Contradictions and Continuities: A Historical Context to Euro-American Settlement Era Fires of the Lake States, USA.

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Research Article

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Abstract

Background

The Lake States experienced unprecedented land use changes during Euro-American settlement (settlement) including large, destructive fires. Forest changes were radical in this region and largely attributed to anomalous settlement era fires in slash (cumulation of tops and branches) following cutover logging. In this study I place settlement era fires in a historical context by examining fire scar data in comparison to historical accounts and investigate fire-vegetation-climate relationships within a 400-year context.

Results

Settlement era fires (1851–1947) were less frequent than historical fires (1548–1850) with little evidence that slash impacted fire frequency or occurrence at site or ecoregion scales. Only one out of 25 sites had more frequent settlement era fires and that site was a pine forest that had never been harvested. Settlement era fires were similar across disparate ecoregions and forest types including in areas with very different land use history. Settlement fires tended to burn during significantly dry periods, the same conditions driving large fires for the past 400 years. The burned area in the October 8, 1871 Peshtigo Fire was comprised of mesic forests where fuels were always abundant and high-severity fires would be expected given the conditions in 1871. Furthermore, slash would not have been a major contributor to fire behavior or effects in the Peshtigo Fire.

Conclusions

Historical records, like written accounts of fires and settlement era survey records, provide a reference point for landscape changes but lack temporal depth to understand forest dynamics or provide a mechanistic understanding of changes. While settlement land use changes of Lake States forests were pervasive, fires were not the ultimate degrading factor, but rather likely one of the few natural processes still at work.

Introduction

The term *unprecedented* is often used to describe destructive wildfires in recent years such as the 2020 fires in western Oregon that burned close to a million acres and forced the evacuation of half a million people (Abatzoglou et al. 2021). While wildfires in what are typically wet forests of the western Cascade mountains are unusual, neither the weather conditions that led to wildfires (Abatzoglou et al. 2021), nor the 2020 fires themselves were unforeseen. Large wildfires have shaped coastal ecosystems including the west Cascades of Oregon over millennia (Agee 1993; Weisberg and Swanson 2003; Weisberg 2009). Historical context is essential not only to understanding rare events, but also past and potential climate change influences on fire frequency, severity, and scale. Understanding disturbance regimes in relation to climate and land use changes is vital for fostering resilient ecosystems that can accommodate an

uncertain future (Landres et al. 1999). In the modern era, human-induced disequilibrium (e.g., fire exclusion via landscape fragmentation, grazing, and fire suppression) has weakened the relationships among fire, vegetation, and climate (Marlon et al. 2012; Higuera et al. 2015). This limits our understanding of these interacting factors, thus necessitating longer-term historical perspectives (Parks et al. 2017). Despite these limitations, much of our understanding of fire history comes from recent decades and periods when both climate and human activities have undergone rapid and unique transformations (Marlon et al. 2012; Meunier and Shea 2020).

Perhaps nowhere is the rapid and unique transformation of land illustrated better than the > 20 million hectare “Great Cutover” of the Lake States forests. While some logging preceded legal title, this era began primarily after the original public land surveys were carried out (Michigan: 1816–1856, Wisconsin: 1833–1866, Minnesota: 1848–1907) and was largely concluded by 1920 after the Lake States were denuded (Stearns 1997; Kates 2001). While the Cutover is sometimes reduced to a relatively discrete, singular event, it occurred in multiple phases over a period of 60 years. The initial phase of cutting, “river lumbering”, was confined to pine forests near rivers and streams as it was unprofitable to haul logs any distance to water (Whitney 1987). It was not until the 1880s that railroad expansion in northern forests opened new areas for logging including more isolated softwood stands and especially hardwoods like maple (*Acer* spp), which could not be floated down rivers (Roth 1898; Larson and Larson 2016). After 1880 both the scale and intensity of logging expanded dramatically, ushering in one of the most intense periods of logging the temperate world has ever seen (Marquis 1975; Whitney 1990). The peak harvest of pine was ca. 1890 (in MI and WI, 1900 in MN) and by 1920 harvest of hardwoods exceeded pine (Stearns 1997). Weaver and Clements (1929) stated that the pine-hemlock forest of the Lakes States had been reduced to such small fragments that there were doubts as to its former existence (Whitney 1987).

While cutover logging was globally unprecedented in its speed and intensity (Whitney 1987; Williams 1989; Schulte et al. 2007) it was the repeated and often intense slash fires (Zon and Cunningham 1931; Schulte et al. 2007) that followed, which “all the authorities agreed” were the instruments of change rather than logging itself (Roth 1905; Curtis 1959; Whitney 1987). In fact, fires at the time were used to justify logging by timber barons who were depicted not as wasteful capitalists, but rather saving forests from waste by fires (Stimson 1910). The sentiment of “more good pine timber was burned than ever reached the sawmills” was handed down as common knowledge among lumbermen at the time (Zon and Cunningham 1931; Dickman and Leefers 2003) and subsequently even by researchers examining the profligate logging practices of the Cutover (Fries 1951; Whitney 1987). Fires fed by pine slash were viewed as the ultimate degradation of Lake States forests -along with the exorbitantly wasteful logging, clearing stumps for farmers (19 million pounds of explosives were used by the University of Wisconsin College of Agriculture alone; Gough 1997), nearly universally failed attempts at farming (Whitney 1987), and subsequent fire suppression.

Certainly, large and destructive fires in this period were common including the deadliest wildfire in American history – the October 8, 1871 Peshtigo Fire in Wisconsin (Gess and Lutz 2003). Named fire events are mostly useful to managers responding to particular conflagrations whereas ecologists tend to

describe large fire years. The fires of October 8, 1871, for example, famously destroyed 9 km² of the city of Chicago, and killed several hundred people. At the same time, they burned > 10,000 km² and multiple cities (e.g., Holland, Lansing, Port Huron, Manistee) in lower Michigan (Dickmann and Leefers 2003). These fires are sometimes collectively called “the great Midwest fires of 1871”. In Minnesota, the “Great Fires” denote the especially destructive fire years of 1894, 1908, 1910, and 1918 (Haines and Sando 1969; Johnson 2020). During these destructive fire years, tens of thousands of hectares also burned elsewhere in the Lake States. In Wisconsin, for example, 1894 is the year of the “Phillips Fire” which burned over eight counties in late July, destroying the town of Phillips and killing several hundred people. What these Euro-American settlement (hereafter settlement) fires have in common is that they were, and remain to be, considered anomalies. Interestingly, 150 years after the fact, we still not only attribute the 1871 fires to extraordinary and anomalous conditions, but also take solace in the belief that those conditions will not repeat themselves (Frelich 2002; NOAA NWS 2021). Yet in the Lake States region, we have only a nascent understanding of fire regimes in relation to vegetation and climate (Meunier et al. 2019a). Thus far, there has been little effort to view settlement era fires in greater historical and ecological context.

The first systematic attempt to evaluate the problem of slash as a fire hazard was led by the architect of research in the U.S. Forest Service, Raphael Zon. Zon and Cunningham (1931) found that settlement era fires were a result of weather conditions, not slash, and that any impact on fire intensity/severity would have been both localized, since slash covered a small proportion of cutover areas, and was short-lived (Cheyney 1939). Yet slash remained a primary culprit for uncontrolled wildfires which posed a “serious problem to those concerned with fire control” (Williams 1955), perpetuating the notion that settlement era fires were unprecedented in intensity and frequency (Dickman and Cleland 2002, White and Host 2008) and driven primarily by slash (Wells 1968; Brose et al. 2001; Frelich 2002). It was commonly held, for example, that fire seldom swept into “virgin stands” for more than 10 rods in the absence of logging slash (Lorimer 1980).

In fuel-limited semi-arid regions the importance of fuel buildup in driving high-severity fire is unequivocal (Parks et al. 2018). Yet, the relative importance of fuels on fire behavior and effects in more mesic temperate forests are less clear (Steel et al. 2015). Interestingly, two of the largest wildfires in Michigan history burned the same ground in 1871 and 1881. The more devastating fires of September 1881 were blamed, in part, on dead timber from the 1871 fires and slash, which popular accounts indicated had been “building up for decades” (Rummel 2003). Slash build up for decades is in direct contradiction to findings by Zon and Cunningham (1931) though repeat high-severity fires are not unheard of - at least in western US montane systems (Coppoletta et al. 2020). In Michigan, fuel loadings in mixed pine stands were found to be more closely tied to the cumulative impact of past fires than stand composition and structure following harvesting (Drobyshev 2008). Repeated fires in Michigan reduced woody debris and the duff layer resulting in less intense subsequent fires (Drobyshev 2008).

As the environmental historian William Cronon (1983) stated, “an ecological history begins by assuming a dynamic and changing relationship between environment and culture, one as apt to produce contradictions as continuities.” This is an attempt to try and ascertain the contradictions and continuities

of our recent fire history for the Lake States, a period of profound changes and importance that we are only beginning to critically evaluate after more than a century. In this study my objective was to evaluate fires of the settlement era in a context of a longer fire chronology and in relation to vegetation and climate. Specifically, I evaluated fire frequency and the similarity of fire events between pre-settlement (prior to 1851), and settlement (1851– ca. 1930) periods. I further assessed fire vegetation characteristics for the 1871 Peshtigo fire in Wisconsin, USA.

Methods

Study area

This study was conducted across Wisconsin (WI) and the Upper Peninsula of Michigan (UP), USA spanning a 4-degree latitudinal (43°–47°N) and 8-degree longitudinal (-84°– -92°W) gradient and included eight ecoregions (Fig. 1; Omernik 1987; Omernick and Griffith 2014). Ecoregions are large ecological landscapes with diverse biophysical characteristics defined, in part, by successive glaciation events that have created diverse forest types across the Lake States (WI DNR 2015, Meunier et al. 2019b). Within these ecoregions fire history data was collected in 25 study sites, each with a component of pine (*Pinus* spp.), but otherwise disparate, allowing comparisons of disturbance history among broad geographical regions with varying physiography and forest types. Ecoregions (east to west) included the:

(1) Northwest Sands (NWS), WI (4,628 km²) – a deep, well-drained sand outwash complex, with relatively flat to rolling topography with lakes limited to the southern portion. This ecoregion had a high proportion of pine (> 93% of settlement survey trees) and barrens. Several notable settlement era fires are documented in historical records in this landscape, including a fire in 1854 (Amery, WI to Iron River, WI), the 1894 Phillips Fire (eight counties surrounding Phillips including NWS, WI; Brown 2009), and an 1898 fire (Barron and Polk counties, WI Historical Society 2021).

(2) Central Sands (CS), WI (7,068 km²) – a glacial lakebed of well-drained outwash sands intermixed with wetlands, but with few natural lakes or rivers and very little topography. Currently, this landscape consists of a high proportion of dry pine-oak barrens and forest. Historically, the region had higher proportions of pine (62% of original land survey witness trees), including red and white pines (*P. resinosa*, *P. strobus*) in the northwest (Bruce Mound, Wildcat Ridge, Stoney Bluff sites) and jack pine (*P. banksiana*) in the central portions (Quincy Bluff site) of the ecoregion. A particularly destructive settlement era fire in this landscape was “The Great Marshfield Fire” in June 1887 (Wood and Marathon Counties, WI).

(3) Blufflands and Coulees (B&C), WI (23,004 km²) – an unglaciated region of silt and loam soils with few natural lakes and wetlands, but complex ridge and valley topography. Within the Bluff and Coulee region I sampled a red pine relict (Pine Bluff) occurring on steep bluffs with an exposed sandstone outcrop in an otherwise hardwood-dominated landscape that was primarily white oak (*Quercus alba*) woodland in pre-settlement times.

(4) Northern Highlands (NH), WI (6,821 km²) – a rolling topography with pitted-gravelly sands and abundant natural lakes, rivers, and streams. While sandy soils predominate, the soils tend to be more productive in this ecoregion and support dry-mesic mixed conifer forests which comprised ca. 56% of witness trees in the original survey notes. Historically this landscape was Wisconsin's greatest pinery, but also contained abundant eastern hemlock (*Tsuga canadensis*)-hardwoods, as well as aspen-birch (*Populus-Betula*). Notable settlement era fires include a large fire in 1904, again in 1907-08, and 1910 (WI Historical Society 2021).

(5) Northeast Sands (NES), WI (2,865 km²) – deep, well-drained outwash sands with level to rolling topography and scattered, small lakes. This landscape had a high proportion of pine forests (62% of settlement survey witness trees). Notable settlement era fires included 1900 (Chequamegon Bay and Menominee River). Two sampling sites in this ecoregion (Wolf Lane and Camp Bird) were old growth pine stands that were never harvested.

(6) The Keweenaw-Baraga Moraines (KBM), UP (2,409 km²) – primarily northern hardwood forest including sugar and red maple (*Acer saccharum* and *A. rubrum*), yellow birch (*Betula alleghaniensis*), aspen (*Populus*), red and white pine, and eastern hemlock. This ecoregion, and sites within it (Bears Den, Pine Bluff Trail), are characterized by broad ridges and steep morainal slopes with well-drained sandy soils. Pine is a scattered but minor component of forests within this ecoregion. A notable fire in this ecoregion was in 1896 which burned > 900 km² leveling the town of Ontonagon to the west (Dickmann and Leefers 2003).

(7) The Seney-Tahquamenon Sand Plain (SSP), UP (3,765 km²) – primarily mixed conifer swamp, muskeg/bog, and patterned peatlands dominated by tamarack (*Larix laricina*) and black spruce (*Picea mariana*) on poorly-drained sand lake plains with mixed pine forests (red, jack, and white pines) on sandy ridges and dunes. Ramsey Lake typified this landscape and was a 900-ha patterned fen peatland.

(8) The Grand Marais Lakeshore (GML), UP (5,284 km²) – red and jack pine ridges and dunes along Lake Superior with interior uplands containing scattered northern hardwoods and eastern hemlock-white pine forests. Peatlands occur in poorly drained lacustrine deposits and in western kettles. Sites in this ecoregion ranged from > 1200 ha peatland (Betchler Lake), pockets of pine along Lake Superior (Bay View), to more extensive interior forest (Corner Lake, Hwy 13).

Data collection and analysis

Within natural origin red pine-dominated stands, I collected sections from remnant stumps and partial sections from snags and fire-scarred living trees at 10 cm height. Stands were either old-growth or had been harvested in the cutover period (ca. 1860–1920) but had minimal recent disturbance (e.g., post cutover logging) and contained pre-Euro-settlement era stumps. Multiple stands comprised a site which ranged in size from small pine stands within hardwood forests to more extensive pine forests with efforts to sample comparable areas (0.12–2.41 ha, $\mu = 0.76$ ha). Samples were collected from randomly placed

plots as well as opportunistically by searching within ~ 200m of plots for additional samples (Meunier et al. 2019b; Sutheimer et al. 2021).

In the laboratory, I sanded samples until the cellular structure of xylem was clearly visible with magnification (Grissino-Mayer and Swetnam 2000) and assigned exact calendar dates to all fire-scars. I compiled and analyzed fire-scar chronologies for each site using Fire History Analysis and Exploration System software version 2.0 (FHAES, Brewer et al. 2019). I analyzed fire return intervals (MFRI- the number of years between fires) within sites in which fires occurred on $\geq 10\%$ of recorder trees by settlement and pre-settlement periods framed broadly by patterns of Euro-American settlement using 1850 as the cutoff (pre-settlement ≤ 1850). For pre-settlement chronologies, I included the years up to the time that a major disruption of fire events was apparent (i.e., I excluded post-settlement fires after effective fire exclusion - prior to unusually long MFRI's). Most trees, once large enough to be protected by thick bark, are not injured by low-intensity fires; however, once injured, trees are more susceptible to repeated injury in subsequent fires and are considered "recording trees" (Swetnam and Baisan 1996). Filtering, based on scarring percentage, provides a relative index of fire size (Farris et al. 2010). A 10% filter, for example, will only consider fire years recorded on $\geq 10\%$ of recorder trees, thus eliminating fires that may have burned only one or few trees in a single lightning strike or localized incident (Meunier et al. 2014). I also calculated Weibull median probability (WMPI) which is a less-biased estimator of central tendency with skewed data (Grissino-Mayer 1999), but MFRI are more commonly reported (e.g., LANDFIRE 2016).

To test for differences in historical fire frequency between settlement and pre-settlement periods I compared MFRI for fire recorded on $\geq 10\%$ of recorder trees between time periods (SigmaPlot Systat Software, 2010). I used two-tailed Student's *t*-test to compare MFRI when data were normally distributed with equal variance, and nonparametric Mann-Whitney rank sum tests to compare periods when data were not normally distributed. I compared fire frequency by time periods for site ($n = 25$) and ecoregion ($n = 8$) and used MFRI distribution to compare median values and data spread (by site and ecoregion) for pre-settlement and settlement periods.

Composite fire intervals (e.g., fires on $\geq 10\%$ recorder trees) are influenced by the number of fire-scarred trees sampled; the more trees sampled the lower the likelihood of missing a fire (Lafon et al. 2017). MFRI's are also influenced by the level of filtering; higher levels of filtering usually result in fewer, larger fire years and longer MFRI. Therefore, I also evaluated temporal variations in fire with a decadal fire index (DFI) which does not depend on compositing and accounts for sample depth (Hoss et al. 2008). DFI is calculated by first summing the number of fires recorded during each decade and dividing by the number of recording trees that are represented during the decade (Lafon et al. 2017). Dividing by the number of recording trees standardized fire sums and permitted comparison of decades with different sample sizes (Lafon et al. 2017). I regressed DFI against time for the entire pre-exclusion period (both settlement and pre-settlement eras) to test for trends (i.e., positive or negative slope) over time. Analyses of fire frequency changes over time (or between periods) were done for each individual site ($n = 25$) as well as for sites pooled by region ($n = 8$). The Cutover generally followed an east-to-west progression (Maine to Michigan

and Wisconsin, then Minnesota) with geographic factors playing an important role in settlement era lumber industry (Stearns 1997). I evaluated regionally composited fire occurrence changes to detect broader spatial scale fire patterns.

There is no robust way to compare historical written accounts of settlement era fires to tree-ring fire scar records. However, to try to ascertain general agreement between historical accounts and fire-scar data, I compiled the proportion of regions recording well-known large fire events. This allowed me to evaluate whether particularly large settlement era fires, as depicted from historical written accounts, had a higher proportion of ecoregions with fire scars recording the same fire year (an indication of widespread fire, Meunier and Shea 2020). I also composited fire history among all sites (659 fire-scar samples) into a single fire chronology and used a more restrictive filter - fires recorded on $\geq 15\%$ of all recorder trees, with a minimum sample size of 10 recording trees - to compare how the largest fire years, reconstructed with fire-scar samples, compared to known settlement era fires. Setting a minimum sample size of 10 recorder trees helps to reduce the influence of early fire years that scar a high proportion of trees due to small sample sizes. I compared the largest fire years (recorded on $\geq 15\%$ of recorder trees across all samples combined) across both pre-settlement and settlement periods with this composited fire history. I used superposed epoch analysis (SEA) to understand climate drivers (average Palmer Drought Severity Index, PDSI, of four grid points across the region; Cook et al. 2007) for both widespread fire years with $\geq 15\%$ rate of scarring across all sites/samples and for notable settlement era fires via historical accounts.

Generally, fire perimeters for settlement era fires are anecdotal and/or lacking detailed descriptions of spatial extent and patterns making fire-vegetation characteristics difficult to ascertain. The 1871 Peshtigo Fire is an exception to this with reasonably well-documented fire perimeter maps (Fig. 2). To evaluate fire-vegetation characteristics in relation to land use changes (i.e., slash) I overlaid the approximate boundaries for the 4,856 km² Wisconsin portion of the October 1871 Peshtigo fire and extracted all settlement era General Land Office Public Land Survey (GLO) witness tree records that intersected the Peshtigo fire boundary (Sickley et al. 2001). The survey, which was designed to form the basis of property boundaries and land records during the settlement era included notes on the species, diameter, and location relative to section corners of two to four “witness trees” (Stewart 1935). I overlaid the Peshtigo fire footprint on a raster map of GLO witness trees and extracted all witness trees within the boundary of the Peshtigo Fire to evaluate forest composition of that landscape at the time of settlement using ArcMap 10.3 (ESRI 2014).

Results

This study included 659 crossdated fire-scarred tree samples collected among the 25 sites spanning the period from 1548 (the first fire included in analyses) to 1947 when effective fire exclusion was apparent among all sites. The temporal extent of tree-ring records varied among sites but, collectively, I identified 3,229 fires from 1548–1947. Despite very different landscape contexts (i.e., ecoregions) and sites (e.g., forest composition), prior to the mid-1900s, fires were historically frequent in all locations with MFRI ranging from 3 to 15 years ($\mu = 8$) for fires recorded on 10% of recorder trees (Table 1). When considering

fires that were recorded on $\geq 25\%$ of recorder trees (larger fire years) fire frequency decreased slightly but were still frequent (MFRI = 5–34 years, $\mu = 12$). In general, fires were most frequent in the Central Sands, Blufflands and Coulees, and Northwest Sands ecological landscapes (MFRI = 4) and longest in the Keweenaw-Baraga Moraines (MFRI = 12) and Seney-Tahquamenon Sand Plain (MFRI = 11).

Table 1

Fire interval metrics (years) for fires recorded on $\geq 10\%$ of recording trees at each site ($n = 25$) until the time of disruption of fire events were apparent.

Site	Region	Years	No. samples	No. fires	No. Int.	MFRI	WMPI	Min-max interval
Totogatic River	NWS	1710–1946	27	206	43	6	5	1–25
Inch Lake	NWS	1699–1926	34	127	37	6	6	1–16
Lampson Pines	NWS	1747–1947	14	96	36	6	4	1–25
Sand Lake	NWS	1737–1884	29	270	38	4	4	1–10
Bruce Mound	CS	1707–1935	59	219	20	11	10	1–31
Wildcat Ridge	CS	1771–1857	49	216	13	7	6	1–16
Stoney Bluff	CS	1704–1934	20	118	25	9	7	1–47
Quincy Bluff	CS	1694–1930	23	180	71	3	3	1–10
Wisconsin Dells	CS	1681–1924	28	225	58	4	4	1–11
Pine Bluff	B&C	1684–1895	17	168	51	4	4	1–17
Cathedral Point	NH	1797–1908	24	60	4	6	4	1–14
Frog Lake	NH	1833–1941	14	53	14	8	7	1–15
Squirrel River	NH	1744–1910	16	48	19	9	7	1–31
Finnerud Pines	NH	1736–1907	39	147	19	9	8	1–18
Buckatabon	NH	1697–1910	15	45	26	8	6	1–38
Camp Bird	NES	1764–1925	17	141	28	6	5	1–14

I report both Mean Fire Return Interval (MFRI) and Weibull Median Probability Interval (WMPI) which is where half of the probability distribution is below, and half above the value.

Site	Region	Years	No. samples	No. fires	No. Int.	MFRI	WMPI	Min-max interval
Wolf Lane	NES	1818–1926	16	109	16	7	6	3–17
Tar Dam Road	NES	1714–1855	25	151	13	11	10	3–31
Bears Den	KBM	1721–1909	13	40	13	15	9	1–55
Pine Bluff Trail	KBM	1659–1927	25	82	26	10	8	1–34
Betchler Lake	GML	1548–1920	62	190	43	9	7	1–32
Bay View	GML	1777–1932	15	67	19	8	7	2–25
Hwy 13	GML	1574–1910	17	75	29	12	7	1–70
Corner Lake	GML	1699–1946	20	63	16	15	9	1–84
Ramsey Lake	SSP	1637–1932	41	133	27	11	9	1–35
I report both Mean Fire Return Interval (MFRI) and Weibull Median Probability Interval (WMPI) which is where half of the probability distribution is below, and half above the value.								

Among the 25 different sites, fire frequency was significantly different between pre-settlement and settlement periods at only three sites (Sand Lake, Pine Bluff, and Camp Bird; Table 2). Two sites (Sand Lake and Pine Bluff) had significantly shorter MFRI ($P < 0.001$, $P = 0.008$ respectively) in the pre-settlement period and one site (Camp Bird) had significantly shorter return intervals ($P = 0.046$) in the settlement (MFRI = 4) versus pre-settlement period (MFRI = 8). Results were similar by ecoregion. The Northeast Sands was the only region which had more frequent fire in the settlement period (MFRI pre-settlement = 8, settlement = 4; $P < 0.001$). The Blufflands and Coulees ecoregion (Pine Bluff) had more frequent fire in the pre-settlement (MFRI = 4) than in settlement (MFRI = 9); whereas there were no statistical differences in fire frequency between periods in the other six ecoregions though intervals were longer during settlement (Fig. 3).

Table 2

Fire history summaries and tests of difference between Pre-Euro-American (pre-settlement, ≤ 1850) and Euro-American settlement (settlement) eras.

Pre-settlement				Settlement			
	Years	MFRI 10% (# Int.)	Min-max	Years	MFRI 10% (# Int.)	Min-max	P-value
<i>Northwest Sands</i>							
Totogatic River	1710–1840	5 (26)	1–14	1854–1946	6 (16)	1–25	0.648
Inch Lake	1699–1847	8 (21)	1–31	1853–1926	5 (15)	2–14	0.092*
Lampson Pines	1747–1846	6 (17)	1–25	1851–1947	6 (18)	1–18	0.548
Sand Lake	1737–1849	3 (32)	1–7	1852–1884	6 (5)	3–10	< 0.001*
<i>Central Sands</i>							
Bruce Mound	1707–1847	11 (13)	1–31	1850–1934	11 (7)	4–18	0.738*
Wildcat Ridge	1771–1841	6 (12)	1–11	1851–1857	x	x	x
Stoney Bluff	1704–1847	9 (16)	1–18	1851–1934	10 (8)	1–47	0.268
Quincy Bluff	1694–1848	3 (45)	1–9	1852–1930	3 (25)	1–10	0.594
Wisconsin Dells	1681–1850	4 (44)	1–9	1853–1924	5 (13)	1–11	0.232
<i>Blufflands and Coulees</i>							
Pine Bluff	1684–1847	4 (45)	1–11	1851–1895	9 (5)	4–17	0.008
<i>Northern Highlands</i>							
Cathedral Point	1797–1846	6 (4)	1–14	1851–1908	x	x	x
Frog Lake	1833–1846	x	x	1855–1941	7 (12)	1–15	x
Squirrel River	1744–1847	10 (10)	1–31	1855–1910	7 (8)	3–15	0.870
Finnerud Pines	1736–1842	8 (13)	1–18	1850–1907	11 (5)	2–16	0.172

Pre-settlement				Settlement			
Buckatabon	1697– 1845	9 (17)	1–38	1854– 1910	7 (8)	1–15	0.447
<i>Northeast Sands</i>							
Camp Bird	1764– 1840	8 (10)	1–14	1860– 1925	4 (16)	1–9	0.046*
Wolf Lane	1818– 1843	x	x	1850– 1926	6 (13)	3–16	x
Tar Dam Road	1714– 1840	11 (12)	3–31	x	x	x	x
<i>Keweenaw-Baraga Moraines</i>							
Bears Den	1721– 1829	14 (8)	1–31	1884– 1909	6 (4)	3–11	0.943
Pine Bluff Trail	1659– 1829	11 (16)	1–26	1862– 1927	7 (9)	1–22	0.833
<i>Grand Marais Lakeshore</i>							
Betchler Lake	1548– 1835	9 (32)	1–32	1853– 1934	7 (10)	2–18	0.802
Bay View	1777– 1848	8 (9)	2–25	1856– 1932	8 (9)	3–13	0.189
Hwy 13	1574– 1846	10 (25)	1–70	1857– 1910	x	x	x
Corner Lake	1699– 1812	14 (8)	1–36	1896– 1946	7 (7)	1–20	0.798
<i>Seney-Tahquamenon Sand Plain</i>							
Ramsey Lake	1637– 1847	10 (21)	1–34	1856– 1932	10 (5)	9–12	0.121

When evaluating trends in fire frequency with decadal fire index (DFI) I found no sites that illustrated a significantly positive slope over time whereas six sites had significantly negative slopes illustrating reduced fire frequency in the settlement period (Table 3). Most sites had no significant changes over time. Similar trends were evident when evaluating DFI by ecoregion. Only the Northeast Sands ecoregion had a positive slope (Fig. 4) but lacked significant differences in DFI over time. Two ecoregions had significantly negative slopes, Bluff and Coulees ($P < 0.001$) and Central Sands ($P < 0.001$), but the Bluff and Coulees ecoregion only had one site (Pine Bluff) therefore would not be expected to change from site

level analyses. In general, there was greater evidence for reduced fire frequency in the settlement period, as compared to pre-settlement, at both site (Table 3) and ecoregion (Fig. 4) scales.

Table 3

Summary of regression models analyzing temporal trends in fire activity for 25 different sites using a Decadal Fire Index (DFI, mean number of fire scars per recording tree, per decade).

	# Samples	# Fires	Time period	# decades	R ²	Trend	P-value
<i>Northwest Sands</i>							
Totogatic River	27	206	1710–1949	25	0.569	↘–	< 0.001
Inch Lake	34	127	1660–1929	27	0.064	0	0.132
Lampson Pines	14	96	1740–1959	22	0.060	0	0.274
Sand Lake	29	270	1730–1889	16	0.211	0	0.074
<i>Central Sands</i>							
Bruce Mound	59	219	1680–1939	26	0.035	0	0.363
Wildcat Ridge	49	216	1770–1888	12	0.813	↘–	< 0.001
Stoney Bluff	20	118	1700–1939	23*		0	0.320
Quincy Bluff	23	180	1850–1930	29	0.011	0	0.585
Wisconsin Dells	28	225	1680–1924	25	0.226	↘–	0.016
<i>Blufflands and Coulees</i>							
Pine Bluff	17	168	1680–1899		0.325	↘–	0.006
<i>Northern Highlands</i>							
Catherdral Point	24	60	1790–1909	12	0.464	↘–	0.015
Frog Lake	14	53	1830–1949	12	0.568	↘–	0.005
Squirrel River	16	48	1740–1919	18	0.002	0	0.867
Finnerud Pines	39	147	1690–1909	22	0.019	0	0.540
Buckatabon	15	45	1690–1919		0.032	0	0.418
<i>Northeast Sands</i>							
Camp Bird	17	141	1760–1929	17	0.000	0	0.939
Wolf Lane	16	109	1810–1929	12	0.172	0	0.181
Tar Dam Road	25	151	1710–1859	15	0.336	↘–	0.024
<i>Keweenaw-Baraga Moraines</i>							
Bears Den	13	40	1720–1909	19	0.001	0	0.908
Pine Bluff Trail	11	42	1650–1929	28	0.019	0	0.481

	# Samples	# Fires	Time period	# decades	R ²	Trend	P-value
<i>Grand Marais Lakeshore</i>							
Betchler Lake	62	190	1540–1959	42	0.041	0	0.200
Bay View	15	67	1770–1939	17	0.015	0	0.643
Highway 13	15	73	1570–1910	35	0.032	0	0.302
Corner Lake	20	60	1699–1949	26	0.001	0	0.867
<i>Seney-Tahquamenon Sand Plain</i>							
Ramsey Lake	41	133	1630–1939	31	0.035	0	0.316

During settlement, an estimated 2,000 km² (half million acres) per year burned (Mitchell and LeMay 1952), thus defining significant settlement fire years is problematic. I did not compile an extensive bibliography of written historical accounts of settlement era fires; however, my interest was primarily to document general agreement between well-known historical events and fire scar reconstructed fires. Three of the four largest settlement era fire years reconstructed via fire scars (based on proportion of ecoregions recording a fire year and filtering of composited fire chronology for all samples) coincided with large fires described in historical accounts. These include (from most widespread to least): 1891, 1910, and 1920 (Table 4, Fig. 5). Interestingly, while 1894 was found in half of ecoregions (Table 4), fire scar records include 1895 as a more widespread fire year (Fig. 5). Both 1894 and 1895 were drought years (averaged PDSI = -2.008, -2.380 respectively). All but one historically documented fire year, 1931, which was a severe regional drought year (PDSI = -3.424), were detected by fire-scars. Fire scar evidence of 1871, one of the more destructive settlement era fire years, did not indicate it as one of the more extensive fire years. Notably, records of this fire year, and all fire years detected by fire-scar methods, are limited to low- and/or moderate-severity fires. High-severity fires are more likely to kill trees that would otherwise record fires and destroy evidence of past fires (Kent 2014). It follows that more detailed maps of 1871 fires illustrate a more extensive footprint of fires (Fig. 2b), albeit lower-severity and less destructive. Both large fire-scar reconstructed fire years (Fig. 5) and notable fires via historical accounts (Table 4) were significantly related to dry conditions (Fig. 6).

Table 4

Notable Euro-American settlement era wildfires in the Lake States organized by proportion of ecoregions ($n = 8$) in Wisconsin and the Upper Peninsula of Michigan detected with fire-scars and then chronologically.

Fire Year	States	% Regions	Event(s)
1891	WI, MI	78	Comstock Fire 260 km ² - WI (May)
1910	MN, WI, MI	67	Baudette-Spooner Fire – 2nd largest in MN (Oct.)
1900	WI	56	Chequamegon Bay, Menominee River (May)
1864	MN, WI	44	Little Souix (BWCAW*) - MN, northcentral WI
1868	WI	44	Fires in northcentral, Kewaunee and Door counties NE (Sep.)
1894	MN, WI	44	Phillips Fire- 8 counties in WI (Jul.); Hinckley Fire, Lac La Croix Fire (BWCA) - largest in MN (Sep.)
1918	MN	44	Cloquet-Moose Lake Fire – 4th largest in MN
1923	WI	44	Fires
1854	WI	33	Single fire runs from Amery to Iron River, 225 km
1863	MN, WI	33	Alice-Saganaga Fire – 3rd largest in MN > 1,000 km ²
1871	WI, MI	33	Peshtigo Fire - WI (Oct.), Great MI Fire > 10,000 km ² (Oct.)
1881	MI	33	3,885 km ² - MI thumb (Sep.)
1897	WI	33	Fires
1908	WI, MI	33	Mosinee (1907-8), Wausau, Rhinelander, Bayfield-WI (Apr.); Chisholm Fire - MN (Sep.); Metz Fire - Lower MI (Oct.)
1920	WI	33	"Widespread fire" - Central Sands; major losses Douglas County - NWS (Oct.)
1936	WI, MI	33	"Worst year of fires in Upper Peninsula" (UP) MI
1874	MI	22	Major fire yr - lower central MI
1875	MN	22	Insula Ogishkemuncie (BWCAW*)
1879	MI	22	Major fire yr - lower central MI
1880	WI	22	Sep. fires

*Boundary Waters Canoe Area Wilderness (BWCA). Sources: WI Historical Society, MN Division of Forestry 1965, Heinselman 1973, Stearns 1997, Pyne 2001, Dickmann and Leefers 2003, USFWS 2004, Brown 2009, Apps 2020.

Fire Year	States	% Regions	Event(s)
1887	WI	22	Marshfield burned (Jun.)
1893	WI	22	"A disastrous fire" Central Sands
1896	WI, MI	22	Ironwood, Hurley-WI; Ontonagon fire (> 900 km ²)-UP MI
1898	WI	22	Barron and Polk Counties - WI (Sep.)
1930	WI	11	1,295 km ² burned in Central Sands
1931	MN, WI	0	Red Lake "Dust Bowl" Fire - MN (Sep.)
*Boundary Waters Canoe Area Wilderness (BWCA). Sources: WI Historical Society, MN Division of Forestry 1965, Heinselman 1973, Stearns 1997, Pyne 2001, Dickmann and Leefer 2003, USFWS 2004, Brown 2009, Apps 2020.			

The Peshtigo Fire is somewhat unique in that there are detailed fire perimeter maps allowing at least qualitative analysis of fire-vegetation-climate relationships. Settlement era witness tree maps of the Peshtigo Fire region indicated that portions of the 1871 fires were a mesic "sugar bush" – a colloquial term for maple (*Acer*) forest used for syrup production (e.g., Lower, Upper, and Middle Sugarbush; Fig. 2a). The most abundant tree species out of 11,014 witness trees identified in the footprint of the Peshtigo Fire at the time of GLO Public Land Survey (ca. 10 years prior to the fire) was hemlock (*Tsuga canadensis*; 21%), followed by cedar (*Thuja occidentalis*; 14%), beech (*Fagus grandifolia*; 12%), tamarack (*Larix laricina*; 8%), and sugar maple (*Acer saccharum*; 8%; Fig. 7). Less than 10% of witness trees in the footprint of the Peshtigo fire were pine of any kind (most of which was white pine – a common component of mesic hardwoods; Curtis 1959). This region was and remains dominated by mesic forests (WI DNR 2015) which were not harvested at any scale until a decade or more following the Peshtigo fire (Stearns 1997).

Discussion

As climate and fire regimes change, new understanding is needed of the inherent resilience of ecosystems and of the implications for human communities and ecosystem services (Hessburg et al. 2019). Following a period of rapid and intense land-use and associated ecosystem changes, forests of the Lake States are now more homogeneous, with less species diversity (Schulte et al. 2007) and less spatial and structural complexity (Meunier et al. 2019a), and are less coupled to local climate controls (Thompson et al. 2013), all of which lead to a loss of resilience in forest ecosystems (Drever et al. 2006). It remains unclear what the relative contributions of logging, slash fires, or subsequent fire suppression were to changes in Lake States forests (White and Mladenoff 1994; Rhemtulla et al. 2009). It was assumed that settlement era fires were anomalous, with more frequent and severe fires resulting from cutover slash (White and Host 2008). Early laws were passed to require disposal of slash (Wright and

Heinselman 2014) and the prevention of wildfires at all costs formed the basis of forest conservation in the Lake States; yet, there is little evidence for slash as a widespread and prolonged fire hazard (Zon and Cunningham 1931) and little or no evidence that fire was more frequent in the settlement period (Tables 2–3, Figs. 3–5). Fuel type (e.g., forest composition), in addition to fuel loading (i.e., slash), needs to be considered in relation to fire-severity particularly for destructive settlement era fires like the October 1871 Peshtigo fire. The assumption that fires were another (or *the*) degrading force of forest following exploitative settlement era land-use changes (Johnson 2020) may be fundamentally flawed and formed, in part, by ignorance of basic historical fire regime characteristics in Lake State forests.

In the context of a longer (ca. 400-year) fire history, settlement era fires were not uncharacteristically frequent nor is there an obvious relationship of fire frequency to slash (Zon and Cunningham 1931). Only one out of 25 sites, Camp Bird in the Northeast Sands (NES), had a significantly shorter fire return interval in the settlement period (Table 1, Fig. 3) and that site was a never-harvested old growth pine stand where slash would have been absent. In most cases fires were less, not more, frequent in the settlement era (Tables 1–2, Figs. 3–4). Interestingly, many of the same settlement era fires attributed to slash are documented in unharvested portions of the Boundary Waters Canoe Area Wilderness (BWCAW; Heinselman 1973) and also the 95,313 ha Menominee Indian Reservation (Sands and Abrams 2011) which has a very different land use history than most cutover Lake States forests. In spite of never having had exploitative logging on the Menominee Reservation, Sands and Abrams (2011) documented 36 settlement era fires between 1850–1910, 14 of which are synchronous with notable historical accounts of settlement fires in the region: 1854, 1864, 1868, 1871, 1879, 1881, 1887, 1891, 1893, 1894, 1896, 1898, 1900, and 1910 (Table 4). Settlement fires in the “virgin” BWCAW forests are also very similar to elsewhere in the Lake States region (e.g., 1854, 1863–64, 1868, 1871, 1874–75, 1880–81, 1887, 1894, 1900, 1910, 1918, 1920, 1936; Heinselman 1973). Importantly, settlement era fires in the BWCAW are generally not viewed as anomalous, in part due to the foundational fire history work by Heinselman (1973), which provided greater context to the incidence of fire there.

Several studies have suggested that the combination of logging and slash fires followed by fire suppression in the 1930s drastically altered forest composition in the Lake States (Miller et al. 2010) and led to a loss of coniferous species and increase in deciduous species in northern Wisconsin (Mladenoff and Howell 1980; White and Mladenoff 1994; Radeloff et al. 1999; Steen-Adams et al. 2007). Other studies have found that establishment dates in Lake States pine-oak forest peaked following logging and fires, particularly between 1891 and 1911 (Cook 2000), which include some of the most widespread settlement era fire years (e.g., 1891, 1894–95, and 1910; Table 4, Fig. 5). Close coupling between tree recruitment and low-severity fires, including in the settlement period, was also noted in the BWCAW (Heinselman 1973). In a study in western Oregon and Washington, effects of slash burning following clearcut harvesting had little effect on the quantity of natural stocking of conifers and subsequent hazard rating was lower on burned than unburned plots (i.e., lower spread rate and more easily controlled; Morris 1970). Remarkably, while land use history varied across the disparate forests and ecoregions in this study (e.g., different composition, harvested or not, timing and intensity of harvest) two factors are common among all locations: fire was historically frequent, and fire was universally excluded by the mid-20th

century (Table 1). It is likely that 100 years of fire suppression, rather than a period of more frequent fires, were primary drivers of expansive forest changes (Paulson et al. 2016).

From the perspective of high-severity wildfires, slash is simply redistributed fuels where boles and branches that were in the canopy are in a different arrangement on the forest floor but with the same amount of available fuel (Evans and Wright 2017). However, cutting (and windthrow) can change fuel moisture of slash which can affect flame length potentially increasing fire-severity (Evans and Wright 2017). Fuel moisture of slash increases with compaction over time which influences combustion dynamics (Wright et al. 2019). Fuels also tends to decompose much faster in eastern forests with higher productivity (moisture and temperature) than in the western US (Graham and McCarthy 2006). It is known, at least in theory, that many Lake State conifer forests inherently have heavy fuel loads (canopy and ground) where fire behavior is controlled more by weather at the time of fire than by any other factor (Bessie and Johnson 1995; Frelich 2002). The relationship between settlement land use changes and fire severity remains an unresolved issue; however, it seems that fires in the Lake State likely had both abundant fuels and, periodically, extended drought conditions. Notably, the 1871 fires in Wisconsin had been burning for many weeks prior to October with little rain since the early part of July and below average snowfall in winter of 1870-71 (Gess and Lutz 2003). Residents described a constant cracking of fire at night and smoke was omnipresent (Pernin 1971). These fires were primarily lower severity, much of which burned pine forests to the north of the October 8 Peshtigo Fire (northern Oconto and Marinette Counties) where presumably slash would have been present (Fig. 2b). These low-severity fires of 1871 were detected across study sites in Wisconsin (NWS, CS, NES), the Menominee Indian Reservation to the northeast (Sand and Abrams 2011), and in the Huron Mountains in the Upper Peninsula of Michigan (Muzika et al. 2015).

Schulte and Mladenoff (2005) in their analysis of GLO data found that stand-replacing fires were never recorded by surveyors within the ecological landscapes associated with the October 8, 1871 Peshtigo Fire (Fig. 2a). Wildfire frequency and intensity are broadly inversely related (Pickett and White 1985; Turner et al. 1989). Fire regimes in many forested systems can be categorized as ranging from “fuel-limited” to “climate-limited” where the former are characterized by more frequent, lower-severity wildfires and the latter by infrequent, more severe wildfires (Steel et al. 2015). The mesic forests of the Peshtigo Fire region (Fig. 7) would be expected to burn infrequently and with high severity. It is not surprising that GLO survey data would not detect fires in this landscape which would be characterized by infrequent fires, nor is it surprising that this landscape would burn with the intensity and devastation that it did with abundant fuels (e.g., hemlock, cedar, larch forests). In 1871 logging was still restricted to river lumbering of pine and while land clearing was associated with settlement it would likely have been limited in comparison to the ca. 5,000 km² area burned, and very little logging and associated slash would have been present. Regardless of the contributions of settlement activities to the Peshtigo Fire, high-severity fires would be expected to predominate in forests there. Notably, the high-severity Peshtigo Fire represents a relatively small proportion of area burned as low-severity fire in that same year (Fig. 2b).

In 1871 there was prolonged regional drought (average PDSI 1871 = -2.364, 1870 = -2.470) where fires had been burning for more than a month, which were then fanned by strong southeasterly winds (NOAA 2021) into an abnormally dry forest with abundant fuels. This story is not unique to the Peshtigo Fire or to 1871, but rather the way many large fire years burned over the last 400 years in the Lake States (Figs. 5–6). This is also the case in the 2020 Oregon fires which had been burning for weeks prior to being pushed by strong downslope winds (Abatzoglou et al. 2021). While land use changes in relation to wildfires occurring during settlement in the Lake States cannot be discounted, they also cannot explain scores of similar fire years, over widely varying landscapes, and over centuries (Fig. 5).

Historical reference information is valuable for understanding how current conditions arose, as well as for developing a mechanistic understanding of ecosystem dynamics and predicting future conditions (Safford et al. 2012; Miller and Safford 2017). Historical data, like written accounts at the time of Euro-American settlement, or settlement era Public Land Survey data, can be useful in describing the magnitude of change in conditions relative to reference landscapes (Rhemtulla et al. 2009), but are not always useful in assessing the drivers of change or in forecasting future conditions (Frelich 2002). Likewise, a single “settlement” reference is a static view of ecosystems that were and remain inherently dynamic. What becomes apparent when considering a longer history and greater context is that frequent fires were one of few continuities within forests of the Lake States during settlement. This is a starting point for unraveling the effects of the myriad land abuses in the settlement period and for understanding the contradictions of defining forest conservation in the Lake States on the premise of fire suppression. Although the nature of future forests will be determined in part by climate change and other exogenous variables, land use and fire have been and are likely to remain the driving factors in shaping forests (Rhemtulla et al. 2009). The question is what type of land uses and what type of fire will be part of those future forests.

Conclusions

Settlement era fires (ca. 1851–1947) were believed to have been abnormally frequent and primarily a result of slash build up following extensive cut-over of Lake States forests. However, historically (over the last 400 years) fires were always relatively frequent occurring on average every 8 years (MFRI = 3–15 years). Settlement fires in the Lake States were not simply slash fires, they were a combination of weather, climate, and fuel arrangements. Large fires tended to be driven by extended drought conditions regardless of time period. Destructive fires in the Lake States, like the October 8, 1871 Peshtigo Fire, burned in mesic forests where large volumes of pine slash would not have been present; however large volumes of fuels were always present and where fires would be expected to burn with high severity.

Abbreviations

B&C: Blufflands and Coulees ecoregion; BWCAW: Boundary Waters Canoe Area Wilderness; CS: Central Sands ecoregion; DFI: Decadal Fire Index; GML: Grand Marais Lakeshore ecoregion; KBM: Keweenaw-Baraga Moraines ecoregion; LANDFIRE: Landscape Fire and Resource Management Planning Tools;

MFRI: Mean Fire Return Interval; NES: Northeast Sands ecoregion; NH: Northern Highlands ecoregion; NOAA NWS: National Oceanic and Atmospheric Administration National Weather Service; NWS: Northwest Sands ecoregion; PDSI: Palmer Drought Severity Index; UP: Upper Peninsula, Michigan; USA: United States of America; U.S. Forest Service: United States Forest Service ; SEA: Superposed epoch analysis; SSP: Seney-Tahquamenon Sand Plain ecoregion; WI: Wisconsin; WI DNR: Wisconsin Department of Natural Resources; WMPI: Wiebull Median Probability Interval

Declarations

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Consent for publication

Not applicable

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

Figure 1

Study sites ($n = 25$) among eight ecoregions in Wisconsin and the Upper Peninsula of Michigan in the Lake States, USA.

Figure 2

Maps depicting burned areas in the (a.) October 8, 1871 Peshtigo Fire, Wisconsin where fire loss and death toll was greatest (by courtesy of Encyclopedia Britannica, Inc., copyright 2020; used with permission) and (b) northeastern Wisconsin region fire maps in 1871 (originally published The Sheboygan Press, Oct. 8, 1929).

Figure 3

Boxplot of median, interquartile ranges, 90th percentiles, and outliers for pre-settlement (left) and settlement (right) era fire return intervals by region (n = 8, arranged west to east).

Figure 4

Decadal fire indices for sites ($n = 25$) composited by region ($n = 8$). Slopes are linear regression lines for the period of first recorded fires to 1930. One region, the Northeast Sands (NES), had a positive slope ($P = 0.353$) but only the Bluff & Coulee (B&C) and Central Sands (CS) regions had slopes (negative) significantly different than would be expected by chance ($P < 0.001$).

Figure 5

Composite fire chronology for all sites of large fire years recorded on > 15% recording trees with > 10 recording trees. Top graph illustrates number of recorder trees (line) and percent of all recorder trees scarred (bars) over time.

Figure 6

Results of superposed epoch analysis (SEA) of the average Palmer Drought Severity Index (PDSI) across the region (Cook et al. 2007) for years prior and subsequent to fire event years (year 0) for (a.) notable historical accounts of settlement era fires (i.e., Table 4), and (b.) > 15% average rate of scarring (minimum 10 recording trees) across all ecological landscapes. Positive PDSI values indicate wet conditions, negative values represent dry conditions. Solid bars indicate PDSI values outside a 95% confidence

interval based on 1,000 Monte Carlo simulations of random distributions of annual PDSI (a. 1850–1950, b. 1600–2000).

Figure 7

Percent of all trees (n = 11,014) by species recorded by Euro-settlement era Public Land Survey notes (1832–1866) within the 485,623-ha footprint of the October 8, 1871 Peshtigo fire.