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We used dendrochronology and historic data to examine spatial and temporal variation in the historic fire regime of a complex landscape adjacent to Lake Superior in the Huron Mountains, Michigan, USA. Across the study area, 330 dated fire scars were identified and cross-dated from 115 trees and seven sites, spanning the years 1439–2005. Most of the fires were small in spatial extent; larger fires were infrequent and occurred primarily in level landscape positions within 1.5 km of Lake Superior. Small, frequent fires also occurred at the higher elevations attributable to lightning ignitions. The mean fire interval (MFI) from 1439–1751 was 49 yr and then abruptly shortened to 18.5 yr until the 1900s, during which time the MFI across all sites was greater than 78 yr. From 1752–1900s, high fire frequency occurred even in relatively wet years, suggesting an increased human influence. We interpret these patterns in fire intervals in the context of topography and changes in human population, land use, and cultural perspectives on fire.

KEYWORDS *fire history, disturbance, anthropogenic fire, climate, dendrochronology, Great Lakes Forest,* Pinus

INTRODUCTION

The reconstruction of historic disturbance regimes provides evidence for mechanisms of long-term changes in natural and human altered landscapes. Therefore, restoration and sustainable forest practices rely on data developed from such reconstructions. Fire history reconstruction, in particular, has the

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potential to influence management and can be used to better understand the effects of fire suppression, fire prescriptions, and wildfire (Falk et al., 2011).

Fire regime chronologies explain temporal patterns of fire and disturbance in general and have been constructed for many forest types and regions in North America. Such reconstructions have revealed a range of fire regime characteristics from infrequent, stand-replacing events such as those in *Pinus contorta* forests to the more frequent fires found in *Pinus ponderosa* forests (Collins & Stephens, 2010; Perry, Hessburg, & Skinner, 2011) in the western United States; or frequent, low-severity fires of the southeastern United States (Huffman, Platt, Grissino-Mayer, & Boyce, 2004; Stambaugh, Guyette, & Marschall, 2011). Arguably, the most robust fire history reconstructions have been developed from the western United States (Falk et al., 2011), but increasing interest in fire-related disturbance regimes in the northeastern United States has generated fire history data despite the difficulty in securing adequate, high-quality samples of fire scars. Fire history reconstruction in northeastern North America can be more difficult owing to rapid decomposition of wood in the humid eastern U.S. forests as well as intensive land use practices that eradicated evidence of past fires.

Fire history reconstructions are critical in discerning the relative importance of humans, climate, landscape, and other factors in the fire regime. The importance of human populations as an influence on patterns of fire has been described in the Ozarks of Missouri (Guyette, Muzika, & Dey, 2002) as well as Northern Michigan (Anderton, 1999); but generally, much remains unknown about the interrelationships of human population density, human activities, and fire regimes. Such research questions are further complicated by incorporating the effects of climate and topography together with human interaction. Although humans have long "managed" natural resources, the interacting influences of human activity, climate, and topography on the fire ecology of the region remain poorly understood.

This project describes a fire regime in a northern hardwood–mixed conifer forest of the Upper Great Lakes region, specifically the Huron Mountains in the Upper Peninsula of Michigan. The study area, the Huron Mountains, is unique in the region for its relatively long history of private ownership, wilderness management, and relative lack of logging or land clearing during post-European settlement (Flaspohler & Meine, 2006; Leopold, 1938, cited in Huron Mountain Wildlife Foundation, 1967, pp. 40–57). The Huron Mountains represent a heterogeneous landscape that is influenced by both local climatic effects associated with Lake Superior as well as topographic effects associated with mountain terrain. This region provided a rare opportunity to evaluate fire regime characteristics in a low to moderate elevation, cold temperate forested ecosystem in the eastern United States. Furthermore, while the importance of humans in defining fire regimes has been established elsewhere (e.g., Guyette et al., 2002; Guyette, Spetich, & Stambaugh, 2006; Stambaugh, Guyette, & Marschall, 2013), there is little known about the importance of humans to the fire regime of the Lake States other than the spatial analysis of Loope and Anderton (1998). Fire history reconstruction studies have been conducted across the broad Great Lakes Region (Drobyshev, Goebel, Hix, Corace, & Semko-Duncan, 2008, Drobyshev, Goebel, Bergeron, & Corace, 2012; Guyette & Dey 1995a, 1995b; Sands & Abrams 2011, among others), but we expect that the Huron Mountains present a distinct suite of topographic, climatic, and human factors that distinguish it from previous studies.

Based on evidence from other documented fire regimes, we hypothesized that forests of the Lake States region were shaped by the combined influences of climate, topography, and human activities which produced and were influenced by a spatially heterogeneous and temporally variable fire regime. This interaction was explored by determining mean fire interval (MFI) within various local landforms and examining the change in MFI over time, specifically identifying the relative importance of climate factors, site factors, and human activity.

MATERIALS AND METHODS

Study Area

This research was conducted in the Huron Mountains, located along the southern shore of Lake Superior in the Upper Peninsula of Michigan (46.87° N, 87.88° W; Figure 1). The Huron Mountain Reserve (HMR) area is a ∼2,600-ha unit within a larger, private ownership, known for its extensive, late successional forests (Flaspohler & Meine, 2006). The HMR has a humid-cold climate, with no dry season, and cool, short summers. The growing season typically extends from early June to late August, and most precipitation occurs as snow. Average monthly temperatures range from −10.2°C in January to 18.6°C in July. The bedrock is mainly Pre-Cambrian Canadian Shield and the topography is composed of low rounded peaks (granite knobs) and interspersed interior lakes across the ownership. A series of dunes and paleo dunes border Lake Superior. The forests are typical of mesic, deciduous, subboreal forests; common trees include *Tsuga canadensis* (eastern hemlock), *Acer saccharum* (sugar maple), *Acer rubrum* (red maple), *Pinus strobus* (white pine), *Pinus resinosa* (red pine), *Pinus banksiana* (jack pine), and a minor component of other hardwoods. Additional details about the region and its forest cover can be found in Dickmann and Leefers (2003), Dorr and Eschman (1970), and Simpson, Stuart, and Barnes (1990).

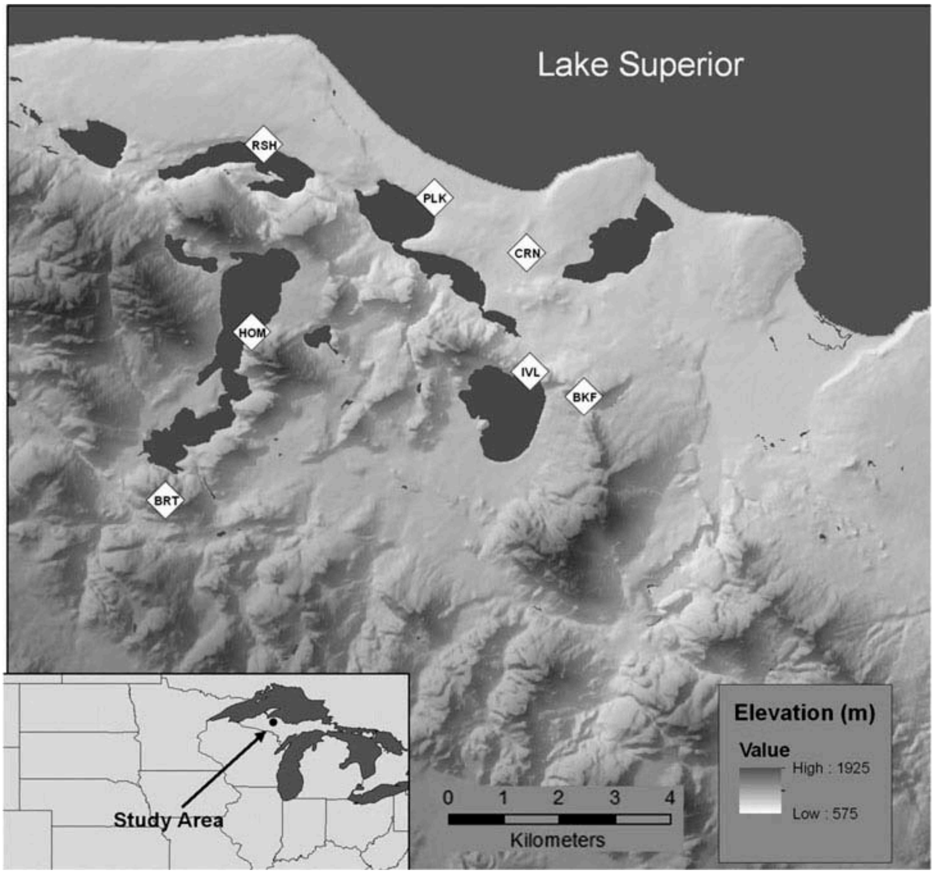

FIGURE 1 Location of study area in northeastern North America, indicating fire history study sites at the Huron Mountain Reserve (HMR). Site codes can be found in Table 1.

Field Sampling

Of the pine species at HMR, *P. resinosa* is most likely to reveal historic fire scars, owing to its fire tolerance and resistance to decomposition. We identified seven potential study areas based on the presence of *P. resinosa* in the overstory and fire scarred stumps and remnant (preserved old wood, either stumps or standing dead snags) material, across a range of landforms and topography. The sampling was limited to dead wood; sampling of live trees was not permitted. Study areas were a minimum of 15 ha, but the "sample area" (Table 1) represented the small spatial subset defined by the area encompassed by individual samples. All sites were located within an area of approximately 3,500 ha, and the greatest distance between any two sites was 8.2 km. The study sites differed in overstory species composition, successional stage, topography, and parent material (Table 1).

We exhaustively sampled each study area for visible fire scars on remnants of *P. resinosa* with at least 100 annual rings. Remnant pieces of pine were stumps or standing dead snags predominantly, but they also included

TABLE 1 Study Site Locations and Characteristics of Red Pine Fire History Sites From the Huron Mountain Reserve, Upper Peninsula, Michigan

Site	Site code	Sample area (ha)	Elevation (m)	Aspect	Slope steepness	Landform	Dominant vegetation
Pine Lake	PLK	11.44	187.00	W	Level	Low dunes, Lake Superior	*P. strobus, P. resinosa* *P. banksiana*
Cranberry	CRN	7.00	196.97	W	Level	Adjacent upland to bog	*Tsuga Canadensis* *Thuja occidentalis* *Betula papyrifera*
Rush Lake	RSH	11.28	208.53	S	Steep	Interior lakeshore	*P. resinosa*
Ives Lake	IVL	2.65	244.44	SSW	Steep	Granite knob Lower slope	*Pinus* spp. *Betula papyrifera*
Homer Mt.	HOM	2.14	257.90	WNW	Moderate	Interior Lakeshore	*P. resinosa* *Tsuga canadensis*
Breakfast Roll	BKF	2.16	274.41	S	Steep	Granite knob Lower slope	*Quercus rubra* *Betula papyrifera*
Burnt Mt.	BRT	9.95	375.54	SSW	Moderate	Granite knob Mid to upper slope	*Pinus, Quercus,* mid-successional hardwoods

Note. Within each study area, the authors collected remnant wood from a defined sample area.

woody debris if the piece was of sufficient structural integrity. Cross-sections were collected using a chainsaw near ground level. All samples were referenced relative to North. The slope and aspect were determined, and sample locations were recorded using GPS (Garmin etrex Legend, Olathe, KS, USA).

Laboratory Methods

In the laboratory, cross-sections were surfaced with an electric hand planer, and the cellular detail of annual rings and fire scar injuries was revealed by sanding with progressively finer sandpaper (80 to 1,200 grit). A radius (pith-to-bark tree-ring series) of the cross-section with the least amount of ring-width variability due to fire injuries was chosen for measurement and cross-dating. The ring-width series from each sample was plotted and cross-dated (Stokes & Smiley, 1968). The COFECHA computer program (Holmes, 1983) was used as a check of tree-ring dating and measurement quality control. Samples were cross-dated with a master ring-width chronology constructed from core samples collected in 2007 from nearby living *P. resinosa* (Stambaugh & Guyette, 2008a).

Fire scars were identified by the presence of callus tissue, traumatic resin canals, liquefaction of resin, and cambial injury (Dieterich & Swetnam, 1984). Fire scar dates were assigned to the year of cambial response to the injury. If possible, the season of fire occurrence was determined based on the position of the scar within the ring. Fire scar positions were classified as being in the earlywood (early, middle, or late portions), latewood, or between rings (dormant season) (Kaye & Swetnam, 1999). We used FHX2 software (Grissino-Mayer, 2001) to graph the fire chronologies and generate summary statistics. Mean fire return intervals (MFIs; the years between fires) and fire frequencies (how often they occur) were derived from the composite fire scar chronology and represent the occurrence of a fire somewhere in the study site.

Topographic and Historic Data

Study sites were mapped (Figure 1), classified according to landform, and described with regard to elevation, aspect, slope steepens, and dominant vegetation (Table 1). This information was used in conjunction with fire scar data to interpret the potential influence of topography on fires regimes.

We determined MFI at each site and across the entire regime by determining the number of years between fires at a study site. A fire scar was assumed to be an event and any other fire scar occurring that year at that site was assumed to be the same event. MFI was simply the number of events divided by the number of years sampled in the overall chronology. We also used point interval data to determine the number of years between fires at a particular location. The point interval describes the number of times a fire occurs within a given period of time.

We developed an annualized Landscape Fire Severity Index (LFSI) to describe the temporal severity and spatial extent of fires. The LFSI uses the number of sites with scars in a given year as a proxy for landscape extent (spatial) and the percent trees scarred at a site to represent fire severity. The LFSI value is a product of multiplying the number of sites scarred in a year by the mean percent of trees scarred across all sites.

In order to evaluate the hypothesis that human influence may be evident in the fire history, we developed an Anthro Fire Index (AFI). AFI provided a way to evaluate the correspondence of the historic fire data to predictions of fire using drought data. The AFI was calculated for the time period that predates the era of contemporary fire suppression (1890s to the present), since humans had a strong influence and well-established role in controlling fire during the last 100 yr. Fire history data from the study sites and reconstructed drought data—expressed as Palmer Drought Severity Index (PDSI)—based on dendrochronological sources from Cook, Woodhouse, Eakin, Meko, and Stahle (2004) were used to develop the index. The AFI is dictated by two major assumptions concerning the relationship between drought and anthropogenic fires: (a) that the absence of fires during drought years was due to a lack of ignitions (human and lightning), and (b) that the occurrence of fires in wet years primarily resulted from human ignitions (accidental or purposeful). Assumption 1 relates to identifying the potential abundance of ignitions when humans were present and influential in an area and the probability that fire increased during drought years. Assumption 2 relates to fire events during "wet" years and that fires during these years occurred within short dry periods and required abundant or intentional ignition by humans. Following these assumptions, we calculated AFI to estimate human influences by comparing time series of annual drought (Cook et al., 2004) with occurrences of fire. Dry years (PDSI < 0) that had no fires were assigned decreasing values of AFI (from -1 to -2.5) based on increasing drought severity (PDSI from 0 to < -3). Years that had fires and were wet (PDSI > 0) were assigned increasing positive values (from 1 to 2.5) based on increasing wetness (PDSI from 0 to > 3). Drought years with fire and wet years without fire were not assigned values nor used in the AFI since these would not contradict expectations.

Time series of assigned values were smoothed using moving averages of two different lengths (11 and 21 yr) and compared. We chose the 21-yr period because the length of time comprised a sufficient number of observations, and it included enough annual drought data to reduce spurious variability from short-term changes in climate. We scaled the moving average to a mean value of zero (stationary) by subtracting the mean of all annual value estimates. Increasingly positive AFI values were interpreted as a reflection of increasing human influence and negative values of AFI were interpreted as reflecting decreasing human influence.

RESULTS

Fire Records, Intervals, Seasonality

We collected and dated 115 trees and identified 330 scars at the seven study sites. Trees displayed fire scars encompassing a period from 1439 to 2005 (Table 2). The 230-yr period from 1630 to 1860 had the most complete record (> 44 sample trees). The temporal variation was distinct, with decreases in MFI after 1752 evident at every site, despite the physical distance among sites (Figure 1). The overall composite MFI was 49 yr before 1752 and 18.5 yr between 1752 and 1897. The length of mean fire intervals (MFIs) among sites ranged from a moderately short interval of 8.3 yr at Burnt Mountain (BRT, mid to upper slope of a granite knob) during the period 1752–1897 to a long interval of 77 yr at Homer Mountain (HOM, interior lakeshore) during the period 1530–1752. After the 1800s the MFIs ranged from over 55 to 100 yr for sites for which data were available.

Point intervals (individual intervals between fires in each specimen sampled) were examined to reveal the number of repeated fire events at a location and the number of years between those repeated events. We used the location with the greatest sample depth (site PLK, low dunes by Lake Superior) to describe how often any fire occurred. Seventy-two percent of the intervals between fires at PLK occurred within the time frame of 5–35 yr, and the most frequent point intervals were in the 15- to 25-yr class (Figure 2). Based on the consistent change in interval at all sites, we segregated the data into two time periods with 1752 as the delineation year. Shorter point intervals were strongly associated with the 1752 to 1891 time period and longer point fire intervals were mostly from the early period of record (before 1752). Only 14% of all the intervals identified occurred before 1752, confirming increased frequency after that time.

Most fire scars (75%) were evident in the latewood portion of the ring, suggesting fires that occurred near the end of the growing or possibly during the dormant season (Table 2). Latewood develops in late summer and might be damaged by a dormant season fire even though cambial expansion has nearly ceased by late summer (Heyerdahl, Miller, & Parsons, 2006). Only one scar was found to be in the earlywood, indicating the rarity of spring or early summer fires in this region.

Temporal Variation in Fires Among Sites

The composite site fire histories of study sites within the HMR reveals a concentration and increased frequency of fires from the mid-1700s to the

TABLE 2 Summarized Fire History Data by Study Site at the Huron Mountains; Fire Data Were Determined by Site, Period, and Seasonality

Site	# trees	# scars	Years	MFI (pre-1752)	MFI (1752–1897)	MFI (1897–2005)	MFI entire record	Seasonality of fire*				
								E	M	L	A	D
PLK	38	199	1480–2005	48	13.5	> 55	26.6	0	7	1	10	0
BRT	30	44	1494–1905	21	8.3	NA	12.8	0	0	0	9	14
RSH	23	38	1439–1976	46	19.3	> 79	27.1	0	2	1	2	5
HOM	6	10	1520–1916	77	23	NA	39.4	0	1	0	4	2
CRN	8	25	1598–1891	52	22	NA	25	0	2	1	3	1
IVL	5	8	1574–1864	44	NA	NA	35.8	0	1	1	3	1
BKF	5	7	1690–1998	NA	24	> 100	25	1	0	0	1	3
ALL	115	330	1439–2005	49	18.5	> 78		1	15	5	35	27

Note. MFI = mean fire interval; NA = inadequate number of samples for the time period; E = early earlywood; M = middle earlywood; L = late earlywood; A = latewood; D= dormant season; see Table 1 for the study site names and codes.
*Scars that were unidentified as to seasonality were omitted from this table.

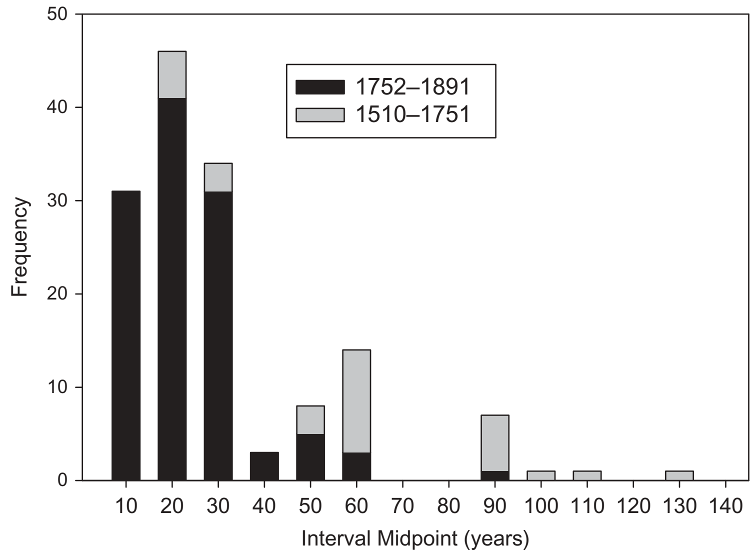

FIGURE 2 The frequency distribution of fire scar point intervals on 38 individual trees at the Pine Lake (PLK) site. The light grey shading represents the earliest 240 yr and the black shading represents the last 139 yr of the fire chronology.

beginning of the 1900s across most sites. Within this composite chronology, certain years appeared to have been important fire years for many sites—e.g., the 1660s, the early 1750s and the early 1780s, and the time period between 1790–1810. At most sites, fire scar records are limited in sample depth and coverage during late 1800s and throughout the 1900s. Only one fire was recorded in the years 1897–2007, although most sites had evidence of fires in the 1890s (Figure 3).

Individual site fire chronologies were presented to provide a perspective on variation in fire events and regimes within the sample area. At PLK (low dunes along Lake Superior), there were at least 20 distinct years in which fires occurred (Figure 4), and those fires commonly scarred many individual trees. The chronology length at RSH (interior lakeshore) was greater, but there were fewer distinct years with fire (Figure 5). For example, between the years 1665 and 1781, there were only two fire scars at RSH. The fire of 1665 is noteworthy for having resulted in a pulse of regeneration shortly afterward, based on the occurrence of pith dates (approximate years of regeneration) from the 1670s (Figure 5), suggesting the possibility that it was a near-stand replacement fire.

The longest fire-free interval observed in the study was at the HOM site (interior lakeshore, chart not shown) across the period of 1618–1872 (254 yr without fire). This finding should be viewed cautiously, however, for only five trees support this interval. The longest fire-free interval at PLK, the site with the greatest number of samples, was 63 yr during the period from 1689–1752.

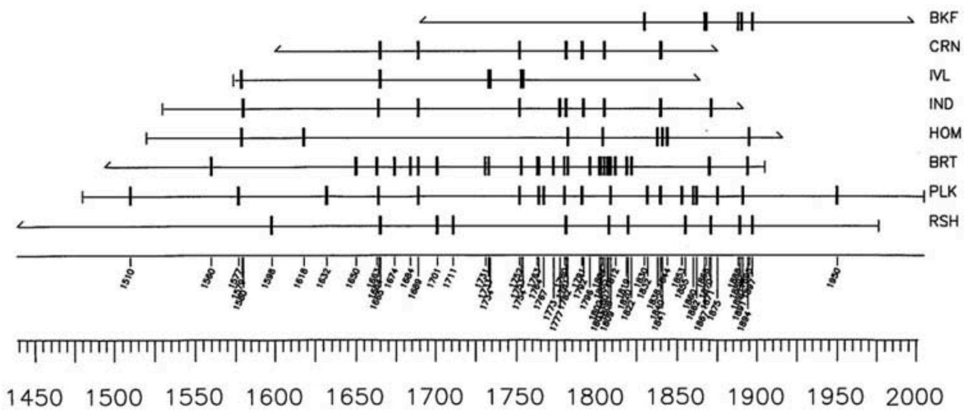

FIGURE 3 Study site composite fire intervals for all sites at the HMR, revealing any year that a fire occurred, as evidenced by scarring. Each site is represented by a horizontal line spanning the length of the tree ring record for that site, with the site code of each site to the right of the horizontal line. Site codes can be found in Table 1. Bold vertical bars represent the year of a fire scar. The study area composite fire chronology with all fire event years at the site appears at the bottom of the figure. The IND site consisted of only two samples and was therefore omitted from subsequent analysis.

Fire was most frequent and fire intervals the shortest at the BRT site (mid to upper slope granite knob; Figure 6). Fires occurred as often as every 1 to 2 yr during some periods. In contrast to PLK (Figure 4) and RSH (Figure 5), few trees were scarred in any particular fire at BRT. At BRT, the MFI was 8.3 yr between 1752 and 1897, and for the entire record it was only slightly greater at 12.8 yr. The longest MFI at this site (21 yr) preceded 1752, but it was the shortest among all sites during that time period (Table 2).

The BRT site (mid to upper granite knobs) with the shortest overall MFI of all study sites (Table 2), had the highest elevation (Table 1), and was the farthest from the Lake Superior lakeshore (Figure 1). However, the fire scars at BRT were the least synchronous (Figure 6) compared to other sites with abundant sample trees, reflecting either fires that were spatially heterogeneous on a small scale or fires with intensity too low to scar most trees. In contrast, tree scars at the PLK site (low dunes adjacent to Lake Superior) and RSH sites (interior lakeshore) showed longer MFIs and highly synchronous, temporally consistent scars (Figures 5, 6) and a much larger number of scars per individual tree (Table 2), suggesting fires that spread throughout the sample area and were severe enough to scar a relatively large percentage of trees. These two sites occupied the relatively low, level, and spatially continuous plains adjacent to Lake Superior. The CRN site also fell within this area (Figure 1) and had a similar MFI (Table 2) but with a sample size too small to describe fire scar synchrony. The HOM and IVL sites had the longest MFIs (Table 2) and occupied interior lakeshores isolated from the Lake Superior shoreline (Figure 1).

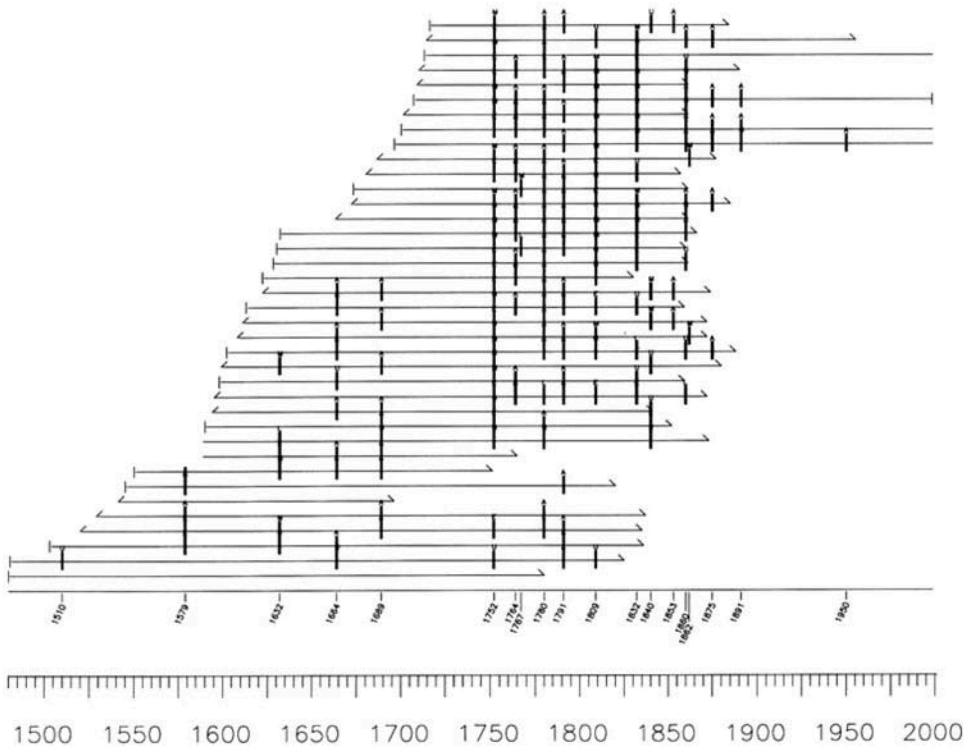

FIGURE 4 Fire history chart from PLK, a low dune area (of Lake Superior), Huron Mountains. Each horizontal line represents the length of the tree-ring record of a *Pinus resinosa* remnant (stump or standing dead snag). Bold vertical bars represent the year of a fire scar. The composite fire chronology with all fire scar years at the site is shown at the bottom of the figure.

Drought, Human Influence, and Fire Extent (LFSI and AFI)

The number of trees and sites scarred (LFSI) correlated significantly with drought (Figure 7). Drought (PDSI) explained 42% of the variance among 24 fire years in the landscape fire index during 1579 to 1869. Fires occurred over a smaller portion of the landscape as drought severity decreased (more positive PDSI) as documented by the number of sites burned and the number of fire scarred trees. The fire scar data for all sites (Figure 3) revealed a pronounced increase in fire frequency after 1752 despite drought index values (PDSI) remaining nearly identical. The fire years with the greatest LFSI values (Figure 7) occurred in drought years before 1810.

The smoothed 21-yr average Anthro Fire Index (AFI) values over the first approximately 200 yr of the time series were relatively low, during which time most fires occurred during dry years (years with low PDSI; Figure 8). AFI increased abruptly after 1750. The increasing positive value of AFI indicates that fire occurred during nondrought years.

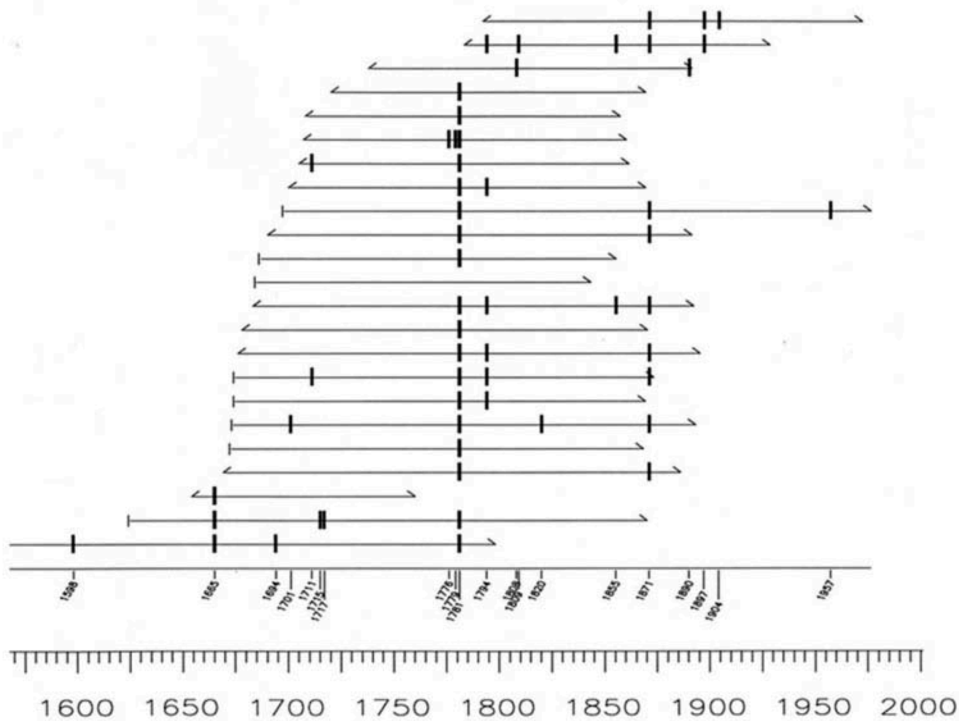

FIGURE 5 An interior lake shore fire history chart from the RSH site, Huron Mountains. Each horizontal line represents the length of the tree-ring record of a *Pinus resinosa* remnant (stump or standing dead snag). Bold vertical bars represent the year of a fire scar. The composite fire chronology with all fire scar years at the site is shown at the bottom of the figure.

DISCUSSION

Point fire return interval analysis in this study indicated that long intervals occurred earliest in the fire record and intervals shortened markedly between 1752–1891 (Figure 2). The abrupt increase in fire frequency identified in this study was similar to that reported by Torretti (2003) at a site within 20 km of the Huron Mountain Reserve. Furthermore, the MFI was similar in both studies, with this study reporting 49 yr pre-1752 and Torretti reporting a pre-1750s MFI of approximately 50 yr. After 1752 the MFI decreased to 18.5 and 16.7 for the two areas, respectively. Despite the similarity in MFI, fires occurred at both places simultaneous only three times, in the years 1791, 1862, and 1891. The 1862 and 1891 fires were most likely Euro-American influenced, a conjecture based on considerable tree mortality occurring circa 1862, possibly indicating Euro-American logging.

The temporal variability in fire at both the HMR and the Torretti study area revealed an apparent increase in fire occurrence coinciding with the

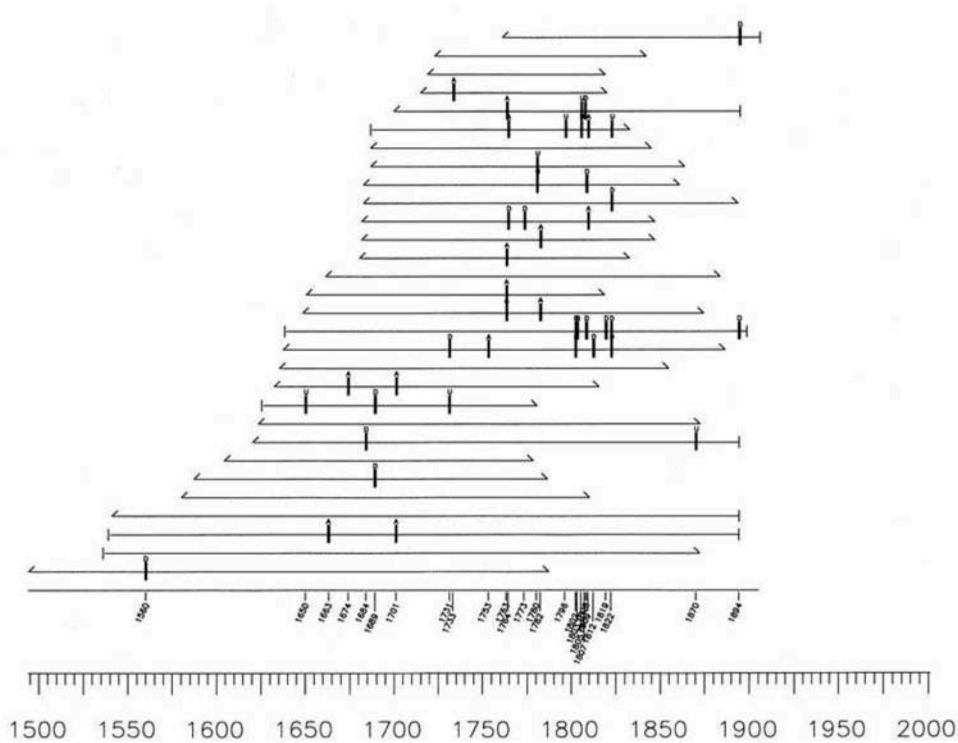

FIGURE 6 The BRT (higher elevation, granite knob) fire history from Huron Mountains. Each horizontal line represents the length of the tree-ring record of a *Pinus resinosa* remnant (stump or standing dead snag). Bold vertical bars represent the year of a fire scar. The composite fire chronology with all fire scar years at the site is shown at the bottom of the figure.

timing of Native American Indian habitation, an increasingly important factor in the Great Lakes region from the mid-1700s until the abrupt cessation in fire after 1891 (Loope & Anderton, 1998). Loope and Anderton (1998) also found that surface fires occurred every 5 to 20 yr in most cases, with fires beginning as early as the 1700s but ending abruptly almost everywhere in the region between 1910 and 1925. Using corroborating archaeological and ethnographic data as well as comparing with the estimate of lightning strikes data, Anderton (1999) suggested that a majority of the fires before 1910 were set by Native populations.

The comparison of our results with those of other regional fire history studies suggests few of the fires were widespread such that multiple areas across the Upper Peninsula of Michigan were affected. Common fire years with the Seney National Wildlife Refuge area (roughly 200 km east of the HMR) include only 1754 and 1791 (Drobyshev et al., 2008, 2012). Dobryshev et al. (2012) defined these as climate driven, major fire years, but the 1754 fire at HMR occurred at only one site (lower slope of a granite knob), scarring

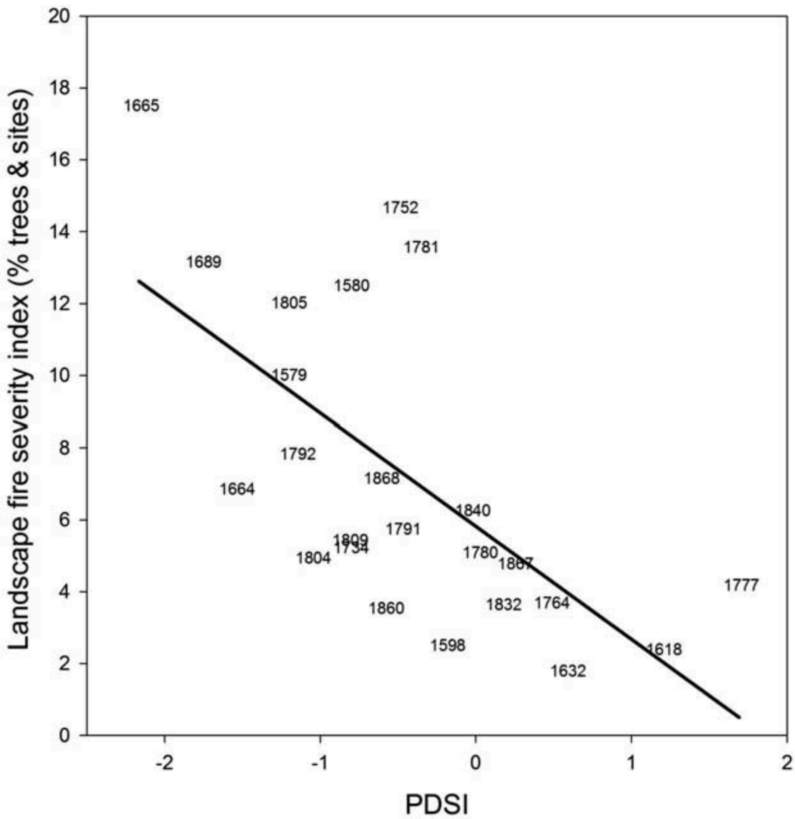

FIGURE 7 Regression line describing the relationship between drought (Palmer Drought Severity Index—PDSI) and Landscape Severity Fire Index (LFSI) in the years in which fire occurred between 1665 and 1868. Negative values of PDSI represent drought years. The regression line is described by: LFSI = 5.821 −(3.14 × PDSI); $r^2 = .42$, $n = 24$, $p < .05$.

only 3% of all trees sampled. The 1791 fire occurred at HMR only on the low dune area adjacent to Lake Superior. However, this fire scarred 70% of the trees sampled at this site, indicating a severe, albeit not mortality causing, event. The limited number of fires at the regional scale suggests that climate does not influence fire consistently in the region.

The importance of drought may be apparent with temporally synchronous fire events and with high severity events. A fire at RSH site in 1665 and at the PLK site in 1664 during drought (Figure 7) appears to have been a high-scarring, possibly stand-replacement event, based on recruitment in the years following (Figure 5). It is possible that the fire(s) of 1664–1665 represented a spatially extensive event that played an important role in maintaining and initiating pine-dominated areas of the Huron Mountains for the centuries afterward, particularly those stands occurring at lower elevations. The occurrence of a scar within a ± 1-yr period could

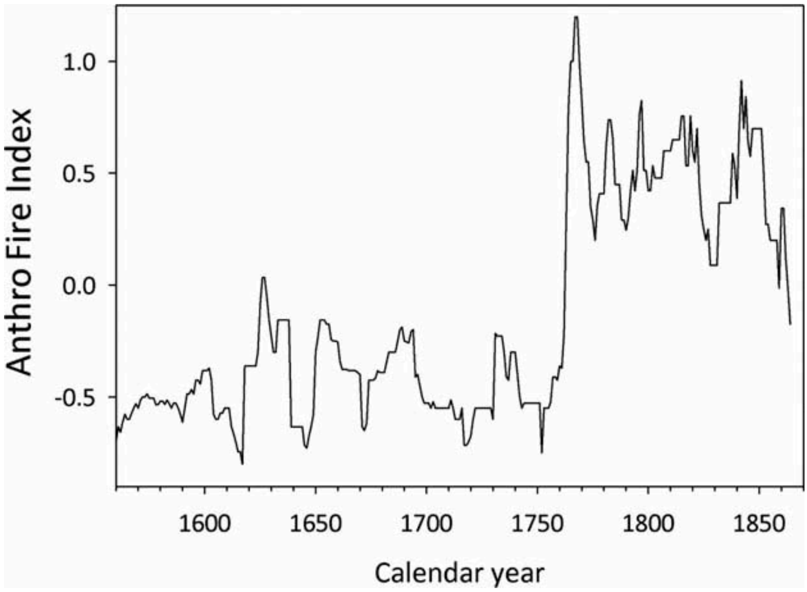

FIGURE 8 A 21-yr moving average of the Anthro Fire Index (AFI) across the time period of 1560–1865. The AFI is derived from fire occurrence and climate data. See text for explanation of AFI calculation.

be due to several factors including: (a) occurrence of different fire events; (b) single, long-duration fires that may burn throughout the growing season and into portions of the dormant season; and (c) differences in the duration of tree growth at the beginning and end of the growing season leading to slight differences in timing of scarring between and within sites. The second explanation may be the most likely at the HMR.

Such extensive fires are commonly associated with drought years. The 1664–1665 fire(s) reported above correspond to evidence of a 1664 stand replacing fire at a *P. resinosa* stand near Grindel Lake (Oconto County) in northeastern Wisconsin (Guyette et al., unpublished report). Furthermore, this fire year was also recorded at many other places in eastern North America, likely associated with drought conditions that covered the majority of the central and eastern United States (Cook et al., 2004). The fire years of 1780 and 1781 appeared in the fire record at six of the study sites at HRM. Fire during 1780–1781 corresponded with a large-scale drought occurring in 1780 that resulted in many fires throughout the eastern United States (Cook et al., 2004; McMurry, Stambaugh, Guyette, & Dey, 2007), and drought effects often occur over multiple years.

We found a preponderance of late-season fires at the HMR, and Drobyshev et al. (2008) found a slight prevalence of late-season fires, but indicated that large fires tended to be late-season events. Precipitation is relatively evenly distributed throughout the year, but snowpack can be substantial during the winter, and therefore in many years early-season fires would be unlikely. Both natural and human ignitions may be responsible for fire in the late season given that it is the driest time of year.

Fire frequency and spatial extent appear to be mediated by landscape position or topographic roughness in the HMR, but only a few studies have examined topographic roughness and fire frequency (Guyette et al., 2002; Stambaugh & Guyette, 2008b). Although there were too few replicates of landform types to identify a statistical association between landform, topography, and fire interval, the association between fire interval and landform type can be inferred. The fire histories at level, lakeshore areas—e.g., PLK, CRN, and RSH—indicate repeated fires where a majority of trees were scarred, suggesting widespread events. The level landscape likely facilitated movement and spread of these fires. By contrast, the higher elevation, granite knobs likely create topographic variability that physically impeded fire spread owing to dissection by moist, shaded drainages as well as interspersion of bare rock, as suggested by low synchrony of fire scars at those sites—e.g., BRT (Figure 6).

Fire intensity often decreases as fires move down slope from lightning ignitions, which are more probable high on the landscape. Given that lightning ignitions typically occur in conjunction with high humidity and rain, such fires were likely to have lower intensity and severity and spread in a patchy manner over a smaller area. In contrast, purposeful human ignitions were likely conducted under conditions of relatively low fuel moisture and adequate wind to achieve intended fire spread and effects. Frequency of human ignitions was presumably greater at low elevations near the lakeshore, which provides a logical location for villages (Christy, 1929; Anderton, 1999).

Despite evidence for the influence of topography and climate on fire frequency, severity and extent, we found evidence that humans can override these factors with intentional burning. Although strong inference suggests lightning-initiated fires at the BRT (granite knob) site, a documented human caused fire event in 1894 (Christy, 1929) at the BRT caused extensive mortality and conversion to an early successional stage (Table 1). The prevalence of trees at this site with a “death date” (last annual growth ring present on tree) of 1894 suggested an unusual high severity fire. Otherwise, fires at BRT appear to have been low severity, judging from the low percentages of trees scarred in a given year. Aside from the 1894 event, previous fires at BRT and similar *Pinus-Quercus* granite knobs may have had very little effect on stand structure. These fires scarred few trees (less than 10% and often as low as 3%) in any years.

Anthro Fire Index values (AFI) suggest an abrupt increase in fire frequency during the mid-1700s. Prior to 1752 there were fewer fires than expected in dry years and after 1752 there were more fires than expected in wet years (Figure 8), suggesting the increased influence of human ignitions during the later period. The Anthro Fire Index values from this analysis mirrors changes in human population and culture commonly associated with eastern North American fire regimes (Guyette et al., 2002, 2006). Although the AFI uses only fire and climate data, and is therefore independent of other historic information, an increasingly important factor in the Great Lakes region from the mid-1700s until the abrupt cessation in fire after 1891 (Table 3), discussed further below. There were more fires in wet (non-drought) years after 1752, suggesting human ignition, and fewer fires than expected in drier years before 1752. Therefore, despite a predisposing climate, there were limited ignitions and therefore limitations to fire before 1752 (Figure 8). The observed decoupling of drought and fire frequency suggests that humans mitigated the influence of climate after 1752 through intelligent, deliberate ignitions.

Within and beyond the HRM, regional cultural and social circumstances account for the changing fire regime during the mid-1700s. Two of the most important and likely causes of this abrupt change were the fur trade and migration of indigenous Native Americans westward as part of the Great Dispersion, at which time Native people (e.g., Ojibway, Anishinabe) were displaced by other groups (e.g., Iroquois and Euro-Americans; Table 3). The fur trade and movement of Native Americans would have resulted in significant increases in human activity and could affect the frequency of ignitions. The fur trade near Lake Superior, involving both Euro-Americans and Native Americans from other areas, was thriving ca. 1755 with hundreds of packs of pelts moving eastward, and the peak of the fur trade in Montreal occurred in 1750. Harris and Matthews (1987) specifically identify trade routes traversing the Upper Peninsula of Michigan. All those involved in fur trading, trapping, and other activity would certainly rely on fires during that time, for everything from cooking to warmth, likely resulting in a high frequency of escaped fires.

Although most of the forestlands in HMR and throughout the East are under a predominantly fire suppression regime, there are implications of these findings for forest management. This research identified the need for caution in associating a reference disturbance regime for restoration efforts. This research also aligned the contemporary forest conditions with the past disturbance history, whereby we could identify some of the effects of the fire events of the past few centuries. Insofar as fire history reconstruction represents de facto stand reconstruction, it is possible to understand more about fundamental importance of fire in the disturbance regimes in the northern hardwood forest particularly as it may be influenced by climate.

In conclusion, fire at the HMR prior to the 20th century was temporally and spatially variable across the entire landscape of the HMR, dictated by a complex interaction of human activity, topography, and climate. Both human and lightning ignitions have been important sources of fire within

TABLE 3 Characterization of the Three Temporal Phases Corresponding With the Changing Influences of Human Activity on the Fire Regime

Data type	Variable	Temporal Fire Regime Phase		
		1751 and earlier	1752–1897	1897–2000
FD	MFI for all sites	49 yr*	18.5 yr*	> 78 yr
FD	Mean # of small fires	9	16	1
FD	Mean # of large fires and (MFI) per 2-yr period[1]	4 (45 yr)	9 (16.5 yr)	0 (> 105 yr)
FD	Percent dormant season fires	21%	39%	NA
SD	Mean PDSI (all years)	0.12	0.11	NA
SD	Mean PDSI (fire years)	−1.58	−0.42	NA
SD	Individual tree rings of record	12,468	11,864	850
FI	AFI (Figure 8)	−0.31	0.69	NA
FI	LFSI (mean)	62	34	NA
HD	Michigan population[2]	< 310 settlers + Native populations	511,643	NA
HD	Cultural and geopolitical identities	New France, Louisiana, Nocquet, Mishinimaki, Menominee, Anishinbae	1763 to British 1797 to U.S., Nocquet, Mishiniamki, Menominee	Private ownership
HD	Land use	Seasonal occupation and subsistence	Fur trade, subsistence	Logging, recreation
HD	Archaeology sites[3]	Few (1600–1730)	Several (1730–1870)	NA
HD	Native American villages and population for given time periods along the south shore of Lake Superior[3]	2 100–1,000 (1679–1755)	6 500–300 (~1,820)	NA
HD	# furs traded to France[3]	~400,000 (1718–1748)	~1,200,000 (1749–1760)	NA

Note. Date sets include fire data (FD), human data (HD), fire indices (FI), and supporting statistical data (SD) to describe the variable influences on each temporal phase; the Anthro Fire Index (AFI) spans 300 yr (1560–1860); the Landscape Fire Severity Index (LFSI) is filtered (> 6.5% fire scars).
[1]Two-year time period used to account for large fires that might continue from a summer growing season (year x) to a dormant season; a dormant season scar may appear to be associated with the next growing season (x+1). [2]Coulson and Joyce (2003); Terrell (1971). [3]Harris and Matthews (1987).
*Represents significant difference of MFI at 0.01 using student's t-test.

particular contexts of landscape and history. While drought can affect fire size and severity, humans can have an additive if not overriding effect of fire regime. Despite evidence in this and other studies for the overarching influence of physiochemical attributes and climate on fire frequency (Guyette, Stambaugh, Dey, Muzika, 2012), the role of human activity—whether suppression or ignition—represents a major factor in identifying historic and contemporary fire regimes. Our findings at the HMR underscore the necessity of considering fine-scale (i.e., site level) physical factors and local history in the context of regional trends in climate and human activities to accurately understand fire history.

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