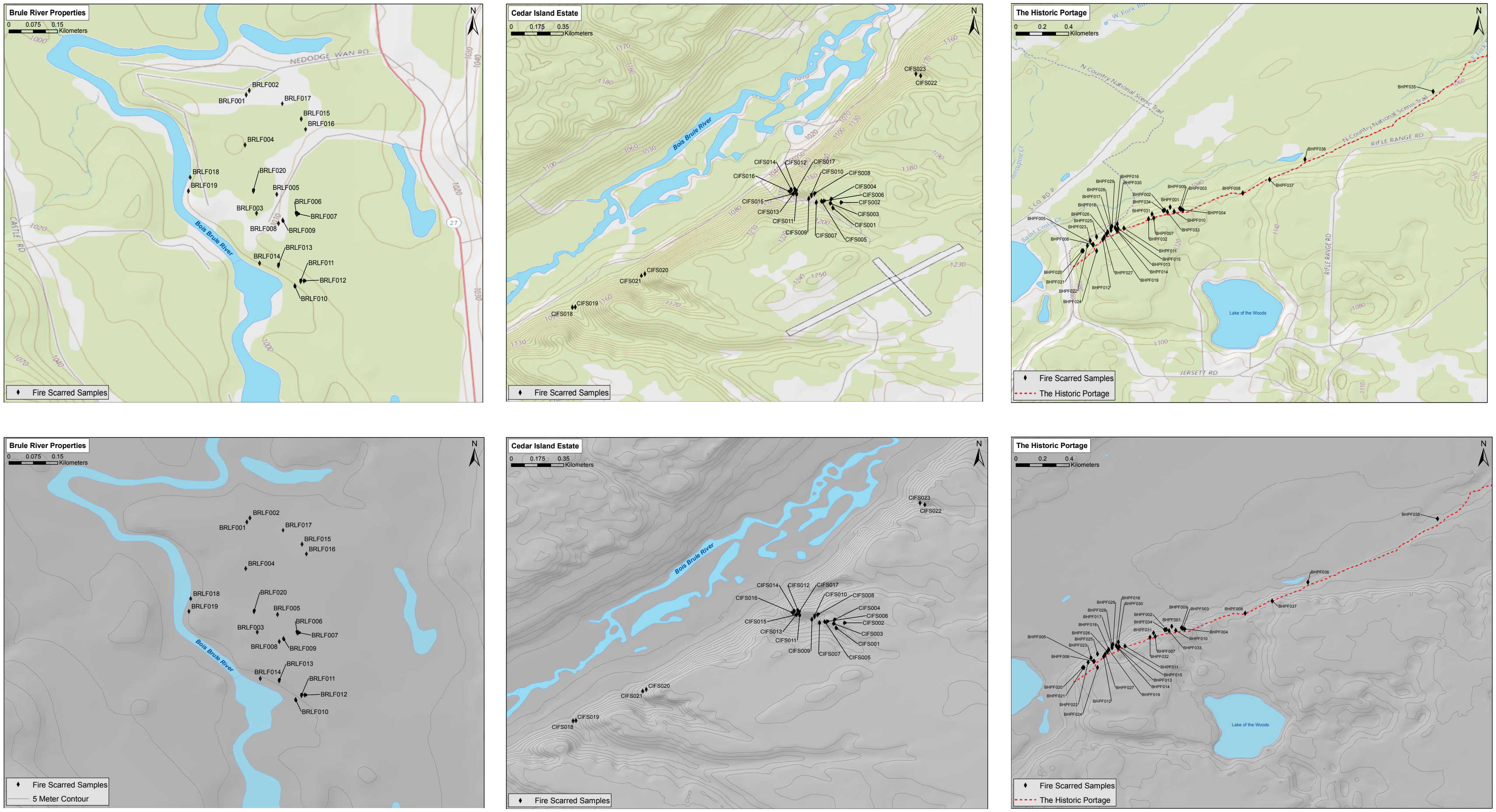

Figure 3. Point locations of all samples collected from each study site. From left to right: Brule River Properties, Cedar Island Estate, The Historic Portage. Top images are topographic maps while the bottom images are shaded relief representations.

METHODS

Field Methods

To develop fire history for the three study sites, we identified fire-scarred stumps and logs based on characteristic healing lobes occurring on the base of potential sample trees. To reduce the impacts of fire-scar sampling, we worked with the private land owners to identify potential samples prior to collection. We walked each study area extensively and attempted to collect samples exhibiting the greatest number of scars. We also sought to collect samples, that as a whole, exhibited a large spatial distribution. Landowners and forest managers restricted fire-scar sampling to dead trees, logs and stumps to limit impacts to the landscape, and visual disturbance. We collected partial cross sections from sound (or relatively intact), fire-scarred stumps that exhibited multiple healing lesions. Samples were collected using a chainsaw, crosscut saw, or arborist saw. A GPS coordinate was recorded for each sample using a recreational GPS device and/or Avenza Maps on a hand-held smartphone. Local physiography details and the number of observable scars were also recorded for each sample collected. Samples collected from BRP were evenly distributed throughout the study area. At CIE, samples were collected from south-west facing slopes. Samples located at THP were primarily collected from a north facing slope.

To facilitate the dating of stumps and logs, we developed a ring width chronology of tree radial growth by targeting large-diameter living red pine co-located with the stumps at BRP. We collected a minimum of two increment cores from each identified tree. Cores were placed in a paper straw and labeled with assigned identification codes.

Laboratory Methods and Analysis

In the laboratory, increment cores were mounted on wooden core mounts and the surfaces were sanded with progressively finer grits of sandpaper until tracheid cells and other distinctive characteristics were clearly visible under 40x magnification (Stokes and Smiley 1968). Fire-scarred samples were mounted to plywood and sanded using hand held belt sanders. Sanding was conducted using progressively finer grit sandpaper (50 to 400) to ensure anatomical features and individual xylem cells were clearly visible under 40x magnification. Hand-held orbital sanders were used with 600 and 800 grit sandpaper to refine the surface, particularly important for facilitating fire scar placement within an annual ring. Fire-scarred samples were then crossdated following standard techniques outlined by Stokes and Smiley (1968). I examined the wide and narrow growth pattern of annual rings in order to facilitate crossdating of shared growth patterns between multiple samples. Crossdating relies on pattern matching of annual ring widths among numerous samples to ensure that each ring is accurately dated in the year in which the ring was produced (Douglass 1941, Stokes and Smiley 1968). The pattern of wide and narrow rings was graphically represented using skeleton plotting techniques (Stokes & Smiley 1968).

Individual ring-widths of each increment core were measured to the nearest 0.001mm using a Velmex measuring system with a sliding-stage micrometer and the program MeasureJ2x (Velmex, Bloomfield, New York, USA) to quantitatively develop a master dating series and verify crossdating. Crossdating was statistically confirmed using the computer program COFECHA (Holmes 1983). COFECHA uses moving correlations to statistically verify ring growth patterns in order to ensure precise dating.

Where skeleton plotting was inconclusive or to verify expected dating, we measured the ring-widths of fire-scarred samples to the nearest 0.001mm using a Velmex measuring system with a sliding-stage micrometer and the program MeasureJ2x. These measurements were compared with those of dated fire-scarred samples, as well as the Brule River master chronology of tree ring growth. Potential dates were then re-examined on the wood to verify dating accuracy and precision.

Fire scars preserved on the samples were assigned dates by determining the annual ring intersected by the lesion. The fire scar(s) position within the annual ring was recorded as earlywood, latewood, dormant, or indeterminate. Dormant scars (scars located in between two annual growth rings) were assigned to the following year and treated as spring fires due to the greater likelihood of fires occurring before green up (Lewis 1982), and based on observations of radial growth phenology in red pine growing in the region (Nagel, Kipfmueller, and Griffin, unpubl. Data). Additionally, spring (March – May) is the most common fire season in Wisconsin ("Risk of wildfire by season," 2017) based on contemporary records. Indeterminate fire-scars were usually due to mechanical cracking that made the exact assignment of seasonality uncertain. Fire scar dates were compiled for each site into a composite site fire history.

Fire History Analysis

For each sampling unit, we visually examined the fire interval distributions (the number of years between successive fires) to compare fire interval distributions between sites. We also examined the fire occurrence by calculating a cumulative fire event curve and a fire chart for each individual site. While the fire histories at each site were considered individually, I also combined the three sites into a single fire chronology representing the larger Brule River Watershed to examine fire history characteristics at a region-wide scale. Fire interval distributions were compared between the three discrete sites using Kolmogorov-Smirnov tests to assess potential differences. We also calculated common standard fire history statistics which included mean fire interval (MFI), Weibull Median fire interval (WMFI) and fire frequency for each site as a supplement to visual examination of the fire interval. Fire frequency for each individual was calculated considering only the time period between adjacent fire scars on a sample, isolating the portion of the record containing reoccurring disturbances and providing an additional metric to compare spatial and temporal fire patterns between sites (Kipfmueller et al. 2017).

Fire-Climate Analysis

We investigated the influence of climate patterns using Superposed Epoch Analysis (SEA) to examine the interannual relationships between fire events and summer drought conditions, as reflected in the PDSI reconstruction for GP197 of the North American Drought Atlas (Cook 1999). SEA is a compositing technique widely applied in fire-climate analyses that computes the mean value of a climate parameter of interest using each observed fire year and the years prior to fire occurrence for each key event year (Baisan and Swetnam 1990; Brown and Schoettle 2008). This assists in the assessment of antecedent climate conditions that may be related to fire occurrence as well as determination of the conditions during fire years. A Monte Carlo simulation is employed such that random draws of fire event years are used to generate confidence limits around the departures of the actual values minus the simulated values. This randomization procedure selects sets of fire years equal in number to the observed number of fires (e.g., the number of large fires in a data set), calculates a mean value for the climate parameter for the windows of these events, and subtracts the observed values from the simulated values. This procedure is completed 1000 times and the average of the 1000 departures with associated confidence limits are calculated. SEA was performed using different combinations of key years:

1. All reconstructed fires at each of the three sites individually (3 sets)
2. Fires recorded by at least 25% of recording trees at each site (3 sets). A 25% threshold is often considered indicative of larger, spreading fires on a landscape and usually is suggestive of climatic patterns related to large fire occurrence.
3. All fires occurring at the three sites combined. That is, combining fire years from (1) above.
4. Fires recorded on 25% of samples at all three sites. That is, combining the fire years from (2) above.

Fire years were examined over a five-year window that included three years prior to the fire event year, the fire event year, and one year following the fire event.

RESULTS

The Fire Regime of the Upper Bois Brule River Fire History

I successfully dated 344 fire scars from 60 fire scarred trees. Sixty-eight unique fire years were reconstructed, with the earliest fire occurring in 1576 at the Historic Portage and the last fire occurring in 1918 at Brule River Properties (Table 1, Figure 4). The median fire interval based on all individual samples was about 16 years (Figure 5). The median fire return interval at the regional scale was 3 years (Figure 6), indicating that fire occurred on the overall landscape at relatively short intervals between successive events. The number of scars derived from individual trees ranged from as few as 1, to as many as 15 (Figure 7).

Twenty samples were collected from the Brule River Properties (BRP). A total of 101 individual fire scars were derived from the BRP samples, identifying 18 unique fire years. The earliest fire at BRP occurred in 1774 and the last fire occurred in 1918. I was able to successfully date 95% of the samples from BRP. The BRP fire history produced a MFI of 15.7 and a fire frequency of 0.125. Living red pine at the Brule River Properties study site tends to be approximately 250 years old.

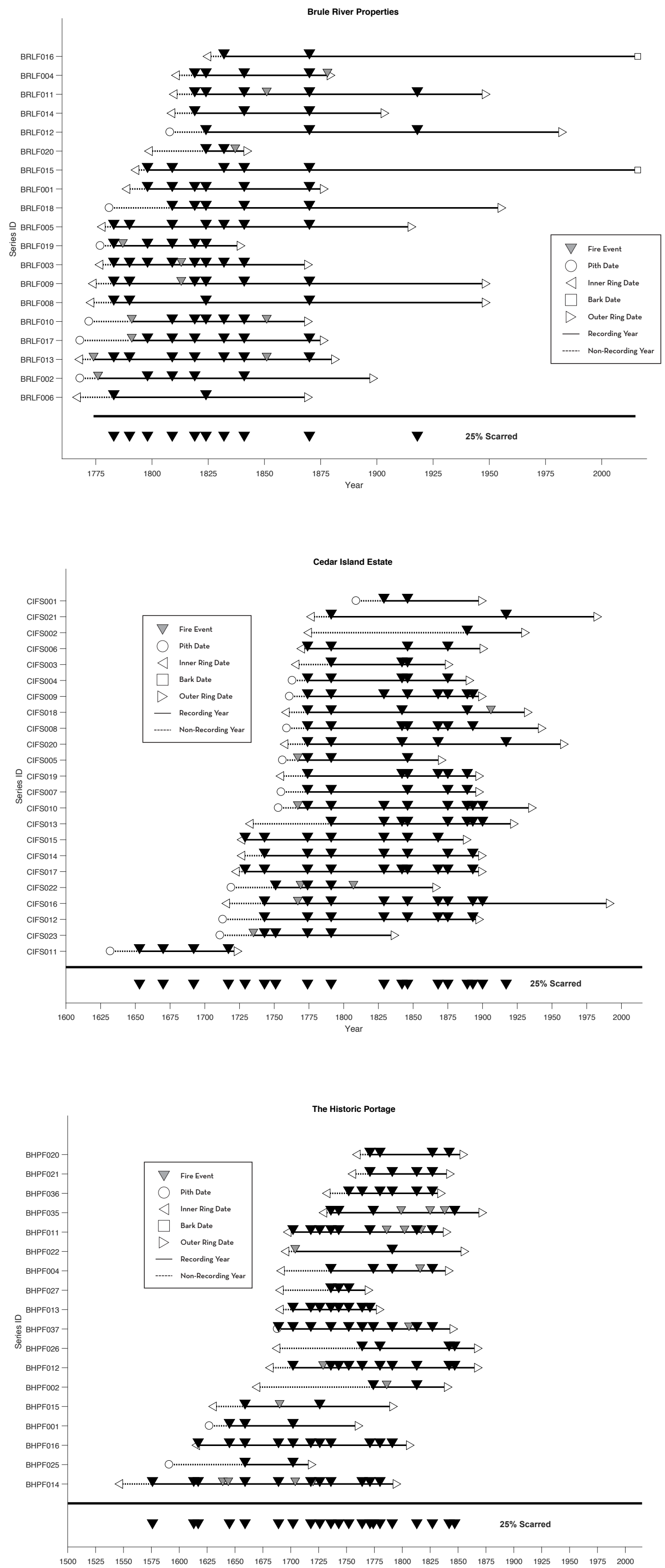

Figure 4. Fire history of each site. Each horizontal line represents the length of time recorded by one tree. Fire events are represented by triangles. Black triangles represent fire events that scarred at least 25% of the trees recording during that time period. From top to bottom: Brule River Properties, Cedar Island Estate, The Historic Portage.

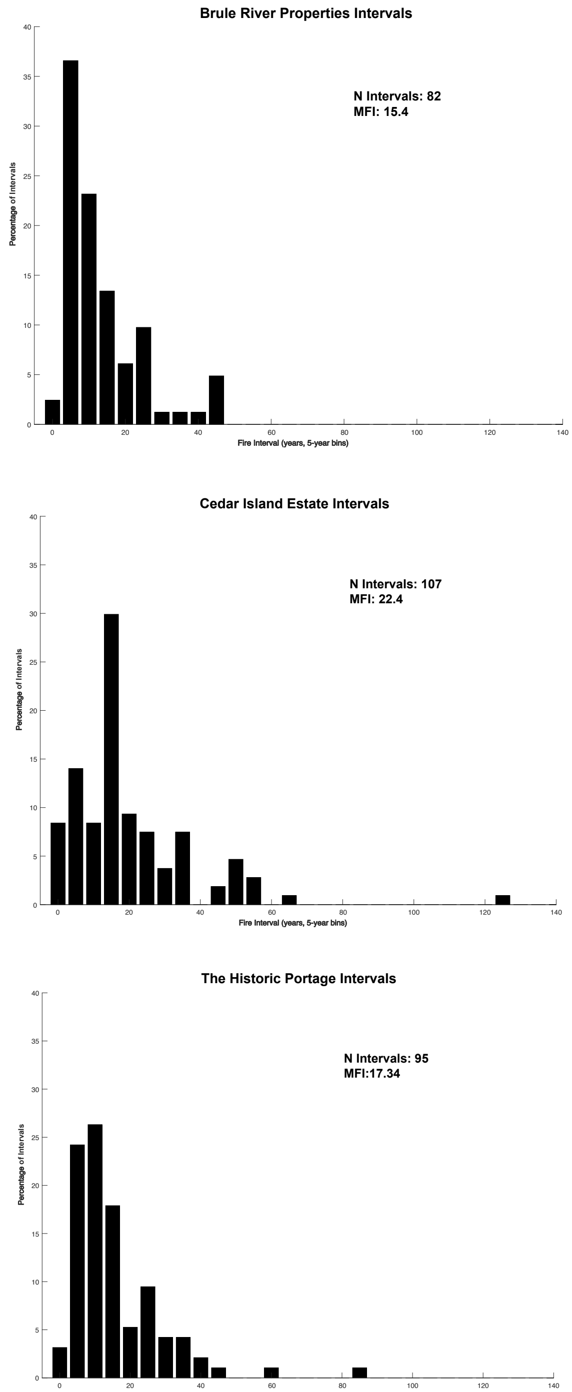

Figure 5. Histograms of reconstructed fire intervals for each study site divided into 5 year bins. From top to bottom: Brule River Properties, Cedar Island Estate, The Historic Portage.

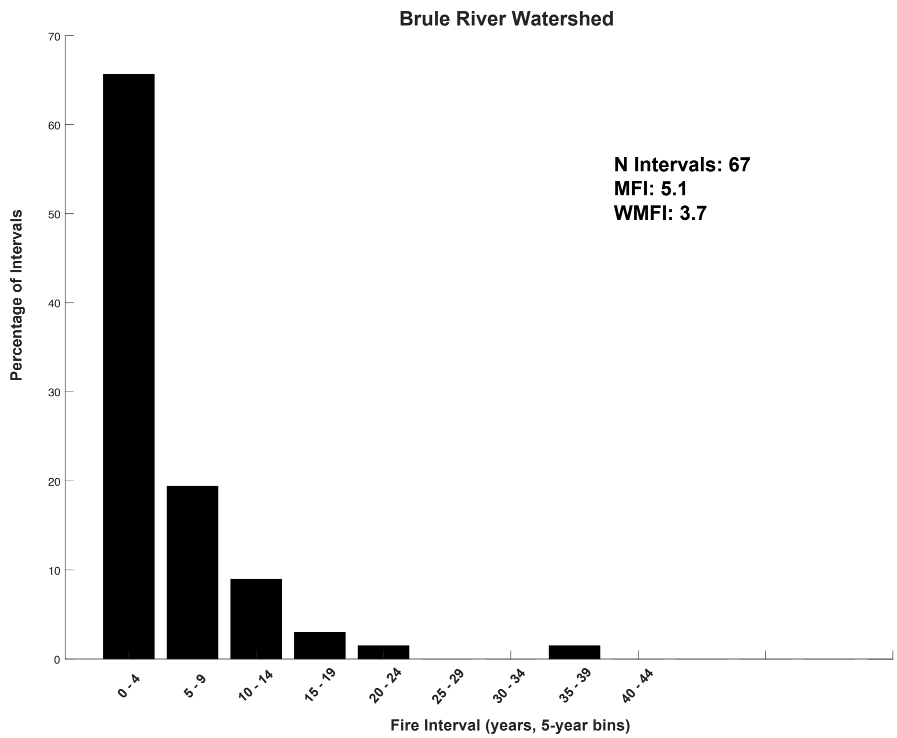

Figure 6. Histogram of reconstructed fire intervals in the Brule River Watershed region divided into 5 year bins.

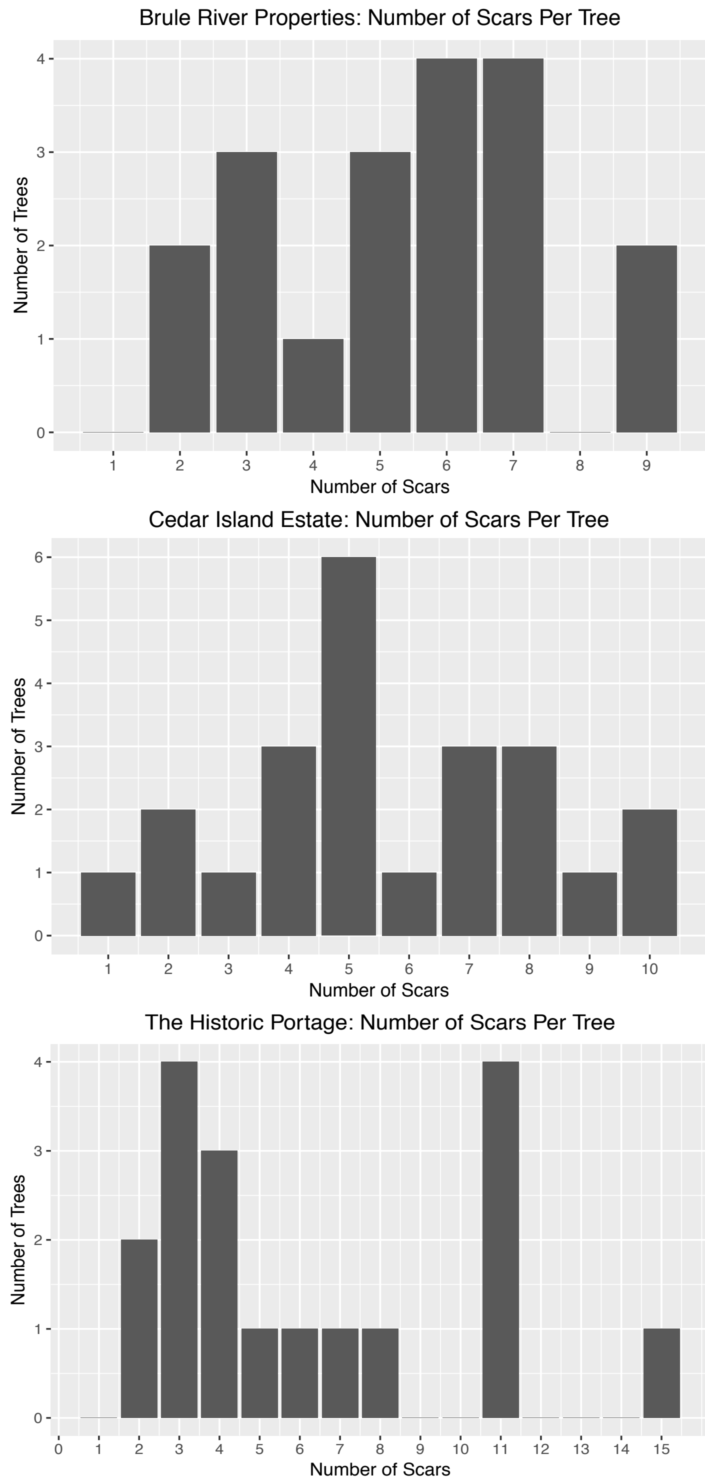

Figure 7. Histograms of number of scars per tree derived from each study site. From top to bottom: Brule River Properties, Cedar Island Estate, The Historic Portage.

Twenty-three samples were collected from the Cedar Island Estate (CIE). I reconstructed 23 unique fire years from the Cedar Island Estate samples. The samples from CIE contained 130 individual fire scars. The earliest fire at CIE occurred in 1653 and the last fire occurred in 1917 (Figure 4). I was able to date 100% of the CIE samples. CIE had a MFI of 22.4 and a fire frequency of 0.087 (Figure 4, Table 1). Three samples from Cedar Island have outer ring dates of 1897 and four samples have end dates of 1899, which corresponds to the time period where logging was thought to occur.

Thirty-seven samples were collected from The Historic Portage (THP). THP samples recorded 113 individual fire scars and 35 unique fire years (Figure 4). The earliest fire at THP was 1576 and the last fire occurred in 1847 (Figure 4, Table 1). I was only able to successfully date 49% of the 37 samples from THP. Multiple samples from THP were not dated because they contained too few rings, which yielded uncertain dating and few potential marker years. The fires recorded at THP produced an MFI of 17.4 and a fire frequency of 0.130 (Table 1). The overstory red pine found here is around 100 - 130 years old and is considerably younger than the red pine found at Cedar Island Estate or Brule River Properties.

Fire Interval Distributions

Relatively short, highly skewed reconstructed fire interval distributions were a characteristic of all three study sites along the Upper Bois Brule River (Figure 5). Overall, the distribution of reconstructed fire intervals were relatively similar. Statistical comparison of fire intervals using a K-S test indicated there was no statistical difference between the three sites when considering the individual fire composites (P>0.05, Table 3).

While all three sites have relatively short intervals, there were subtle difference between the sites. Fire intervals at BRP exhibited less variation overall, with over 35% of the intervals occurring at time frames of 5 – 9 years (Figure 5). CIE intervals were generally longer with a majority of fire occurring between 15 – 19 years (Figure 5). Fire intervals at THP were generally less than 14 years (Figure 5).

Temporal Pattern of Fires

Of the three sites presented here, samples from The Historic Portage span the earliest time period (1547 – 1871). The record from Brule River Properties spans the most recent time period (1767 – 2016). Cedar Island Estate bridges the temporal gap between the Historic Portage and Brule River Properties (1632 – 1958) (Figure 8, Figure 9).

Fires at The Historic Portage started earlier than those fires recorded at BRP or CIE. From 1775-1850 THP and BRP share a similar, high rate of fire (Figure 10, Top). CIE maintained a more gradual rate of fire occurrence throughout its entire record (Figure 10, Top). Proportionally, BRP has a steep inclining accumulation curve from 1775 – 1900, representing a high rate of fire over a relatively short time period (Figure 10, Bottom). CIE and THP share similar proportional accumulation fire curves (Figure 10, Bottom). The rate of fire begins to slow at BRP in the 1870s, before completely leveling off in 1918. The rate of fire at CIE remains fairly consistent up until the last fire recorded,

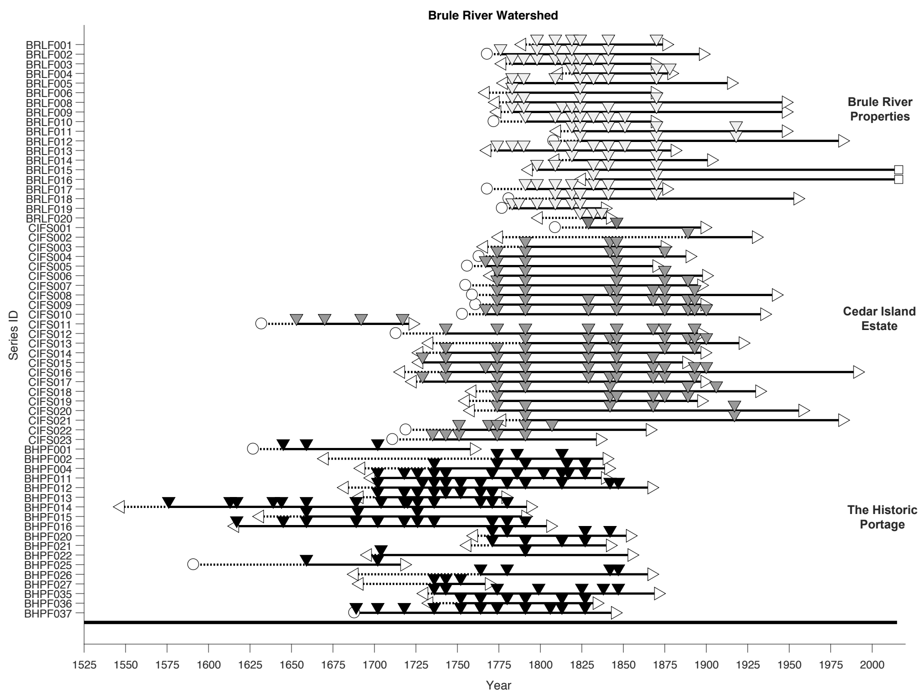

Figure 8. Fire history of the Brule River Watershed. Sites are arranged from north (top) to south (bottom). Each horizontal line represents the length of time recorded by one tree. Fire events are represented by triangles.

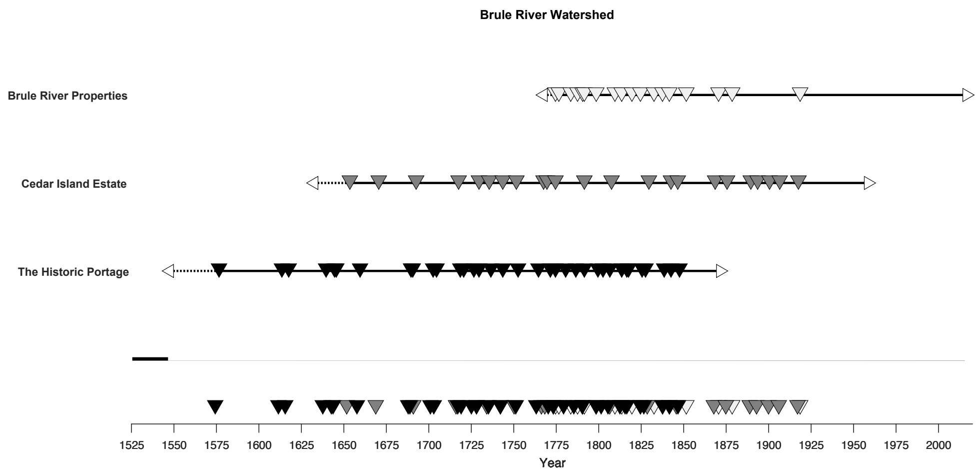

Figure 9. Composite fire chart for the Brule River Watershed. Each horizontal line represents that total amount of time spanned by the record of sampled trees within each respective site. All fire events in each respective site were compiled. Fire events are represented by triangles.

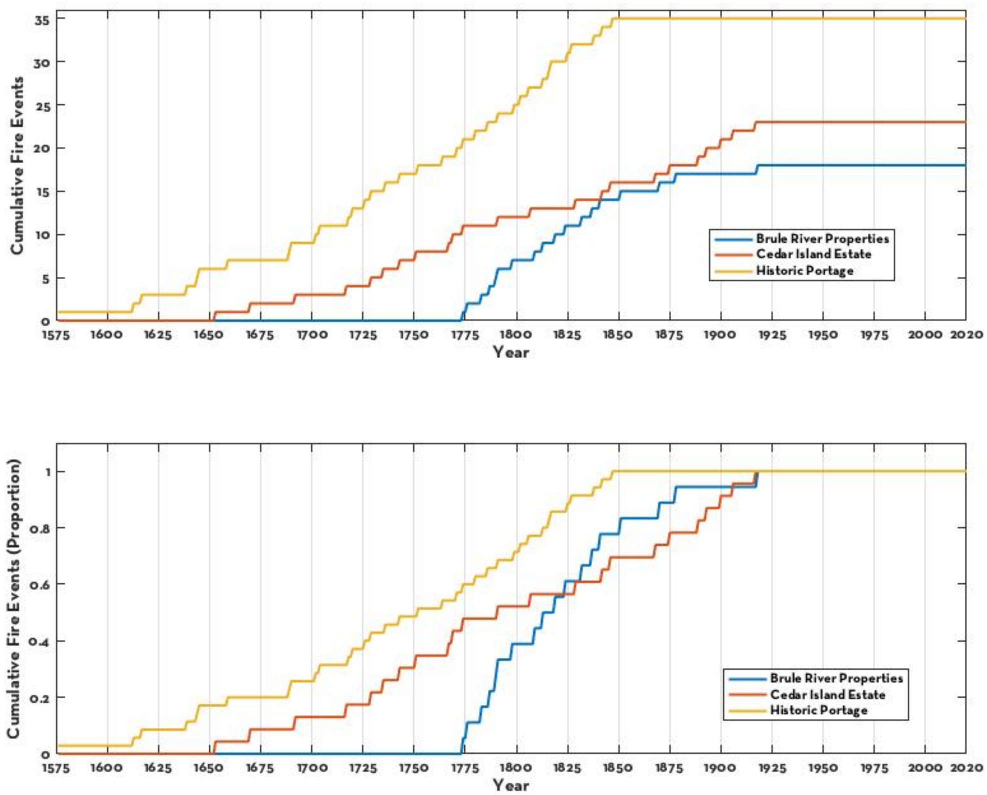

Figure 10. Top Figure: Cumulative fire events for each individual study site. Bottom Figure: Proportion cumulative fire events for each individual site.

which occurred in 1917. Fire ceased at THP earlier than the other two sites, with the last fire being recorded in 1847.

There was a notable absence of fire from 1850 – 1870 at both Brule River Properties and Cedar Island Estate (Figure 8, Figure 9). Additionally, CIE had a second disturbance free period that spanned 1791 – 1829. THP did not contain substantial gaps in the fire record, however the tree-ring record at THP diminishes near the 1850 - 1870 gap shared by BRP and CIE.

Spatial Patterns of Fire

Sixty-two (91%) fire events occurred at only one site, 4 (6%) fire events occurred at only two of three sites and 2 fire events were shared amongst all three sites. While fires tended to not be shared between sites, fires were highly synchronous within an individual site. That is, if a fire occurred at a study site it tended to scar most trees recording during that time period. Ten of the 18 (55%) fire events scarred at least 25% of the trees recording at BRP, 18 of the 23 (78%) fire events scarred at least 25% of the trees recording at CIE and 21 of the 35 (60%) fire events scarred at least 25% of the trees recording at THP.

Climate Relationships: Superposed Epoch Analysis

Fire-climate relationships varied by site and with increasing levels of within-site synchrony. For example, no significant relationships between regional summer drought and the all fires class at any of the three individual sites were detected (Figure 11). However, when only fire years that were recorded on at least 25% of samples at

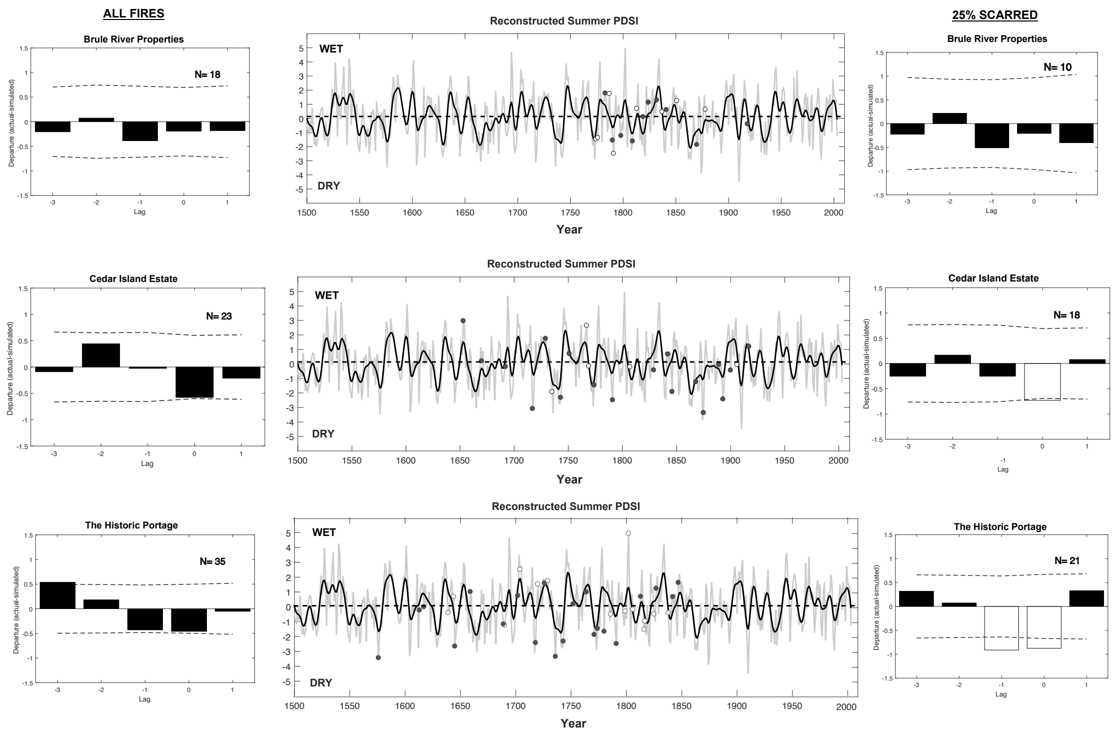

Figure 11. Superposed Epoch Analysis (SEA) results for individual study sites. Top figures: 95% confidence intervals are represented by dashed lines. Differences between actual values vs. simulated values are represented by bar graphs. Bottom figure: Reconstructed PDSI (grid point 197) is represented by the grey line. A 10-year cubic smoothing spline is represented by the black solid line. Black circles represent fire events that scarred at least 25% of samples at each respective site. White circles represent fire events that did not scar at least 25% of samples at each respective site.

individual sites were examined, climate patterns were significantly related to fire occurrence during the fire year, and in some cases, the year prior (Figure 11). For example, fire events recorded on at least 25% of the samples at Cedar Island (n=18) were significantly related to summer drought. Additionally, at the Historic Portage, the 25% scarred class (n=21) indicated that the event year and one-year prior to fire years were significantly related to regional summer drought (Figure 11). There was no significant relationship between the Brule River Properties 25% scarred class (n = 10) and summer moisture levels (Figure 11).

BRP was the only site to exhibit no significant drought relationship with fire occurrence. The 'all fires' and the '25% scarred class' were likely not significant because 10 of the 18 fire events occurred during wet (positive) PDSI years. Of the 25% scarred class fire years, 5 occurred in wet years and 5 occurred in dry years. Fairly low sample sizes (n = 18 and n = 10) produced slightly wider confidence limits within the BRP SEA runs. CIE and THP also produced a relationship that was not climatically related to drought when 'all fires' were tested individually. However, significant relationships to summer drought were derived from both sites (CIE and THP) when I isolated the widespread fire years using the 25% scarred class. The majority of fire years at both CIE and THP occurred during dry years. Sixteen of the 23 CIE fire years occurred during negative PDSI years and 12 out of 18 CIE fires that scarred 25% of the trees occurred during dry years. Twenty-one of all 35 fire events occurred during a moisture deficit at THP and 12 of the 21 25% scarred class events occurred during dry years.

The scale of analysis and sample size (n = 68) increased when all fire years were pooled together from all three sites, presenting a slightly more robust climate signal in the event year, compared to when each site was tested individually (Figure 11). When fires across the Brule River watershed are considered in aggregate, fire events (n=68) are significantly related to dry years (Figure 12). The strength of the relationship increased moderately when I removed those fire years that did not scar 25% of the samples at any given site. The fires that did not scar 25% of trees may have burned a small spatial distribution or been very low in intensity due to limited fuels. The cumulative 25% scarred set of fire events in the Brule River Watershed (n=45) is significantly linked to summer dryness during both the year of the fire and the prior year (Figure 12).

Both fire events that occurred at all three sites, 1774 and 1791, coincide with drier than average summers in the event year. Three consecutive negative PDSI values occurred leading up to 1791 (i.e. 1790, 1789 and 1788 were all drier than average). Six consecutive negative PDSI values occurred leading up to 1774. A fire that burned near the Cedar Island Estate in 1936, which was not captured by our tree ring record, was driven by a 6-year drier than average period that started in the year 1930 during the Dust Bowl (*personal correspondence with Beth Bartol WDNR Forest Fire Dispatcher*). In Wisconsin, a total of 18 days in June, July and August had temperatures exceeding 100° F in 1936 (Hoyt 1938). Prolonged drought may have increased the spatial area consumed by fire events along the Upper Bois Brule River.

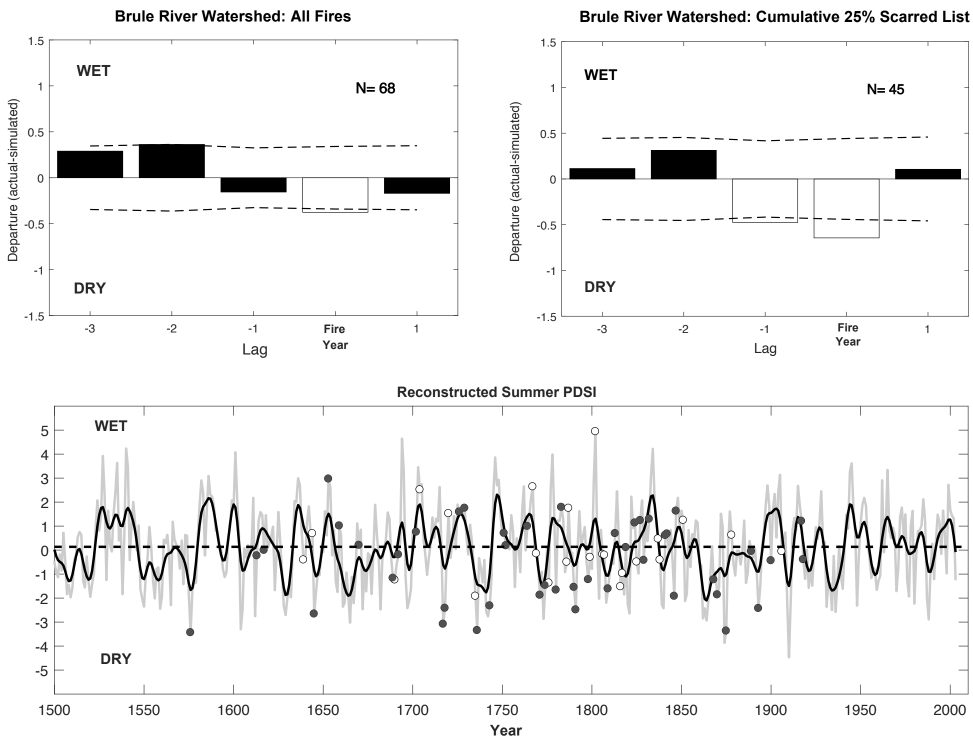

Figure 12. Superposed Epoch Analysis (SEA) results for the Upper Bois Brule River. Top figures: 95% confidence intervals are represented by dashed lines. Differences between actual values vs. simulated values are represented by bar graphs. Bottom figure: Reconstructed PDSI (grid point 197) is represented by the grey line. A 10-year cubic smoothing spline is represented by the black solid line. Black circles represent fire events that scarred at least 25% of samples at each respective site. White circles represent fire events that did not scar at least 25% of samples at each respective site.

Seasonality

Reconstructed fire scar seasonality tended to vary between sites (Table 2, Figure 13). Seasonality at BRP was fairly evenly distributed between the three scar position classifications: dormant (36.84%), earlywood (34.21%) and latewood (28.95%). A majority of the fire scars (nearly 50%) reconstructed from CIE samples occurred in the dormant position. Fifty-six percent of fire scars recorded at THP occurred in the earlywood position. Only 5% of fire scars occurred in the latewood position at THP.

DISCUSSION

Frequent Surface Fires Along the Upper Bois Brule River

Within the past 10 years, fire history studies in the Great Lake region have begun to focus more directly on the importance of surface fires as an ecosystem shaping agent, in particular during the period prior to effective fire suppression (Drobyshev 2008, Muzika et al. 2015, Johnson and Kipfmueller 2016, Guyette et al. 2016, Larson and Green 2017, Kipfmueller et al. 2017). This is particularly important in light of the earlier focus on large, stand-replacing fire events highlighted by Frissell (1973) and Heinselman (1973), important research that largely shaped thinking regarding fire ecology and fire management in Great Lakes pine forests over the last four decades. Living trees and old, remnant stumps with multiple fire scar lobes, paired with relatively short intervals, indicate that low intensity, frequent surface fires likely played an important role in shaping the composition of forest age classes. Relatively short reconstructed fire intervals were a characteristic of all three study sites along the Upper Bois Brule River (Figure 5).

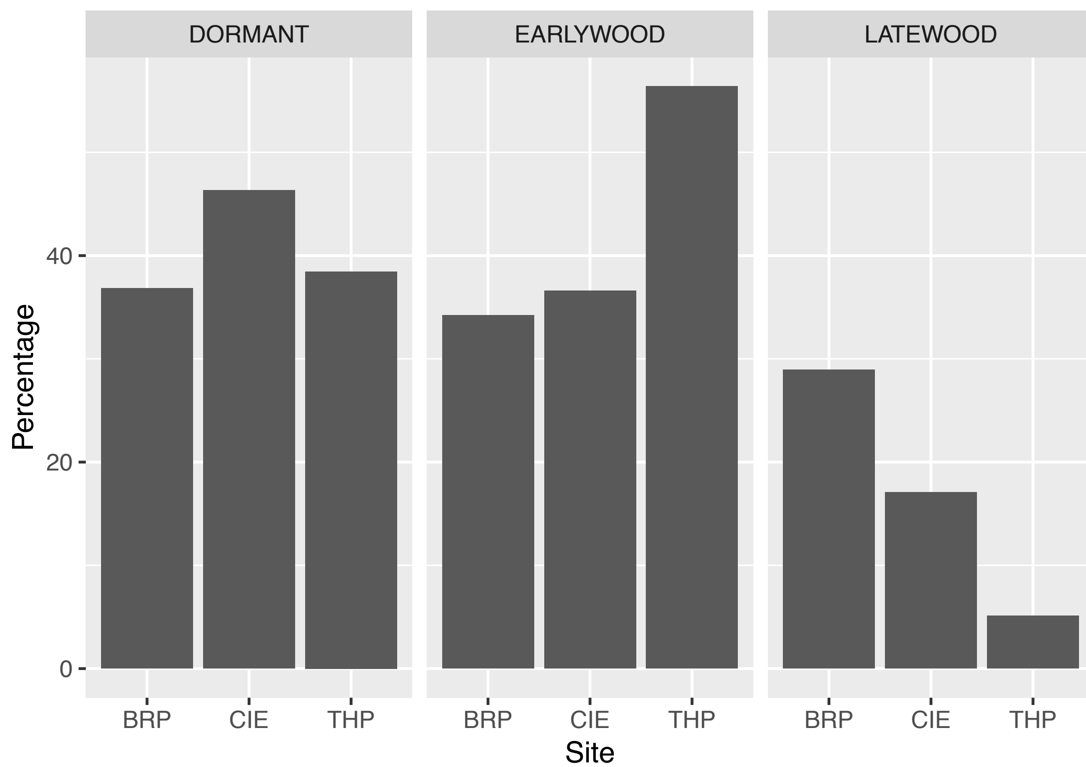

Figure 13. Reconstructed scar class seasonality per individual study site.

The frequent fires at these sites along the Brule River highlight the combined effects of biophysical processes such as fuel accumulation, topography, fire-adaptiveness, and climate, integrated with the impacts of anthropogenic activities, including the active use of fire to manage landscapes. The clustering of fire intervals at less than about 20 years at all sites suggests a fire regime that is difficult to fully explain invoking lightning alone as a causal agent. At the same time, it is also clear that climate, at least in part, drives fires during some years, particularly those years where fire is more widespread across the landscape. While these landscapes are all largely similar with respect to their fire regime characteristics, there are subtle differences that are worth noting.

Site Fire History Analysis

While all three sites have short intervals, there are subtle difference between the sites. These small differences, paired with the cultural history of the Ojibwe in the area, presents a unique opportunity to understand the historic fire regime of the Upper Bois Brule River. One key feature of interest is that the fire histories of BRP and THP appear to be more similar to one another than that of CIE. This is especially interesting because BRP and THP have a greater spatial distance between one another compared to the distance between CIE and THP or CIE and BRP (Figure 2). BRP and THP had a relatively high rate of fire from 1775 – 1850 (Figure 10, Top). Cedar Island Estate has a somewhat lower rate of fire during this time period, as exemplified by the more gradual curve in cumulative fire accumulation.

Compared to either THP or BRP, CIE appears to be more similar to a local fire history reconstructed at the Moquah Barrens. Guyette (et al. 2016) conducted a fire history at the Moquah Barrens in Northwest Wisconsin, which is located approximately 16 miles from the study sites presented here. The Moquah Barrens site was described as a woodland forest containing red pine and mixed hardwoods, situated next to grassy pine barrens composed of red pine and jack pine. Guyette (et al. 2016) reported a 12.8 MFI for the time period of 1591 – 1937, however it is unclear if the MFI was calculated with sample or site scale intervals. The fire frequency for the Moquah Barrens was 0.078, which is very similar to CIE (0.087) and lower compared to BRP (0.125) and THP (0.129). CIE, which was historically situated adjacent to pine barrens, has a comparable fire frequency. Interestingly, CIE also shares several fire years with the Moquah Barrens study site.

Lightning and People as Potential Ignition Sources in Northwest Wisconsin

Given preponderance of short fire intervals in this record, it seems unlikely that the fires along the Upper Bois Brule River could be due to lightning alone, although it is clear dry conditions were important at least during some fire years, and in particular, during years where fires spread over entire study sites (synchronous fires). Curtis (1959: 461) suggested that while it is possible the fire adapted communities in Wisconsin were maintained by dry lighting, it is more likely, that they were maintained, in part, by human induced ignitions sources. Curtis wrote:

"To a limited extent, the results could have been obtained by lightning fires, but the known incidence of dry lightning in Wisconsin is totally incapable of explaining the huge areas influenced by fire. It is possible that such storms were more frequent in the past, particularly during the extension of influence of the continental westerlies at the time of prairie expansion, but it is equally probable that during the preceding period of conifer dominance such storms were even less frequent than now. In any case, the presence of nomadic hunting tribes throughout the state in the entire postglacial period means that man-made fires were an important if not the sole cause of fires (Curtis 1959: 461)."

Modern forest fire data clearly suggests that historic fires may have been influenced by factors other than lightning. Kay (2007) used fire occurrence data from 1970 – 2002 from the National Interagency Fire Center to calculate the number of lightning ignited fires per year (per 400,000 ha) for national forest lands throughout the United States. Chequamegon and Nicolet National Forest, both located in Northern Wisconsin, separately averaged 1 lightning fire per year (per 400,000 ha). The rate of fire per year along the Bois Brule River ranges from 0.087 – 0.130, or about one fire per decade. However, it is important to pair the rate of fire with the scale of the spatial area being considered. The study sites presented here have spatial areas ranging from 21.1 – 143 ha. When spatial scale is considered and scaled up, the rate of fire reconstructed here is more than 200 times than that of the lightning ignited rate of fire in Wisconsin. Thus, it seems unlikely that lightning ignited fires can fully explain the fire regime reconstructed along the Upper Bois Brule River.

Short reconstructed fire intervals and historical accounts prompt the need to investigate the possibility of ignition sources, other than lightning, along the Upper Bois Brule River. The Ojibwe had multiple encampments along the Upper Bois Brule River. Prior to 1886, an Ojibwe site, composed of a dozen cedar bark wigwams, was located near Brule River Properties. Additionally, an Ojibwe canoe maker used to live near the BRP study site. Lastly, there are some culturally modified trees (or peel trees) found on the west side of the study site, near the Bois Brule River. It seems likely that BRP was a past Ojibwe camp, or was at least used in some capacity by the Ojibwe.

Historical documentation also indicates that the Ojibwe had a presence near The Historic Portage. Historical documents indicate a Native American site was located on the island in Upper St. Croix Lake, just south of THP. Journal records from fur traders in the area describe remnants of old Native American camps found along the Historic Portage (Curot 1911). The Historic Portage was also a popular fur trade route, frequently used by the Ojibwe and French. The first European explorer used the trail in 1680. It is speculated that the Ojibwe ceased using the trail in 1886 (Jerrard 2011: 164). There is no written record that suggests the Ojibwe had a presence at the Cedar Island Estate study site.

A number of authors have outlined the use of fire by Native Americans for specific purposes. Loope and Anderton (1998) and Anderton (1999) have documented the direct use of fire to promote berry production, particularly blueberries. Kipfmueller et al. (2017) has also speculated that there is a discernible influence on fire regimes possibly due to Ojibwe burning for berry production. In 1959, Curtis suggested that at least 50% of the vegetation found in Wisconsin had been effected by the Native American’s use of fire (Curtis 1959). This hypothesis was likely partly informed by the work of R.E. Murphy, whose ethnographic evidence indicates that humans may have used fire as a land management tool in the Northwest Sands Ecological Landscape (Murphy 1931). Murphy, who authored *The Geography of the Northwestern Pine Barrens of Wisconsin,* describes the possibility of Ojibwe using fire as a means to increase blueberry production. While the total value of the blueberries produced in the barrens was unknown, Murphy (1931) stated that in a good year the yield would be "undoubtedly considerable".

Murphy's account was reinforced by Carolissa Levi (1956), who wrote *Chippewa Indians of Yesterday and Today*. Within the book the author quoted an article from the Ashland *Daily Press* that sheds light on the importance of the blueberry crop to the Ojibwe people:

> "Every year the berry harvest proves to be a valuable aid to Indians, who, after scouting fields, move with their families into the Barrens, and through their backbreaking efforts, realize enough profits to see them through the winter".

Indigenous populations did not use fire solely for blueberry reproduction. Lewis (1982) conducted a series of ethnographic interviews with the Cree in Alberta and found that fires may have been set to clear trails and portages of understory brush in order to ease travel. Miller and Davidson-Hunt (2010) interviewed members of the Pikangikum First Nation, a band of Ojibwe located in northwestern Ontario and deduced that fire may have been used to maintain travel corridors. Additionally, multiple studies indicate that Native Americans would use fire as a means to clear campsites of understory brush (Lewis 1982, Berkes and Davidson-Hunt 2006, Miller and Davidson-Hunt 2010). Accidental ignition sources may have also played a role during the fur trade era. It was most likely more advantageous for the Ojibwe or fur traders in the region to leave a fire burning, rather than extinguishing it and having to restart the fire, which may have been inefficient (Kipfmueller et al. 2017).

Site Fire History Analysis Paired with the Possibility of Human Influence

The configuration of the study sites, coupled with cultural history can possibly explain observed differences in fire history. Brule River Properties, where the Ojibwe's presence seems best documented as a living site (as opposed to strictly a travel corridor), has the shortest reconstructed MFI (Table 1). It is very possible that the Ojibwe used fire to clear or regularly maintain their encampment at the Brule River Properties study site, prior to 1886. Routine burning practices might explain the fairly consistent rate of fire (about every 10 years) reconstructed at BRP. The cessation of fire at the Brule River Properties coincides with the documented absence of the Ojibwe camp near the study site, after 1886. Only one fire, that scarred a total of two trees in 1918, was recorded after 1886. Documented changes in land use/occupancy may have played a role in altering fire occurrence at the Brule River Properties study site.

Additionally, it is possible that a portion of reconstructed fire years from BRP were a product of augmented ignition sources in order to increase blueberry yields. Around 30% of fire scars reconstructed at BRP occurred in the latewood position, which is when the Ojibwe are speculated to have burned in order to increase the blueberry crop. The Ojibwe would sometimes set controlled fires after the summer harvesting season in order to produce berries for the following year (Anderton 1999). While latewood (29%)

is not the dominant scar position at BRP, it is considerably more common than the latewood scar class at CIE (17%) or THP (5%) (Table 2, Figure 13).

It is possible that the Ojibwe used fire as a means to clear The Historic Portage of understory brush in order to ease travelling conditions. While there is no ethnographic evidence to suggest that the Ojibwe repeatedly burned The Historic Portage, the study site has the highest fire frequency (0.130) amongst all three fire history locations. The Historic Portage also has a relatively short MFI: 17.4. Burning may have taken place prior to green up in order to reduce understory vegetation and to ease travel during the snow-free season. The seasonality of the reconstructed fire scars at THP support this hypothesis. Thirty-eight percent occur in the dormant position and 56% occur in the earlywood position (Table 2, Figure 13). Only 5% of reconstructed fire scars from THP occurred in the latewood position (Table 2, Figure 13).

There is no direct or ethnographic evidence that suggests the Ojibwe were present at the Cedar Island Estate study area. This does not mean that human influence was completely absent from the Cedar Island Estate fire history, but rather that it remains unknown whether anthropogenic ignitions played a role in shaping the fire regime. Although it is possible the area was used to some extent, based largely on the short intervals observed between fires in the record.

The level of suitability each study site has to offer as a campsite or berryground seems to match the reconstructed fire record. For example, BRP is almost completely level, situated directly adjacent to a bend in the Bois Brule River. This area could have been used as a campsite or a berryground. Additionally, the direct river access would have aided transportation to and from the area. In contrast, Cedar Island Estate contains steep topography, which would decrease the chances of the area being utilized as a campsite. Additionally, the area with the highest density of fire scarred samples is far off stream. It seems unlikely that the Ojibwe would choose a location far from their main transportation route.

It is possible that the Cedar Island Estate fire history was influenced by lighting fires that spread from the local pine barrens. Fires that occurred in the pine barrens were much more widespread than those areas containing lakes and bogs, where fires events were more localized (Fassett 1944). This is one plausible explanation as to why Cedar Island Estate is similar to the Moquah Barrens, a study site also situated adjacent to the Northwest Wisconsin pine barrens.

Given the high rate of fire, the seasonality of the events and the local presence of the Ojibwe, it seems possible that fire regimes of BRP and THP may have been influenced by increased anthropogenic ignition sources. There is more evidence to suggest that BRP and THP were influenced by humans more so than CIE, which is one plausible explanation that may have contributed to the subtle differences that separated BRP and THP from CIE.

Absence of Fire

Our tree-ring record shows there were multiple temporal periods when fire was absent from the local landscape. It is possible that fires occurred during the temporal gaps and did not scar the recording trees. However, this seems unlikely due to the fact that these trees were already scarred in the early portion of their record and thus, were more susceptible to fire injury. These temporal gaps, paired with climate data and human land use records, may provide useful information regarding the fire drivers along the Upper Bois Brule River or lack thereof.

The shared fire absence gap from 1850 – 1870 at BRP and CIE is particularly interesting. PDSI values from 1850 – 1870 are relatively low, suggesting that regional climate may not fully explain the decreased rate of fire (Figure 11). One plausible explanation is that the fire gaps were a product of human land-use change.

President Zachary Taylor signed an executive order in 1850, which required the Ojibwe to relocate from their lands in Wisconsin (Satz & Apfelbeck 1996: 55). This executive order was later rescinded by President Millard Fillmore in 1852 and replaced with the treaty of 1854, which granted the Ojibwe four reservations in Wisconsin. It is plausible that the fire absence gap from 1850 – 1870 was related to fluctuating land rights and sociopolitical tension between the Ojibwe and Washington D.C.

Climate and Fire Relationships in Northwest Wisconsin

Fire events in the Upper Great Lake states are driven partly by climatic conditions, namely regional drought (Drobyshev et al. 2012). The study sites along the Upper Bois Brule River are clearly linked to drought occurrence, particularly as fires are filtered based on their level of within and between site synchrony. There is no consistent climate pattern (wet or dry) that is statistically linked to fire occurrence when each site was tested individually. For example, the Brule River Properties showed no sign of a climate signal, while the Cedar Island Estate and The Historic Portage 25% scarred class indicated that regional drought may have played a role in the fire regime (Figure 11). A clearer fire-climate signal becomes evident when fires across the Upper Bois Brule River are considered in aggregate. All fire events (n=68) are significantly related to dry years. The cumulative 25% scarred set of fire events in the Brule River Watershed (n=45) is significantly linked to summer dryness, during both the year of the fire and the prior year (Figure 12).

Changes in regional climate conditions (e.g. Drobyshev et al. 2012) and anthropogenic ignition sources (e.g. Johnson and Kipfmueller 2016, Kipfmueller et al. 2017) have been shown to influence fire regimes in the Great Lake States. The results provided here show that climatic drivers and anthropogenic ignition sources are not necessarily independent of one another. Drought is significantly related to aggregated fires years and the short fire return intervals combined with the cultural history of the region are suggestive of anthropogenic ignitions, at least in part. While we speculate that short fire return intervals may be connected to a human induced fire regime, this does not mean that climatically driven fires are entirely absent from the reconstructed regime.

Red Pine and Future Land Management

The transition from fire adapted species to shade tolerant species, due to a fire suppression and logging practices, has been well documented within the Great Lake States (e.g., Paulson et al. 2016). Current forest stands in Wisconsin are now less structurally diverse and have a higher stem density compared to forest stands present in pre-settlement times as has been documented in computer simulations of landscape change (Stoltman et al. 2007). It is plausible that portions of the forested ecosystem along the Upper Bois Brule River and The Brule River State Forest may have undergone a similar transition. The reduced surface fire activity over the 20th century may have led to an increase in the stem density of shade tolerant balsam fir (*Abies balsamea*) and other hardwood species like red maple (*Acer rubrum)*.

Historically, fire has played an important role thinning shade tolerant species, increasing species diversity and creating a range of age classes within any given fire dependent forest stand (Heinselman 1973). Red pine, specifically, is a fire adapted species that is maintained by a mix of frequent surface fires (every 20 – 40 years) and infrequent crown fires (every 150 – 200 years, Heinselman 1973). Surface fires create an optimal seed bed for red pine, clearing the forest floor of competing, shade tolerant vegetation (Van Wagner 1970). Crown fires remove overstory trees, creating gaps in the canopy that allow light to reach the forest floor (Gilmore & Palik 2006). With the absence of fire along the Upper Bois Brule River, it is possible that there has been very little red pine regeneration over that past 100 years within any of the study sites.

It is unlikely that the current rate of lightning will be able to maintain the historic rate of red pine regeneration and dominance along the Upper Bois Brule River. The reconstructed fire history presented here was most likely augmented by human activities in some capacity, either on purpose or accident. Land managers and property owners can compare the human influenced reconstructed fire intervals to the current living red pine at the study sites in order to make decisions about the future desired conditions for the species and surrounding ecosystem. If the goal is to maintain red pine dominance along the Upper Bois Brule River, land managers and property owners alike could consider reintroducing fire to the landscape. If goals do not intend to prioritize red pine regeneration, land managers need to at least attempt to simulate a fire type disturbance by thinning portions of the understory forest, especially near housing structures, in order to reduce the risk of a future uncontrolled fire.

Managing Fuels in the Wildland-Urban Interface

One unique quality that separates the Upper Bois Brule River fire history from most, is the number of housing structures located throughout the study area. Housing density in the Northwest Sands Ecological Landscape has increased steadily from 1940 onward and the trend is projected to continue into the future (Radeloff et al. 2001). Mesophication, the conversion of forest dominance toward shade-tolerant species, may limit the occurrence of future forest fires, but the increased stem density of understory trees poses a risk for more destructive wildfires than those that likely occurred in this landscape in the past. The Germann road fire is an example of this type of disturbance this landscape can now support, which burned 7,442 acres and consumed 100 buildings over the course of two days in the spring of 2013 (The Germann Road Fire After Action Review 2014).

The number of housing structures located throughout the study area, combined with increased fuel loads, not only poses a serious fire risk, but also increases the difficulty of land management. Different areas will require different treatments depending on the number and spatial arrangement of structures. Fire and land management of the pine barrens and red pine forests in this region should be managed with both ecological and sociological information squarely in mind (Radeloff et al. 2001).

Limitations

The red pine specimens used in this study did not exhibit strong ring width variability, and instead were fairly complacent. A series of suppressed ring widths immediately following a fire scar made up a majority of the variation within the tree-ring record. The lack of variation in ring widths during periods of no (or low) fire occurrence made the dating of the red pine specimens extremely difficult. As a result, some collected samples were not able to be dated due to ring width complacency. Of the 60 samples I was able to date, multiple lines of evidence were used to ensure accuracy, including subtle ring markers and strong COFECHA correlations. The cumulative series intercorrelation for crossdated increment cores and fire scarred samples was 0.50.

CONCLUSIONS

Study Objectives:

A: On average, at any given site along the Upper Bois Brule River, fires tended to occur at the time scale of 10 – 20 years. The shortest fire return intervals and fire frequencies occurred at the Brule River Properties and The Historic Portage. Comparatively, the longest fire intervals and lowest fire frequency occurred at the Cedar Island Estate.

B: The fire histories of Brule River Properties and The Historic Portage might have been driven more by anthropogenic ignition sources than lightning, while Cedar Island Estate might have been driven by a mix of lightning and human induced fires. CIE might have also recorded fires that spread from the local pine barrens.

It seems likely that the Ojibwe could have been using fire to clear their campsite or to regenerate blueberries at the Brule River Properties. The fires at Brule River Properties decreased dramatically after the noted absence of a local Ojibwe community, circa 1886. Additionally, it is possible that the Ojibwe set fire to the trail to remove the understory brush and facilitate travel at The Historic Portage. The amount of travel that the trail received from Native Americans and French Voyagers increases the chances of accidental ignition sources.

It is possible that different human land use motives at BRP and THP resulted in different fire histories, compared to what the rate of fire would have been without the influence of people, even if these differences are subtle. An anthropogenic driven fire history, or a higher rate of fire, might have resulted in additional red pine regeneration.

C: While humans may have influenced the reconstructed fire regime in some capacity, this does not mean that regional climate was absent as a forcing agent. Regional summer drought is significantly related to different subsets of reconstructed fire years. A scaled up, region-wide analysis using shared fire years from multiple fire histories would likely show a stronger relationship to regional climate patterns.

D: Land managers should consider using controlled ignitions as a means to restore both a cultural tradition and a natural ecological process. If land managers do not seek to restore fire to the landscape due to logistical constraints, they should at least consider thinning the forest in order to reduce the potential damages that could be caused by future wild fires.

Research Implications

The Upper Bois Brule River may have undergone a species compositional shift over the course of the past 150 years, which fits squarely with the overall trend occurring throughout the Great Lake States region, from fire adapted species to shade tolerant, hardwood species (Paulson et al. 2016). Fires at the Brule River Properties and Cedar Island Estate ceased in the early 1900s (the Historic Portage record did not span this time period). The last fire derived from our tree ring record occurred in 1918. While other fires were known to occur in the Brule River Watershed post 1918 (*personal correspondence with Beth Bartol WDNR Forest Fire Dispatcher*), the rate of fire is not likely comparable to the previous 200 years, as shown by this tree ring record. It is possible that red pine regeneration may have decreased at the three study sites and balsam fir, which was previously sparsely located throughout the southern portion of the Brule River Watershed (Fassett 1944), will become relatively abundant (*personal observation*).

Reconstructed fire histories, like the one presented here, can be used by land managers as a guide to restore fire, as both a human induced cultural tradition and a natural ecological process (Swetnam et al. 1999). The Apostle Islands National Lakeshore recently took an important step by incorporating Ojibwe cultural traditions into their modern land management plan. A controlled burn, conducted on Stockton Island in partnership with members from Red Cliff and the Bad River Band, was used to honor past Ojibwe land management / conservation practices. Historically, the Ojibwe had burned portions of Stockton island in in order to regenerate blueberries, which they harvested seasonally. A part of the rationale for reintroducing fire to the landscape was that the area, historically, was a *human modified system.* Additionally, the restoration of fire had been in the National Park Service's land management plan since 2005. The fire, served as a first step in restoring an Ojibwe cultural practice and an ecological process that benefits fire-dependent vegetation communities.

While adding fire to the Upper Bois Brule River landscape may prove to be difficult and complicated, the alternative, letting fuels increase as the landscape vegetation runs its course, is a risk that land managers should not take. The research presented here advocates for the restoration of fire to the ecosystem, reiterating the land management recommendations that Frissell and Heinselman made in the report, "The ecological role of fire in natural conifer forests of Western and North America", published in 1973. Land managers and property owners have a unique opportunity to maintain the biodiversity of the Upper Bois Brule River and reduce the potential damage of future wildfires through the use of innovative fire management.

Table 1. Fire History information and site characteristics. MFI and WMFI are based on point intervals.

Site Name	Site Code	No. Samples Collected	No. Samples Dated	Time Period	First Fire / Last Fire	No. fires	MFI	WMFI	Fire freq.
Brule River Properties	BRP	20	19	1767 - 2016	1774 / 1918	18	15.7	13.5	0.125
Cedar Island Estate	CIE	23	23	1632 - 1958	1653 / 1917	23	22.4	19.3	0.087
The Historic Portage	THP	37	18	1547 - 1871	1576 / 1847	35	17.4	15.3	0.130

Table 2. Derived fire scar positions within annual rings. Indeterminate scars were excluded from this analysis.

Site Name	Dormant	Earlywood	Latewood
Brule River Properties	36.84%	34.21%	28.95%
Cedar Island Estate	46.34%	36.59%	17.07%
The Historic Portage	38.46%	56.41%	5.13%

Table 3. K-S test comparing fire intervals derived from composite fire chronologies.

Comparison	Significantly Different	K-S Statistic	Probability
Brule Properties (n=18) x Cedar Island (n=23)	No	0.382	0.091
Brule Properties (n=18) x Historic Portage (n=35)	No	0.118	0.996
Cedar Island (n=23) x Historic Portage (n=35)	No	0.313	0.118

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Addendum: Chronology Development

Introduction

The tree-rings of old red pine specimen, found along the Upper Bois Brule River, offer a unique chance to study interannual variations throughout time. Tracts of old growth forest are considered a rarity in northern Wisconsin, due to the heavy logging that the area endured in the late 1800s (Peterson & Ronnander 2017). We attempted to take full advantage of the preserved records by developing and presenting a 245 year, red pine tree-ring chronology.

Methods

I developed a tree-ring chronology along the Upper Bois Brule River in northwest Wisconsin. I collected increment core samples from 25 red pine specimens found throughout the Brule River Properties study site. A minimum of at least two increment cores were collected from each living tree sampled.

Each increment core sample was processed and crossdated following standard dendrochronology procedures (Stokes and Smiley 1968). Individual rings widths were measured using a velmex sliding stage micrometer. Exact dating was confirmed statistically with COFECHA (Holmes 1983)

The measured tree-ring series were detrended using a cubic smoothing spline set to equal 66% of each individual series' length using the program ARSTAN (Cook 1985). Actual measured values were divided by the fitted curve values for each series and then combined with other series using a bi-weight robust mean (Cook *et al.* 1992).

Results and Discussion

The chronology presented here is composed of 42 series, spanning the time period 1771 – 2016 (Table 4). Sample depth remains fairly consistent from 2016 through the early 1800s (Figure 14: Bottom). The number of radii begins to decrease as the chronology extends further into the past. The sharpest decrease in sample size occurs in the late 1700s, when sample depth decreases from 33 in 1800 to 1 in 1771.

There is a notable decrease in the ring width index from 1835 – 1845. It is possible that the decrease in the ring width index is a product of crown scorch (i.e. when a tree's photosynthetic material is killed by the heat of a fire). Local fire years, such as 1832, 1837 and 1841, may have influenced the Upper Bois Brule River ring-width chronology.

The average interseries correlation was 0.578 and the mean sensitivity was 0.198 (Table 4). Both of these statistics are comparable to other regional red pine chronologies (e.g. Kipfmueller et al. 2010).

Table 4. Chronology statistics for the red pine tree ring chronology developed along the Upper Bois Brule River in northwest Wisconsin.

Site Name	Lat	Long	Time Period	No. Series	AVG ISC[a]	Mean SENS[b]
Brule River Properties	46.30	-91.36	1771 - 2016	42	0.578	0.198

[a] Average interseries correlation
[b] Mean sensitivity

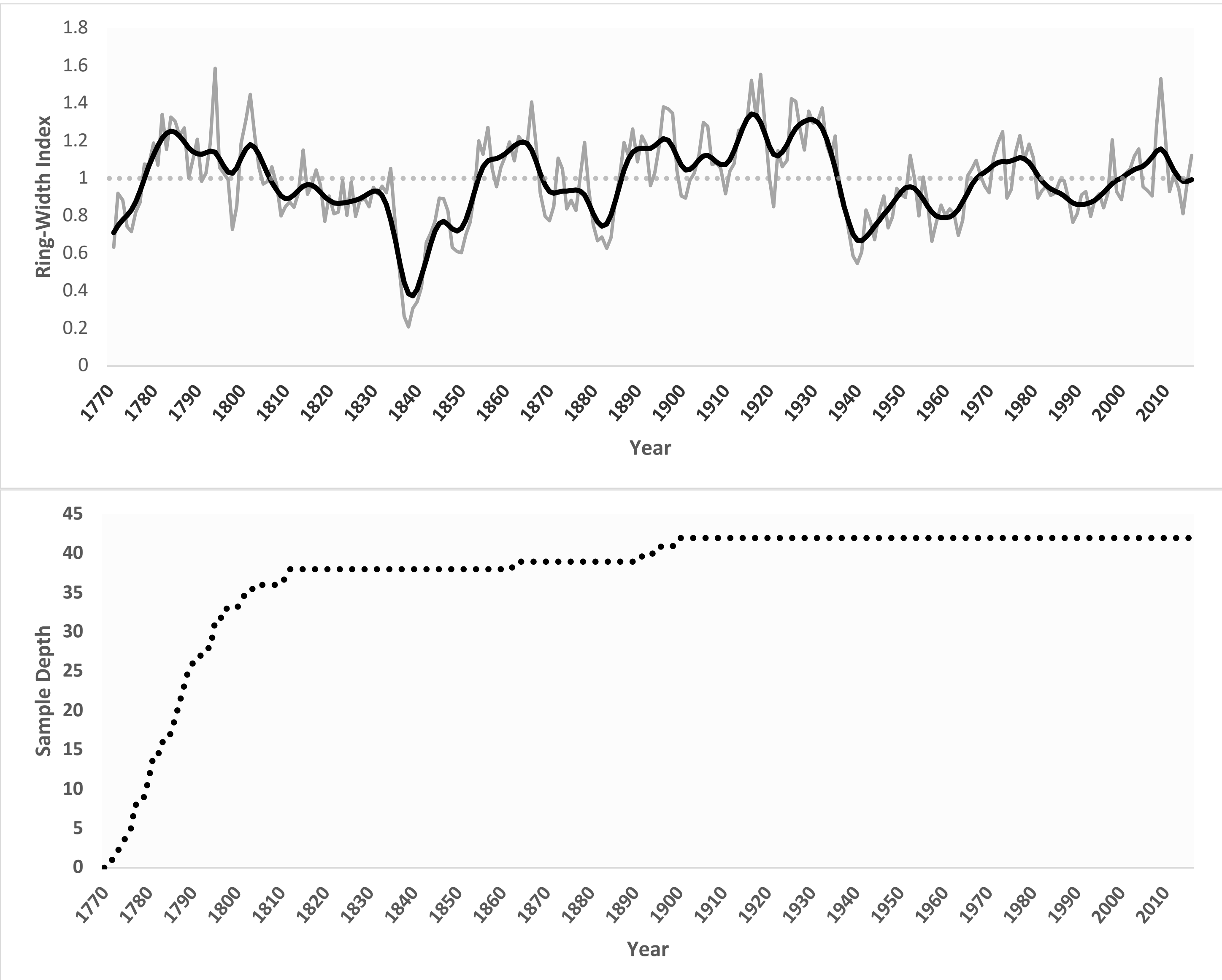

Figure 14. Top: ring-width indices from the Upper Bois Brule River, WI. Gray line represents derived interannual values, black line is a 10 year smoothing spline. Bottom: dotted black line indicates sample depth over time.

Supplementary Materials

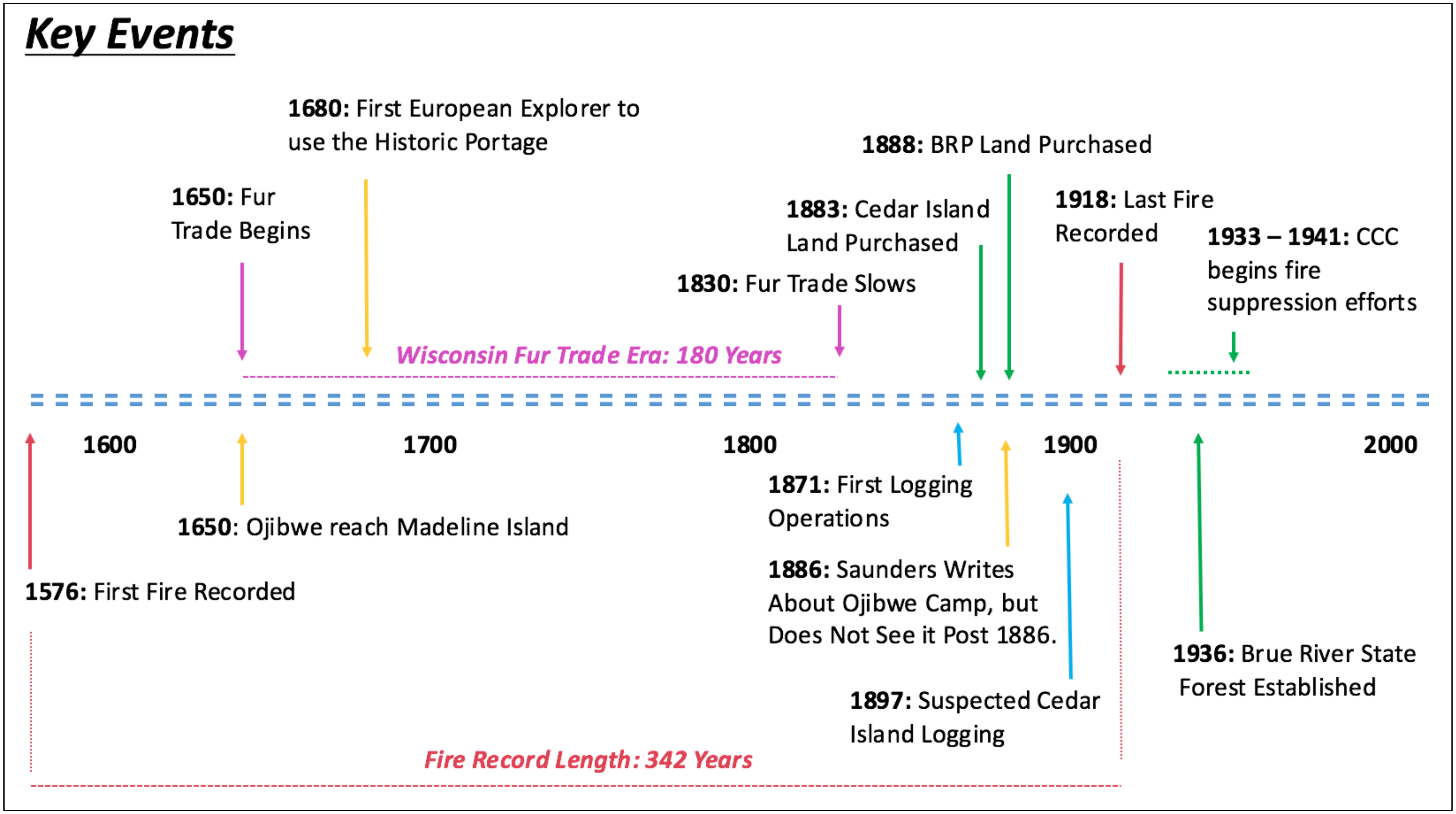

Figure 15. Timeline of key events that occurred in northwest Wisconsin from 1576 – 2018.

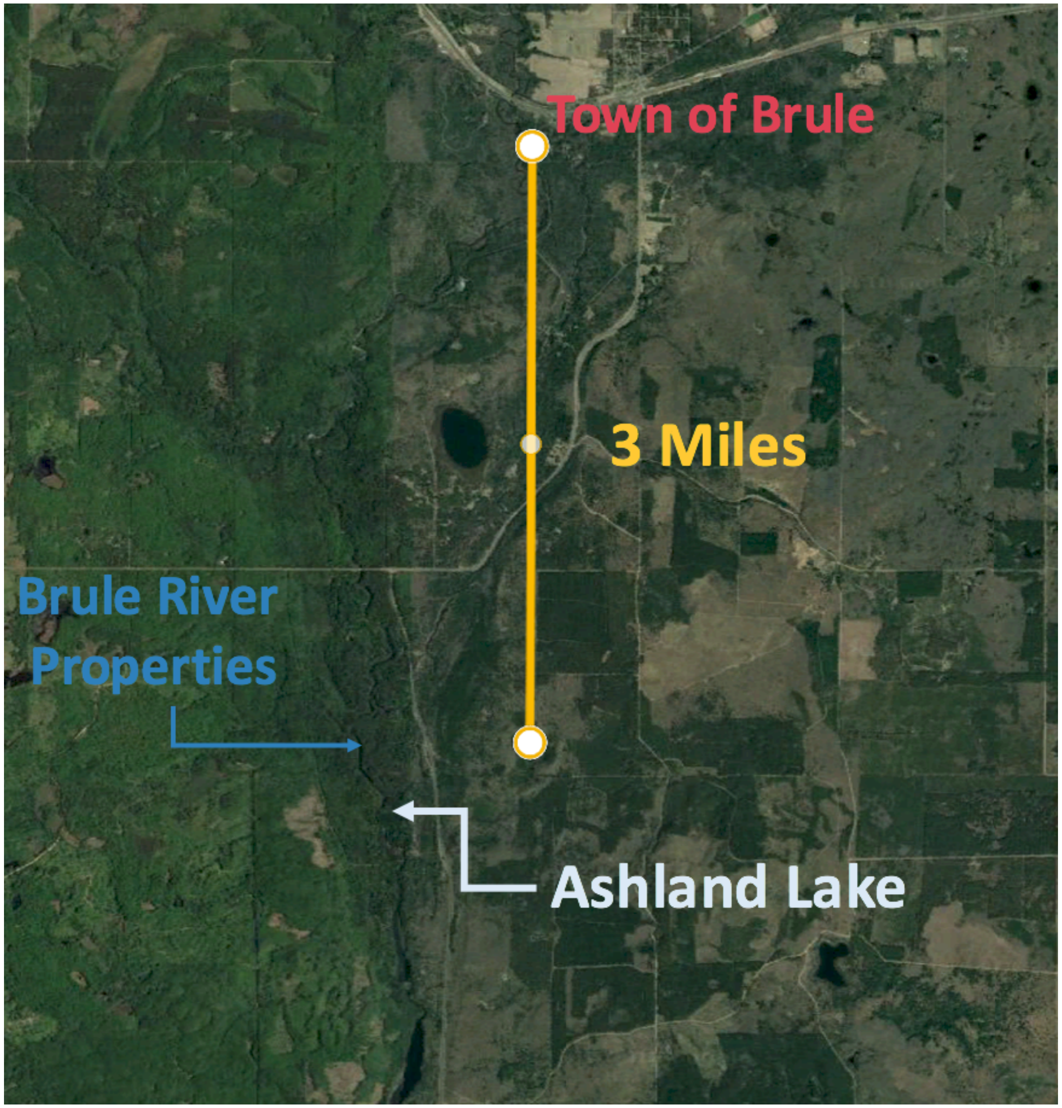

Figure 16. Aerial imagery of the town of Brule, Ashland Lake and the Brule River Properties site.