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Historic fire regime dynamics and forcing factors in the Boston Mountains, Arkansas, USA

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Abstract

We used dendrochronological methods to construct three fire history chronologies in the interior of the Boston Mountains of Arkansas from 281 dated fire scars identified on 86 shortleaf pine (*Pinus echinata*) remnants and trees. We describe and contrast these interior sites with sites on the southern perimeter of Boston Mountains that were documented in an earlier study and examine human, topographic and climatic spatial and temporal controls on these fire regimes. Fire frequency and human population density at the interior sites were positively correlated during an early period (1680–1880) of low levels of population, but were negatively correlated during a later period (1881–2000) as human population levels increased to a much higher level. Wide spread fire occurred more often during drought years in the 1700s with fires likely achieving sizes unprecedented during the last century. The early (before 1810) fire scar record showed that fire intervals were about three times longer (MFI = 35 years) at the interior sites than at the perimeter sites. Early transitional (1810–1830) settlement by Cherokees at population densities under 0.26 humans/km^2 was highly correlated ($r = 0.90$) with the number of fires per decade in the interior region of the Boston Mountains. Multiple regression analyses further implicated humans as well as short- and long-term climate variability such as forced by the El Niño/Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO).

Keywords: Ozarks; Dendrochronology; Human population; Fire scar; Climate; Drought; ENSO; AMO

1. Introduction

The relationships between humans, topography, climate and wildland fire are complex and becoming increasingly important in the management of fuels and fire regimes. This paper addresses the history of these interactions in the Boston Mountains and to a lesser extent the Ozark Highlands of Arkansas and Missouri using records of fire history derived from dated fire scars and builds upon results from an earlier paper (Guyette and Spetich, 2003). These temporally and spatially explicit fire histories provide perspective and baseline data relevant to forest restoration, fuels management, human and ecological history, and species distributions (Rudis and Skinner, 1991).

Anthropogenic ignitions have overwhelmed the influence of natural ignitions in much of the central hardwood region including the Ozarks (Dey and Guyette, 2000; DeVivo, 1991). Despite 50–70 thunderstorm days per year (Baldwin, 1973), only about 1–5 natural ignitions per year occur per 400,000 ha (Schroeder and Buck, 1970). In contrast, humans have caused an average of 105 fires per year per 400,000 ha in the Ozarks of southern Missouri (Westin, 1992) and in Arkansas (USDA Fire Statistics). Human population density and topography have been characterized as important variables for understanding temporal changes and interactions in anthropogenic fire regimes (Guyette et al., 2002). For example, introduced European diseases are hypothesized to have decimated many Native American populations in the Arkansas River valley (Rollings, 1995) and consequently may have reduced the frequency of anthropogenic fires.

Climate change and drought occurrence have been shown to affect the frequency and extent of wildland fires over yearly to century long time scales (Brown and Sieg, 1996; Caprio and Swetnam, 1995; Donnegan et al., 2001). Most of these studies document changing climate–fire relationships in the western United States with very few studies documenting fire or climate changes in the eastern or midwestern United States (Dey et al., 2004; Schuler and McClain, 2003; Shumway et al., 2001).

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The goals of this study were to describe the frequency, forcing and extent of fire during the last 320 years in oak-pine forests in the interior of the Boston Mountains. We examined how human population, topographic roughness and climate have affected this fire regime, especially during the ignition limited period (Guyette et al., 2002) when burning was less influenced by fire suppression and land use change.

2. Methods

2.1. Study sites

The Boston Mountains of Arkansas are classified into Lower and Upper ecological subsections (Foti, 2004). Three study sites in the Ozark National Forest (Fig. 1, Table 1) were located in the Upper ecological subsection or interior of the Boston Mountains about 22 km north of the Arkansas River Valley. The study sites were selected by consulting Forest Service district personnel on the location of stands with shortleaf pines and remnant wood. From surveys of these sites, three sites (separated by as much as 40 km) were selected based on the number, soundness, and age of shortleaf pine trees and remnant wood. The study sites were limited in area as much as possible to approximate point mean fire intervals that are unaffected by both scarring rates and site area (Baker and Ehle, 2001). The interior of the Boston Mountains is forested and very little non-forest agricultural activity occurs in the region. Forest vegetation is mixed hardwood-pine dominated by oak (*Quercus* spp.) and shortleaf pine (*Pinus echinata*) species. The climate is humid and continental with mean winter minimum temperatures of −2.2 °C and mean summer maximum temperatures of 32.8 °C. Mean annual precipitation is 125 cm. The interior Boston Mountains are topographically rough with hillsides 350 m in elevation and slopes of 20–30°. The region is comparable to Appalachia in roughness but not in absolute elevation.

2.2. Sample collection and processing

Shortleaf pine was selected in preference to other tree species because of the length of record, the scars have charcoal, the preservation of wood, and the sensitivity of the species to scarring. Samples were selected based on age and soundness. Locations (GPS coordinates), slope, and aspect were taken at each tree site. Cross-sections from shortleaf pine trees, cut stumps, and natural remnants were surfaced, measured, and cross-dated. Surfaces of cross-sections were sanded with successively finer sandpaper (220–1200 grit) and ring widths were then measured on two radii. Ring-width series from each sample were plotted and used for visual cross-dating and signature year identification (Stokes and Smiley, 1968). A master dating chronology was constructed from the tree-ring measurements (Stambaugh and Guyette, 2004). The samples and dating chronology were cross-dated and verified with shortleaf pine chronologies from Missouri (Guyette, 1996; Stambaugh and Guyette, 2004) and Arkansas (Dewitt and Ames, 1978). Computer program COFECHA (Holmes et al., 1986; Grissino-Mayer et al., 1996) was used to ensure the accuracy of cross-dated tree-ring series.

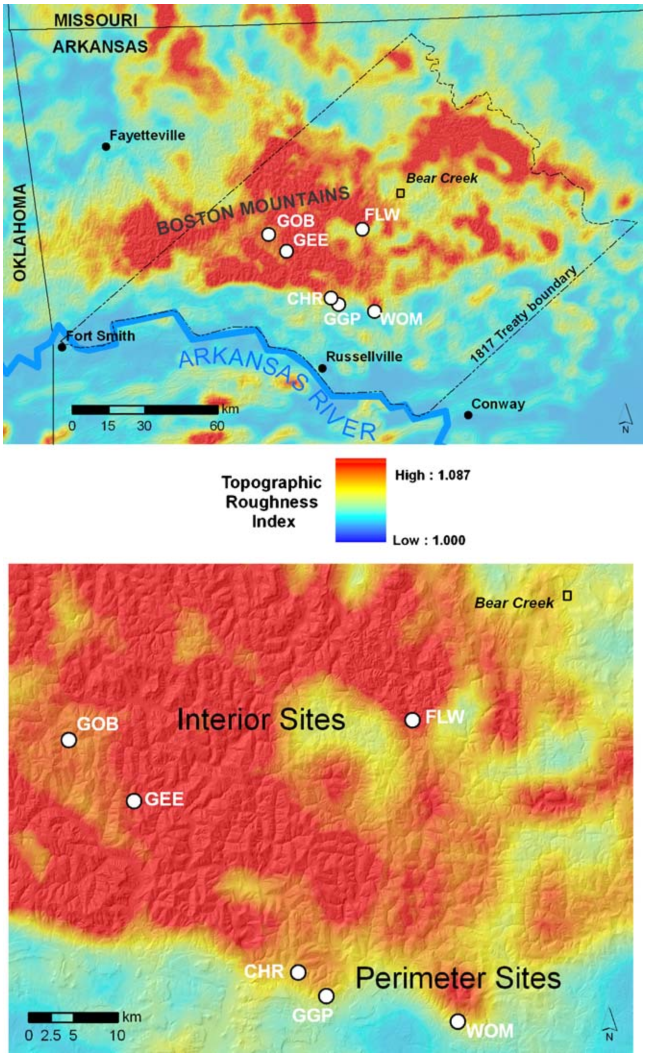

Fig. 1. Top: map of topographic roughness index (see Section 2 for explanation) for the northwest portion of Arkansas. Fire history study sites and codes are given in white (GOB = Gobbler's Knob, FLW = Falling Waters, GEE = Gee Creek). Codes for sites from a previous study are CHR = Chigger Road, GGP = Granny Gap, WOM = White Oak Mountain. This study's sites are located in the Boston Mountains in an area (dashed line) given by treaty to the Cherokee in 1817 (Pitcaithley, 1978). Bottom: this enlarged view of interior and perimeter Boston Mountains fire history sites shows the topographic roughness indices with hill shade and portrays the dissected topography of interior sites and the proximity of the perimeter sites to relatively smooth topography of the Arkansas Rive valley. The black square represents the region of former Cherokee settlement along Bear Creek.

2.3. Fire scars and chronologies

Fire scars were identified by cambial injury, callus tissue, traumatic resin canals, and charcoal. More than 90% of the fire scars were on the uphill side of the bole (Gutsell and Johnson, 1996; Guyette and Cutter, 1997). Fire scars were dated to the year of cambial injury (most often dormant season fires dated to the following growing season).

Table 1
Site and fire characteristics of three fire history sites in the interior of the Boston Mountains, Arkansas

	Site name		
	Gee Creek	Gobblers Knob	Falling Waters
Location	35°31′N, 93°05′W	35°29′N, 93°03′W	35°28′N, 92°53′W
Site area (ha)	50	60	40
Elevation (m)	300–379	404–533	452–529
Ecoregional section, province	Interior Boston Mountains, Ozarks	Interior Boston Mountains, Ozarks	Interior Boston Mountains, Ozarks
Forest type	Oak and pine	Oak and pine	Oak and pine
Number sample trees	34	26	26
Total years of record	5056	3159	3761
Years with fire	61	61	64
Number of fire scars	99	91	91
Period of record	1587–2003	1616–2003	1706–2004

Experiments have shown that a 15–20 min exposure was required to kill the cambium under 4 cm of bark when exposed to air temperatures of 532 °C (Lowery, 1968). Thus, fire intensity and duration differences among tree sites make the scarring of trees highly variable. For this reason multiple samples are needed in order to minimize spatial scarring differences due to differences in temperature.

We used computer program FHX2 (Grissino-Mayer, 2001) to generate summary statistics and create tree and composite fire scar chronology graphs and SAS/STAT (2002) system was used for the summaries of means, regression modeling, and correlation analyses. Superposed epoch analysis (SEA) was conducted to determine the association between drought and fire occurrence for the eight fire events with the highest percentage of trees scarred during the pre-Cherokee and European settlement periods (1700–1810) (Swetnam and Baisan, 1996). Fire event data were compared to proxy climate data reconstructed from tree rings to determine if climate was significantly different from average during the 6 years preceding and 4 years succeeding fire events. The proxy climate data used were the reconstructed Palmer Drought Severity Indices (PDSI) (Cook et al., 2004) averaged for the Ozark region (see Section 2.7).

In addition to the three interior Boston Mountain composite fire scar chronologies we used four additional data sets of fire scar chronologies in the analysis. First, we averaged both the percentage of trees scarred per year and the number of fires per decade for the three interior Boston Mountain sites. This created two separate time series that were used in correlation analyses with population and topographic roughness index data. Second, we averaged the percentage of trees scarred and fires per decade data from the three interior Boston Mountain sites with that from three fire scar chronologies from the perimeter of the Boston Mountains (Guyette and Spetich, 2003). This data set was also used for correlation analysis with northern Arkansas climate and human population data. Third, we used published fire scar data from sites in Missouri for a topographic comparison analysis and for a regional Ozark description of fire occurrence in drought years (Cutter and Guyette, 1994; Guyette and Cutter, 1991; Batek et al., 1999; Guyette and Stambaugh, 2003a,b; Dey et al., 2004; Stambaugh et al., 2005).

2.4. *Fire intervals*

Fire intervals have been described in several ways. Mean fire intervals (MFIs) are the most often used and are simply the mean of the periods between fire scars (i.e., fire events) in years (Dieterich, 1980). Weibull median fire intervals (WFIs) take into account the often skewed non-normal distribution of fire intervals in calculating a value of central tendency (Grissino-Mayer, 1995). For fire scar history studies the use of MFI and WFI computational methods work well for periods with many intervals but pose problems in early and less homogenous (with respect to fire frequency) periods. One analysis approach (Grissino-Mayer, 2001) is to omit the tree-ring record of trees until they are first scarred. However, when early portions of fire chronologies are not considered because of no or few fire events despite having multiple potential recording trees present then the analysis of fire frequency using MFI or WFI statistics can be misleading. Furthermore, when many recorder trees (trees that are scarred) show no fire in the early periods of record (as occurred in this study) we suggest this likely can be interpreted (from the data) as a period of no or few fires. For example, in this study at the Falling Waters site (FLW), the period 1740–1810 has only one fire scar and the resulting MFI and WFI would be missing for this 680 years of individual tree tree-ring records. If there were two closely spaced fire scars the MFI could be 2 years. Not considering the period of record prior to an initial fire scar suggests that the tree was not susceptible to fire and contradicts the findings that smaller trees scar more easily (Guyette and Stambaugh, 2003c; results later in this study), and is a violation of the scientific method (manipulating the data based on unproven and preconceived ideas). Thus, in attempt to consider the full period of the tree-ring record we used a mean fire occurrence period (MFOP) defined as a period of time divided by the number of fire events in the composite fire scar chronology. The MFOP statistic better describes the frequency of fire when the lengths of intervals are changing or there are very few scars but is nearly identical to mean fire interval when the fire scar record has many scars during a given period of record. Correlation analysis was used to relate fire frequency (MFIs, WFIs, MFOPs, fires per decade) to topographic roughness indices, human population density, and climate. Multiple regression analysis was used to develop equations describing the variability of both the percent of trees scarred and fire frequency from topographic roughness, human population density, and climate variables.

2.5. Topographic roughness

Irregularities in the landscape surface, or topographic roughness, can contribute to the spreading behavior of fire in an area of highly dissected topography. The rate of spread of a low intensity surface fire may decrease because fire burns slower down steep slopes; because fuel continuity is broken by creeks, rivers and rocky outcrops; or because fuel moisture content varies by aspect. Fire size, as mitigated by topography, affects the frequency of fire spreading into a site. Indices of topographic roughness were used to reflect topographic inhibition of the propagation of fire across the landscape. Indices of topographic roughness were developed by comparing surface area measurements made with two different sized scales (Guyette and Dey, 2000; Guyette and Kabrick, 2002). A circular area, 2.7 km in radius was delineated for all cells using a 30 m digital elevation model. The surface area of the earth circumscribed by this circle was calculated from pixels that are 30 m on a side. Their slope and a trigonometric conversion were used to estimate the area of the uneven land surface. The pixels were summed to estimate the surface area of the landscape enclosed by the circle. This measure was then divided by the planimetric surface area (the large scale in this case) of a circle that is 2.7 km in radius. This ratio of the actual surface area to the planimetric surface area is an index of topographic roughness (Fig. 1). Correlation analysis was used to document changes in the influence of topographic roughness on mean fire intervals by stage of the anthropogenic fire regime.

2.6. Human population density

Human population data were derived from decadal Arkansas census data and population estimates (Coulson and Joyce, 2003). Historical estimates of Cherokee population west of the Mississippi are between 3500 and 6000 in Southeast Missouri and later in Northwest Arkansas (Royce, 1899; Gilbert, 1996). During the winter of 1811–1812 many Cherokee moved from Missouri to Arkansas and their population in northwest Arkansas increased to about 4500 (Stevens, 1991). By treaty, in 1817, they were granted an area of about 15,570 km^2 between the Arkansas and White Rivers (Fig. 1) (Pitcaithley, 1978). In 1828, the Cherokee moved west to Oklahoma. Thus, population density of the Cherokee in the ceded territory peaked at about 0.29 humans/km^2 in the 1820s. The fire history study sites are located in the Cherokee lands and near (10–30 km) one of the former Cherokee village sites on Bear Creek (Fig. 1). Linear interpolation was used to calculate annual population density from decadal census data and above-mentioned population data were used to calculate pre Euro-American settlement population densities.

2.7. Climate data

We averaged the percentage of trees scarred at the study sites and from three previous study sites located on the perimeter of the Boston Mountains (Guyette and Spetich, 2003) to address the broad scale effects of climate (see Section 2.4). Additionally, we used fire history data from all sites in the Boston Mountains and sites in Missouri for a region-wide Ozark drought-fire analysis (Batek et al., 1999; Guyette et al., 2002). Several hemispheric proxy climate indices and variables were obtained and considered including: the Atlantic Mutidecadal Oscillation (AMO) (Gray et al., 2004a,b), North Atlantic Oscillation (NAO) (Glueck and Stockton, 2001), El Niño/Southern Oscillation (ENSO) (Cook, 2000), North American temperature (Briffa et al., 1998), the Pacific Decadal Oscillation (PDO) (Biondi, 2001), and Ozark region reconstructed Palmer Drought Severity Index (PDSI) (Cook et al., 1999, 2004) as predictor variables. Ozark region reconstructed PDSI data were averaged for Arkansas (gridpoint 202) and southern Missouri (gridpoints 201, 210). In a time-series analysis of fire frequency, drought data were smoothed using a 10-year moving average so to correspond to fires per decade. All data are available from the National Climate Data Center, National Oceanic and Atmospheric Administration.

3. Results

3.1. Fire scars and record

Two hundred and eighty-one fire scars were identified and dated to the calendar year at the three study sites (Figs. 2–4). The period of record ranged from 1587 to 2003. Fire scar dates ranged between 1608 and 2000. The fire scar record and the evidence of fire extended to before 1750 at all of the sites (Table 1). A total of 11,979 tree rings (years) were recorded by the 86 dated woody remnants and trees.

3.2. The early fire record (trees not scarred or few fires)

The age when trees are first scarred reflects their vulnerability to initial scarring based on their diameter. The

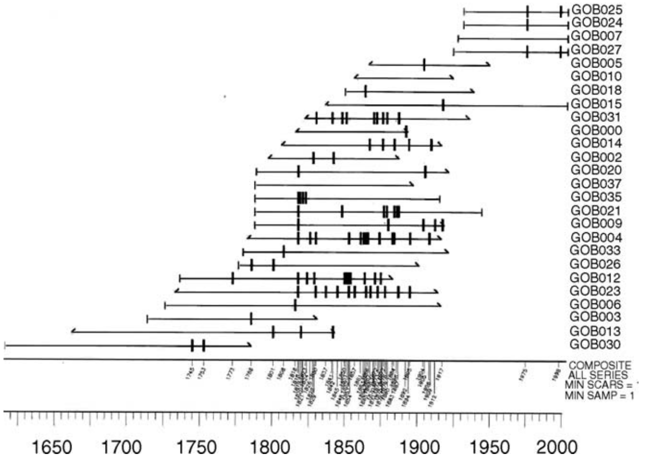

Fig. 2. The Gobblers Knob fire history showing the fire scar dates of individual trees and a fire scar composite chronology (bottom of figure). Each horizontal line represents the length of a trees potential fire scar record.

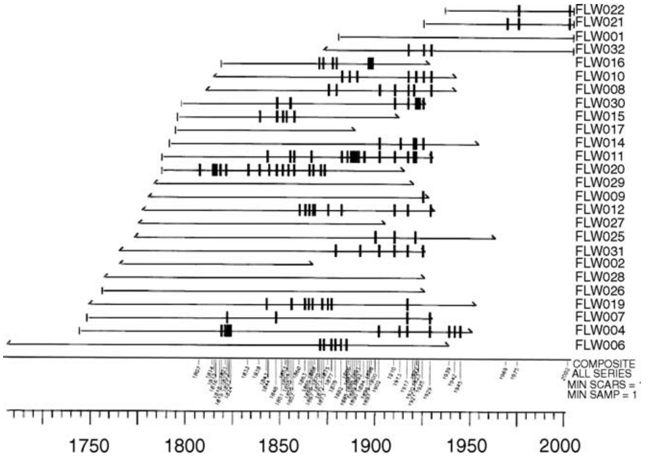

Fig. 3. The Falling Waters fire history showing the fire scar dates of individual trees and a fire scar composite chronology (bottom of figure). Each horizontal line represents the length of a trees potential fire scar record.

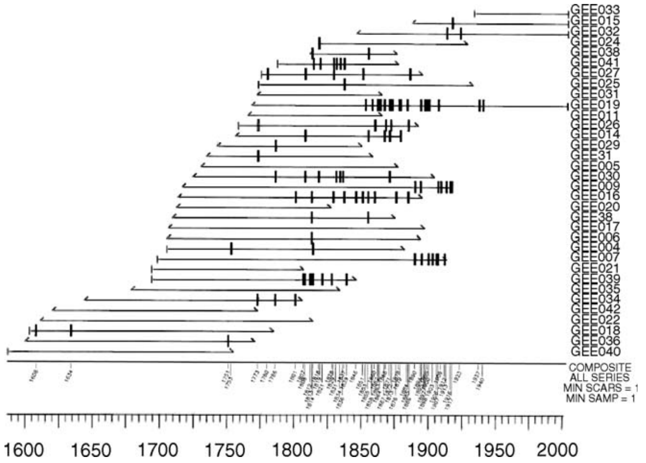

Fig. 4. The Gee Creek fire history showing the fire scar dates of individual trees and a fire scar composite chronology (bottom of figure). Each horizontal line represents the length of a trees potential fire scar record.

best fire recorder trees are small trees that get scarred and survive. We found that 82% of initial scars were on trees that were under 60 years of age (Fig. 5). This information is critical in the interpretation of the early record of many fire scar chronologies. For example, in the Falling Waters fire scar chronology (Fig. 3) more than 60 calendar years and 735 years of record show a single fire scar. Does this mean that the trees are not recording? This is doubtful since most of the trees during this period are at an age (<60 year) and size when they are most vulnerable to initial scarring. Thus, we feel that these trees are recording a period of few fires in the study region. This period of low fire frequency is replicated by the Gee Creek fire scar chronology (Fig. 4).

3.3. Composite fire intervals

Fire scar dates were combined into composite fire scar chronologies for each site (bottom line Figs. 2–4). Composite fire intervals ranged in length from 1 to 117 years. Site level WFIs and MFOPs for the combined sites are given in Table 2. These metrics document the presence of a fire in at least one location within a study site that was of sufficient intensity to scar at least one tree. The fire intervals for the depopulated Native American Period (<1680–1810) at all sites were about 10 or more times longer than the two later periods of Cherokee and Euro-American settlement (1811–1880) and Regional Development (1881–1920). Fire intervals (MFOPs) at all of the interior Boston Mountains sites increased in length abruptly circa 1920 (Table 3).

3.4. Seasonality

Over 90% of the scars were from injuries received during the dormant season or were undetermined as to seasonality. These injuries occurred when cambial growth was inactive, which usually begins in September and ends in mid- to late-April, a period when climate (low humidity, higher surface winds) and fuels (annual input of fresh dry leaf litter, more solar exposure of the litter fuels) favor burning.

3.5. Fire frequency and human population

Fire frequency (fires per decade) at the study sites was found to be positively related to the population of Cherokees moving in and out of the study region (Fig. 6). Beginning circa 1817 the Cherokee began moving to Northern Arkansas by treaty and then in 1829 they moved out of Arkansas to Oklahoma. All three interior Boston Mountain fire scar chronologies show an increase in fires per decade associated with Cherokee population density. A maximum of about seven fires per decade (a MFI of 1.43 years) occurred when Cherokee population density was highest (about 0.26 humans/km^2).

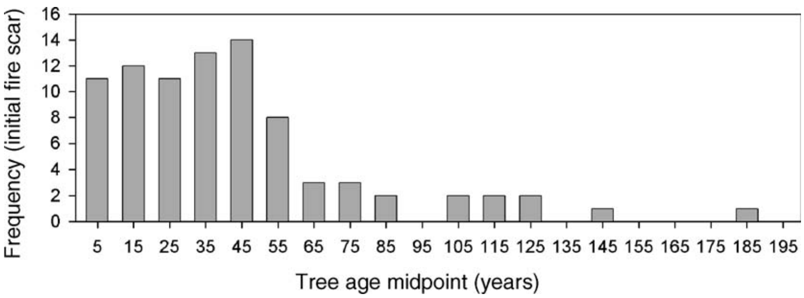

Fig. 5. This frequency distribution of the age of shortleaf pine trees when first scarred illustrates that young trees are the most susceptible to scarring.

Table 2
Periods and characteristics of the fire regime at three sites in the interior of the Boston Mountains

	Period				
	Depopulated Native American	Transitional Native American	Euro-American settlement	Regional development	Fire suppression and timber management
Factors most limiting fire	Ignitions	Ignitions and fuels	Fuels	Fuels	Value of xylem over protein
Dates	~1680–1810	1810–1830	1821–1880	1881–1920	1920–2000
Economic activities	Hunting and gathering	Subsistence agriculture and hunting	Subsistence agriculture and hunting	Regional trade in forest resources and subsistence	Industrial forestry and tourism
Mean human population density (humans/km^2)	0.08	0.65	2.4	9.6	12.6
MFOP (3 site mean)	34.7 years	2.2 years	2.1 years	2.5 years	26 years
Gee Creek WFI	na	2.0	2.2	1.8	na
Gobbler Knob WFI	na	1.4	1.5	2.4	na
Falling Water WFI	na	1.5	3.8	5.4	3.7

The fire scar record for the depopulated Native American period begins at different times (see Table 1). MFOP is the mean fire occurrence period and WFI is the Weibull median fire interval. Weibull distribution estimates are not applicable (na) for early and late periods with no or few clumped fire event dates.

Table 3
Comparison of fire regimes and variables for the interior and perimeter Boston Mountain fire history sites

	Fire site code					
	GEE	GOB	FLW	GGP	CHR	WOM
Distance to the perimeter of the Boston Mountains (km)	13	23	30	1.5	2	2
Topographic roughness (index)	1.039	1.034	1.042	1.028	1.022	1.021
MFOP (before 1810) in years	22.2	22.0	60	5.2	13.9	13
MFOP (before 1820) in years	14.7	15.5	11.6	4.6	13	16
MFOP (1810–1830) in years	2.5	1.8	2.2	4.0	10	6.7
MFOP (1821–1880) in years	2.4	1.7	2.1	3.1	2.0	3.0
MFOP (1881–1920) in years	2.2	3.1	2.1	5.0	1.4	2.4
MFOP (1921–2004) in years	27.7	41.5	7.5	>80	>80	>62

Interior Boston Mountain site codes are GEE for Gee Creek, GOB for Gobblers Knob and FLW for Falling Waters. Perimeter Boston Mountain site codes are GGP for Granny Gap, CHR for Chigger Road and WOM for White Oak Mountain (Guyette and Spetich, 2003). MFOP is the mean fire occurrence period.

Although it is difficult to address the statistical significance of these autocorrelated series because of the dependence of these observations (moving averages and annual population interpolation), the strength of the correlation between fires per decade and Cherokee population was robust ($r = 0.90$) and predicted prior to this analysis.

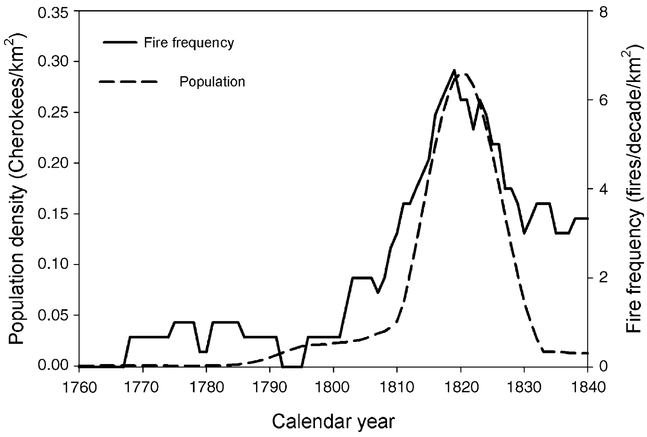

Fig. 6. Comparison of Cherokee population density and fire frequency at the interior Boston Mountain fire history sites. Human population data is interpolated from decadal estimates and fire frequency data is a moving average of the number of fires per decade at the interior Boston Mountain study sites.

3.6. Fire intervals and topographic roughness

The interior Boston Mountain fire history sites are surrounded by very rough topography. This topography is hypothesized to reduce the spread of fire into these sites thereby lengthening fire intervals (Guyette and Dey, 2000). The three interior Boston Mountain sites did not have enough degrees of freedom for a statistical test of the significance of the correlation among mean fire intervals and topographic roughness so we used both Arkansas and Missouri fire history sites for this test. We found that the length of fire intervals during the early fire record (<1750–1810) when anthropogenic ignitions were limited (Guyette et al., 2002) were significantly and positively correlated ($r = 0.78$, $p < 0.01$) with the topographic roughness index (Fig. 7). This analysis included other sites from Arkansas and Missouri (see Section 2.3). Comparisons between interior and perimeter Boston Mountains sites (Table 4) suggest topographic roughness is an important control on the fire regime and caused pre-settlement fire intervals to be longer in the more topographically rough interior.

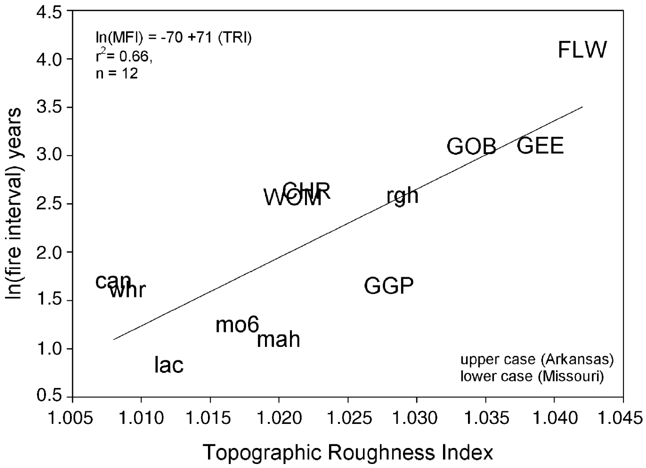

Fig. 7. Log-normal scatter plot of pre-European and pre-Cherokee (1700–1810) fire intervals (mean fire occurrence periods) and topographic roughness at six sites in Arkansas (this study with MFOP compared with MFOP from a previous study (Guyette and Spetich, 2003)) and six sites in Missouri (Batek et al., 1999).

3.7. Fire extent and co-occurrence in the Boston Mountains

Several fires scarred 25 or more percent of the sample trees at the study sites. The highest percentage of trees scarred was in 1818 at Gobblers Knob (57%), in 1813 at Gee Creek (31%), and in 1917 at Falling Waters (67%) sites. The 1917 fire at Falling Waters, which scarred far more trees than usual, could have been a slash fire during disturbance from logging activity. The study sites had several fire years in common during the 1700s although there were no years before 1810 when fires occurred at all the Interior Boston Mountain sites. Before 1810, two-thirds of the study sites showed evidence of fire in 1808, 1801, 1786, and 1753. Many fire years at the interior study sites were years in which there was evidence of fire at the perimeter Boston Mountains sites and in the Missouri Ozarks (Table 5). Years with many fires (>25% sites burned) in the Missouri and Arkansas Ozarks appear to have occurred about every 8.5 years between 1748 and 1808 (Table 5). The most extensive fires occurred in 1780 when 58% of all Arkansas and Missouri sites showed evidence of scarring.

3.8. Fire and climate

Before 1810 the percentage of trees scarred at all Boston Mountain sites was weakly correlated with drought severity and ENSO indices, but not with PDO and AMO (Table 6). Between 1810 and 1910 the percent of trees scarred was significantly correlated with the AMO. A superposed epoch analysis (Swetnam and Baisan, 1996) showed significant patterns in the occurrence of drought during large fire years. Eight of the

Table 4
Comparisons among fire history variables between the interior and perimeter Boston Mountain sites before 1810

	Fire site group							
	Interior Boston Mountains				Perimeter Boston Mountains			
	GEE	GOB	FLW	Interior sites or trees	GGP	CHR	WOM	Perimeter sites or trees
Composite site fire interval (before 1810), MFI range	22.2 (1–117)	14.2 (7–20)	60 (>60)	32.1	5.2 (1–9)	13.9 (6–27)	13 (5–82)	10.7
Site years of record per scar (before 1810)	169	110	780	353	21.9	75.2	83.8	60.3
Scar per year per tree (before 1810)	0.0074	0.009	0.0026	**0.0066**	0.040	0.012	0.014	**0.0177**
Scars per tree (before 1810)	0.62	0.571	0.063	**0.46**	4.86	0.889	0.75	**1.59**

Six sites and 131 trees were used in this comparison. Shaded columns are means for sites or trees and were tested for means (H_O: means are not different). Variables in shaded cells with bold font are significantly different ($p = 0.05$) within rows.

Table 5
Major fire years at the interior Boston Mountain study sites, six sites in the Arkansas Ozarks, and 26 sites in the Missouri Ozarks

Fire year	Arkansas (6 sites) (%)	Interior Boston Mountains (3 sites) (%)	Missouri (26 sites) (%)	Drought condition (PDSI)	Rank	Ozark region mean (%)
1780	66	33	50	Incipient dry, −0.99	1	58
1808	66	66	26	Near normal, −0.46	2	46
1786	66	66	23	Mild drought, −1.14	3	44
1772	50	0	27	Extreme drought, −4.45	4	38
1753	33	66	39	Mild drought, −1.78	5	36
1801	33	66	31	Extreme drought, −4.33	6	32
1800	33	0	27	Severe drought, −3.34	7	30
1748	33	0	20	Mild drought, −1.41	8	26

Rank is by the mean percentage of all Arkansas and Missouri Ozark region sites. Drought is the Ozark region reconstructed Palmer Drought Severity Index (PDSI) (Cook et al., 1999, 2004). More negative values have increasing drought severity.

Table 6
Correlation coefficients among the percent of trees scarred at all the Boston Mountain sites and climate variables

	Percent trees scarred 1680–1810	Percent trees scarred 1810–1910	Percent trees scarred 1680–1910
PDSI	−0.22	−0.20	−0.18
ENSO	−0.25	−0.17	−0.19
PDO	0.05	0.068	0.003
AMO	−0.08	0.31	−0.025

Climate variables are: Palmer Drought Severity Index (PDSI), El Niño/Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Mutidecadal Oscillation (AMO).

years with the largest percent of trees scarred between 1740 and 1810 in the Ozarks of Arkansas and Missouri occurred in drought years that were preceded by wet years (Fig. 8). These eight fire years had an average PDSI of −2.20. Significantly wet years proceeded the eight large fire years by 3 and 4 years.

Multiple regression analyses (including all Boston Mountain sites) indicated that both anthropogenic ignitions and climate are forcing factors in the fire regime of the Boston Mountains. We analyzed fire and climate data during the Ignition Limited Period between 1740 and 1880—a period when widespread burning and frequent ignitions did not inundate the landscape and a positive relationship between human population density and fire frequency was expected (Guyette et al., 2002; Guyette and Spetich, 2003). In addition, we began the analysis in 1740 when all interior and perimeter Boston Mountain sites had a fire history record. The percent of trees scarred at all the Boston Mountain sites during a particular year was a function of population density (an ignition proxy), drought (PDSI) and sea surface temperature (ENSO) as expressed in the following equation:

$$\text{Trees scarred} = 2.24 + 1.21\,(\text{POP}) - 1.3\,(\text{ENSO}) - 0.61\,(\text{PDSI}), \qquad (1)$$

where ‘Trees scarred’ is the percentage of trees scarred, POP is humans/km^2 with a partial r^2 of 0.227, ENSO the El Niño/Southern Oscillation Index with partial r^2 of 0.062, PDSI the Palmer Drought Severity Index with a partial r^2 of 0.025, and a model r^2 of 0.31. The low percent of variance explained by ENSO and PDSI in addition to their autocorrelation cast doubt on their statistical significance, however they are included because of their probable climatic significance.

Fire frequency (fires per decade) was primarily a function of population density (an ignition proxy), the Atlantic Multidecadal Oscillation (AMO), and drought (PDSI) as expressed in Eq. (2) and Fig. 9. For Eq. (2), model significance and degrees of freedom was based on an average autocorrelation ($r = 0.70$) of dependent and independent variables at 10-year lags:

$$\text{Fire frequency} = 1.04 + 1.45\,(\text{POP}) - 1.04\,(\text{AMO}) - 0.56\,(\text{PDSI}), \qquad (2)$$

where ‘Fire frequency’ is the moving average of scars per decade, POP the humans/km^2 (partial $r^2 = 0.83$), AMO the Atlantic Multidecadal Oscillation (partial $r^2 = 0.10$), PDSI the smoothed Palmer Drought Severity Index (partial $r^2 = 0.02$), d.f. = 23, model $r^2 = 0.95$, model significant ($p < 0.05$). Again, the low percent of variance explained by AMO and PDSI combined with their autocorrelated observations calls their statistical significance into question.

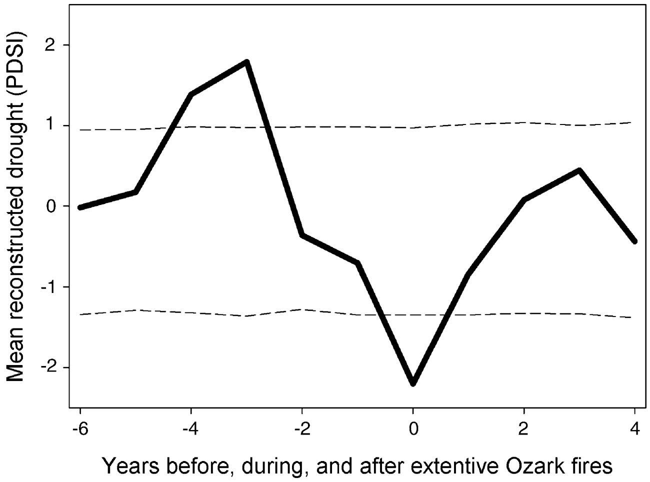

Fig. 8. Superposed epoch analysis showing the serial pattern of drought conditions before and after the eight largest fire years (Table 5) during the pre-Cherokee and pre-European settlement period (1700–1810) at the study sites. The fire years are the zero years. Dotted lines are the 95% confidence intervals.

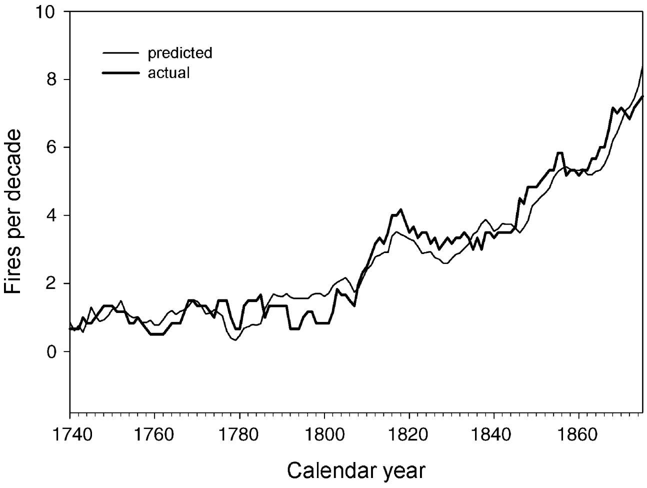

Fig. 9. Actual (bold line) and regression estimates (thin line) of fires per decade (1740–1880) predicted from human population density and climate variables for all sites in the Boston Mountains (Eq. (2)).

4. Discussion

4.1. Fire scars and the early record

The most striking aspect of the fire scar record in the interior Boston Mountains was the reduced evidence of fire compared to sites at the perimeter prior to the movement of the Cherokee into the study area. This evidence is well founded as the interior fire chronologies contained an abundance (4538 years of record) of smaller (more scar susceptible trees) trees during this period. The reduced influence of fire (Table 3) at the study sites in the interior supports the hypothesis that fire frequency in this region was mitigated by the effects of topographic roughness on the propagation of fire from neighboring sites.

Composite MFIs or WFIs are poor descriptors of fire events when intervals are few and incomplete. The MFOP, which closely approximates MFI type intervals during periods with many fire intervals, makes comparisons between sites possible when the record has little evidence of fire. The MFOP metric is particularly well suited for the early part of a tree's record and is made possible by statistics presented here and elsewhere (Guyette and Stambaugh, 2003c) that indicate younger and smaller trees are better recorders of fires than larger diameter trees.

4.2. Seasonality

Nearly all of the fire scars were caused by dormant season injuries indicating that fall, winter, and early spring fires were most common. The only fire scar evidence for the season of burning (i.e., fall versus spring) is speculative. The superposed epoch analysis (Fig. 7) indicates that fires occurred most often in the year of reconstructed drought. This type of response is temporally most closely associated with spring fires which are dated to the calendar year of the drought reconstruction. Fall fires and their subsequent wounding, although dated to the following year's injury response, precede the growing conditions used to reconstruct drought by about half a year (October–April). We expect that fire regimes with primarily fall fires would have scars that would be most strongly associated with the reconstructed drought of the year before a dated injury. The epoch analysis does show that large fire years are often preceded by drier than normal condition (PDSI = -0.70), but this is much less than the drought conditions of the dated scar year. We conclude, based on evidence provided by superposed epoch analysis, that both large spring and fall fires were common in the Boston Mountains.

4.3. Fire intervals and topographic roughness

The pre-settlement fire intervals in the interior of the Boston Mountains are consistent with expectations about the effects of fire propagation as mitigated by topographic roughness. Compared to other Ozark fire history sites the interior Boston Mountain sites are among the most topographically rough and subsequently are associated with long pre-settlement fire intervals. The fire intervals are generally consistent with propagation limited fire regimes found in Arkansas and Missouri in that the relationship between topographic roughness and fire intervals appears to be non-linear (logarithmic *y*-axis, Fig. 6). Topographic controls on the frequency of fire become less important as ignitions become more widespread and frequent with increasing human population density. The data bear this out as fire becomes equally prevalent despite topography after human population reaches greater and greater densities.

4.4. Fire frequency and human population

This study has important implications for the study of fire, humans, and historical vegetation in eastern North America. These implications concern how many Native Americans, with a known culture of burning, were required to maintain a given frequency of fire in a given landscape. Through this concept fire frequency can be a function of human population in time and space. The fire chronologies indicate that population densities of 0.26 humans/km^2 (e.g., Cherokee) can bring fire intervals to less than 2 years in the highly dissected Boston Mountains. These intervals approach the limits on fire frequency caused by fuel accumulation (see fuel limited periods, Guyette et al., 2002) needed to support the propagation of fire across this landscape. This human–fire relationship is important beyond the Boston Mountains. Seldom are data available both before and after Native American occupation that allow for the calibration of fire frequency and population densities in a landscape with moderate resistance to the propagation of fire. If this level of population density can result in a high frequency of fire (MFI = 1.5 years) then it is not difficult to imagine that in much of eastern North America a population density of about this magnitude in a landscape much less topographically rough would have had a major impact via fire on the vegetation and landscape (Batek et al., 1999; Delcourt and Delcourt, 2004).

4.5. Fire extent and co-occurrence in the Boston Mountains and the Ozarks

The extent of fires that burned during severe drought conditions in the Arkansas and Missouri Ozarks during periods of low human population has not been addressed before. Assuming the study sites are representative of the Arkansas and Missouri Ozarks (sites were not randomly chosen), then this landscape had rotation intervals for large-scale fires that approached phenomenal. Between 1748 and 1810 the Ozarks sites in Arkansas and Missouri were burned over 310% in 60 years (Table 5). This yields a rotation interval of about 19.3 years for fires that occurred under moderate or severe drought conditions. In other words, an area the size of the Ozarks (12,950,000 ha or 50,000 mi^2) burned about every 20 years. Although the Ozarks are often characterized as having a fire regime of frequent low intensity surface fires, we should add to this that fires occurred over large sections of the Ozarks (an 8.5 year mean fire interval for large-scale fires) during moderate to extreme drought years. Because of the association between fire size and severity many of these fires may have been classed as mixed severity.

Large fires (with mixed severity) may have contributed to the dominance of oak species in the Arkansas Ozarks. Fires are likely to suppress tree species that are significant competitors to oak and to open forest canopies, thus increasing the competitive capacity of oaks relative to fire susceptible competitors (Spetich, 2004). Based on General Land Office survey records from the early 1800s Foti (2004) found that oak represented 70% of the survey record trees in the Boston Mountains. These communities were also more open than today. These conditions are consistent with that expected after frequent and periodically severe fires described above.

4.6. Fire and climate

We analyzed the possible forcing of both fire frequency (fires per decade) and the percent of trees scarred by climate variables. Although large fire years occurred in drought years as discussed above, many drought years ($\text{PDSI} < -2.0$) such as 1742, 1767, 1785, and 1799 had little or no occurrence of fire. Since both dry fuels and ignitions are required to produce a wildland fire the forcing of fire by climate was expected to be dependent on anthropogenic ignitions.

Climate was found to be significantly related to both fire frequency and the percent of trees scarred. Although, we found weak and often transient correlations between fire and proxy climate variables (Table 6), multiple regression analysis enabled the examination of climate and fire variable residuals after the influence of human ignitions was removed. The percent of trees scarred model (Eq. (1)) indicated that both ENSO and PDSI may have an effect on the percent of trees scarred in a year. The small response of the percent of trees scarred to climate compared to many fire regimes in western North America is probably due to the lack of ignition during many of the drought years, the asynchrony of the fire season (dormant season) and the growing season based drought reconstructions, and the mitigation of surface fire propagation by topographic roughness. The analysis of changing fire frequency (Eq. (2)) using stepwise multiple regression showed that two proxy climate variables: smoothed PDSI and the AMO were predictors of fires per decade in addition to human population density. The AMO is hypothesized to be related to midwestern drought and possibly the frequency of fire (Gray et al., 2004a). These results suggest that drought as influenced by low frequency climate cycles such as the El Niño/Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO) serves to amplify the frequency of fire and the percent of trees scarred in the Ozark region.

5. Conclusion

This study found that fires occurred less frequently in the interior of the Boston Mountains in comparison to the perimeter during the pre-settlement era. The difference between the interior and perimeter sites suggests that topographic roughness limited the propagation of surface fires when the fire regime was ignition-limited but not after settlement when human ignitions became spatially abundant. However, due to the small sample size and area covered by the interior sites (3 sites and 86 trees) these results may not be applicable across the whole interior of the Boston Mountains. After Euro-American settlement, differences in fire frequency between interior and perimeter sites were no longer significant as all sites burned equally frequent ($\text{WFI} < 2.5$ years).

Fire frequency was strongly associated with the timing and location of human populations and their associated ignitions below a threshold population level (4.46 humans/km^2) that was exceeded in the Boston Mountains circa 1880. Above this population threshold more humans are associated with decreasing fire frequency. Historically, a small group of Native Americans, the western Cherokees, that occupied northern Arkansas by treaty between 1817 and 1829 are associated with a peak in fire frequency of about 6.7 fires per decade ($\text{MFI} = 1.5$ years) at a population density of about 0.26 humans/km^2. This short mean fire interval may reflect a concerted silvicultural effort to culture a less densely forested landscape.

We found that drought and large-scale circulation patterns (e.g., AMO and ENSO) exhibit probable forcing of the Boston Mountain fire regime. Although, climate effects proved to be much less important than human effects, large fire years during early periods of low population density were strongly climate influenced, particularly by drought. Fires during these drought years burned large areas (26–58%) of the Arkansas and Missouri Ozarks at frequent (about every 8.5 years) intervals. Because the size of fires and their severity are often highly correlated we speculate that during large Ozark fire years mixed severity fires occurred across the landscape.

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References

Baker, W.L., Ehle, D., 2001. Uncertainty in surface-fire history: the case of ponderosa pine forests in the western United States. Can. J. For. Res. 31 (7), 1205–1226.

Baldwin, J.L., 1973. Climates of the United States. US Department of Commerce, NOAA, Envir. Data Service, Washington, DC, 113 pp.

Batek, M.J., Rebertus, A.J., Schroeder, W.A., Haithcoat, T.L., Compas, E., Guyette, R.P., 1999. Reconstruction of early nineteenth century vegetation and fire regimes in the Missouri Ozarks. J. Biogeog. 26, 397–412.

Biondi, F., 2001. North Pacific decadal climate variability since AD 1661. J. Climate 14 (1), 5–10.

Briffa, K.R., Jones, P.D., Schweingruber, F.H., Osborn, T.J., 1998. Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature 393, 450–455.

Brown, P., Sieg, C.H., 1996. Fire history in interior ponderosa pine communities of the Black Hills, South Dakota, USA. Int. J. Wildland Fire 6 (3), 97–105.

Caprio, A.C., Swetnam, T.W., 1995. Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. In: Brown, J., Mutch, R., Spoon, C., Wakimoto, R. (Tech coord.), Proceedings: Symposium on Fire in Wilderness and Park Management: Past Lessons and Future, Missoula M.T. INT_GTR_320. Ogden UT.

Cook, E.R., 2000. Niño 3 Index Reconstruction. International Tree-Ring Data Bank. IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series #2000-052. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Cook, E.R., Meko, D.M., Stahle, D.W., Cleaveland, M.K., 1999. Drought reconstructions for the continental United States. J. Climate 12, 1145–1162.

Cook, E.R., Woodhouse, C.A., Eakin, C.M., Meko, D.M., Stahle, D.W., 2004. Long-term aridity changes in the western United States. Science 306 (5698), 1015–1018.

Coulson, D.P., Joyce, L., 2003. United States state-level population estimates: colonization to 1999. USDA Forest Service General Technical Report RMRS-GTR-111, 55 pp.

Cutter, B.E., Guyette, R.P., 1994. Fire history of an oak-hickory ridge top in the Missouri Ozarks. Am. Midl. Nat. 132, 393–398.

Delcourt, P.A., Delcourt, H.R., 2004. Prehistoric Native Americans and Ecological Change. Cambridge University Press, UK, 203 pp.

DeVivo, M.S., 1991. Indian use of fire and land clearance in the Southern Appalachians. In: Novin, S., Waldrop, T. (Eds.), Fire and the Environment: Ecological and Cultural Perspectives. USDA Forest Service General Technical Report SE-69, 429 pp.

Dewitt, E., Ames, M., 1978. Tree-ring Chronologies of Eastern North America. Chronology Series IV, Lab. of Tree-Ring Research, vol. 1. University of Arizona, Tucson, AZ.

Dey, D.C., Guyette, R.P., 2000. Sustaining oak ecosystems in the central Hardwoods Region: lessons from the past-continuing the history of disturbance. In: McCabe, R., Loos, S. (Eds.), Transactions of the 65th North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Washington, DC, pp. 170–183.

Dey, D.C., Guyette, R.P., Stambaugh, M.C., 2004. Fire history of a forest, savanna, and fen mosaic at White Ranch State Forest. In: Spetich, M.A. (Ed.), Upland Oak Ecology Symposium: History, Current Conditions, Sustainability. USDA Forest Service General Technical Report SRS-73, pp. 132–137.

Dieterich, J.H., 1980. The composite fire interval—a tool for more accurate interpretation of fire history. In: Stokes, M.A., Dieterich, J.H. (Tech. Coord.), Proceedings of the Fire History Workshop. USDA Forest Service General Technical Report RM-81, pp. 8–14.

Donnegan, J.A., Veblen, T.T., Sibold, J.S., 2001. Climatic and human influences on fire history in Pike National Forest, Central Colorado. Can. J. For. Res. 31, 1526–1539.

Foti, T.L., 2004. Upland Hardwood Forests and related communities of the Arkansas Ozarks in the early 19th century. In: Spetich, M.A. (Ed.), Upland Oak Ecology Symposium: History, Current Conditions, and Sustainability. USDA Forest Service General Technical Report SRS-73, pp. 21–29.

Gilbert, J., 1996. The Trail of Tears Across Missouri. University of Missouri Press, Columbia, MO, 122 pp.

Glueck, M.F., Stockton, C.W., 2001. Reconstruction of the North Atlantic Oscillation, 1429–1983. Int. J. Climatol. 21 (12), 1453–1465.

Gray, S.T., Graumlich, L.J., Betancourt, J.L., Pederson, G.T., 2004a. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. Geophys. Res. Lett. 31, L12205.

Gray, S.T., Graumlich, L.J., Betancourt, J.L., Pederson, G.T., 2004b. Atlantic Multidecadal Oscillation (AMO) Index Reconstruction. IGBP PAGES/World Data Center for Paleoclimatology. Data Contribution Series #2004-062. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Grissino-Mayer, H.D., 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. PhD Dissertation. University of Arizona, Tucson, AZ, 407 pp.

Grissino-Mayer, H.D., 2001. FHX2—software for analyzing temporal and spatial patterns in fire regimes from tree rings. Tree-Ring Res. 57 (1), 115–124.

Grissino-Mayer, H.D., Holmes, R.L., Fritts, H.C., 1996. International Tree-ring Data Bank Program Library Version 2.0 User's Manual. Lab. of Tree-Ring Res. University of Arizona, Tucson, AZ, 106 pp.

Gutsell, S.L., Johnson, E.A., 1996. How fire scars are formed: coupling a disturbance process to its ecological effect. Can. J. For. Res. 26, 166–174.

Guyette, R.P., 1996. Tree-ring data, Ontario and Missouri. International Tree-ring Data Bank. IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series # 92-014. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.

Guyette, R.P., Cutter, B.E., 1991. Tree-ring analysis of fire history of a post oak savanna in the Missouri Ozarks. Nat. Areas J. 11, 93–99.

Guyette, R.P., Cutter, B.E., 1997. Fire history, population, and calcium cycling in the Current River Watershed. In: Pallardy, S.G., Cecich, R.A., Garrett, H.G., Johnson, P.S. (Eds.), Proceedings of the 11th Central Hardwood Forest Conference. USDA Forest Service General Technical Report NC-188, 401 pp.

Guyette, R.P., Dey, D.C., 2000. Humans, topography, and wildland fire: the ingredients for long-term patterns in ecosystems. In: Yaussy, D.A., (Compiler), Proceedings of the Workshop on Fire, People, and the Central Hardwoods, Landscape. USDA Forest Service General Technical Report NE-274, 129 pp.

Guyette, R.P., Kabrick, J., 2002. The legacy and continuity of forest disturbance, succession, and species at the MOFEP sites. In: Shifely, S.R., Kabrick, J.M. (Eds.), Proceedings of the Second Missouri Ozark Forest Ecosystem Project Symposium: Post-treatment Results of the Landscape Experiment. USDA Forest Service General Technical Report NC-227, pp. 26–44.

Guyette, R.P., Spetich, M.A., 2003. Fire history in the Lower Boston Mountains. For. Ecol. Manage. 180, 463–474.

Guyette, R.P., Stambaugh, M.C., 2003a. Fire history of Missouri Ozark Forest Ecosystem Project (MOFEP) Site 6. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #USMF6001. NOAA/NGDC Paleoclimatology Program, Boulder, CO, USA.

Guyette, R.P., Stambaugh, M.C., 2003b. Fire history of Missouri Ozark Forest Ecosystem Project (MOFEP) Site 5. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #USMF5001. NOAA/NGDC Paleoclimatology Program, Boulder, CO, USA.

Guyette, R.P., Stambaugh, M.C., 2003c. Post oak fire scars as a function of diameter, growth, and tree age. For. Ecol. Manage. 198, 183–192.

Guyette, R.P., Muzika, R.M., Dey, D.C., 2002. Dynamics of an anthropogenic fire regime. Ecosystems 5, 472–486.

Holmes, R.L., Adams, R., Fritts, H.C., 1986. Quality control of crossdating and measuring: a users manual for program COFECHA. In: Tree-ring Chronologies of Western North America: California, Eastern Oregon and Northern Great Basin. Lab. of Tree-Ring Res, University of Arizona, Tucson, AZ, pp. 41–49.

Lowery, R.F., 1968. The effect of initial stem temperature on time required to kill cambium of shortleaf pine. MS Thesis, University of Missouri, Columbia, MO, 52 pp.

Pitcaithley, D.T., 1978. Let the River be, a History of the Ozark's Buffalo River. Southwest Cultural Resources Center, National Park Service, Santa Fe, NM, 133 pp.

Rollings, W.H., 1995. Living in a graveyard: native Americans in colonial Arkansas. In: Whayne, J. (Compiler), Cultural Encounters in the Early South. University of Arkansas Press, Fayetteville, AR, 208 pp.

Royce, C.C. (Compiler), 1899. Indian Land Cessions in the United States. In: Eighteenth Annual Report of the Bureau of American Ethnology, 1896–1897, Part 2. Government Printing Office, Washington.

Rudis, V.A., Skinner, T.V., 1991. Fire's importance in South Central U.S. forests: distribution of evidence. In: Nodvin, S.C., Waldrop, A. (Eds.), Fire and the Environment: Ecological and Cultural Perspectives. USDA For. Serv. S. For. Exp. Stat. Gen. Tech. Rep. SE-69, pp. 240–251.

SAS/STAT, 2002. SAS Users Guide: Statistics, Version, 5th ed. SAS Institute, Cary, NC, 955 pp.

Schroeder, M.J., Buck, C.C., 1970. Fire Weather, 360. USDA For. Serv. Agric. Handb., 288 pp.

Schuler, T.M., McClain, W.R., 2003. Fire history of a ridge and valley oak forest. USDA For. Serv. Northeastern Res. Sta. Res. Paper NE-724, 9 pp.

Shumway, D.L., Abrams, M.D., Ruffner, C.M., 2001. A 400-year history of fire and oak recruitment in an old-growth oak forest in western Maryland, U.S.A. CJFR 31, 1437–1443.

Spetich, M.A., 2004. Upland oak ecology—a synthesis. In: Spetich, M.A. (Ed.), Upland Oak Ecology Symposium: History, Current Conditions, and Sustainability. USDA Forest Service General Technical Report SRS-73, pp. 3–9.

Stambaugh, M.C., Guyette, R.P., 2004. Tree Ring Data, Mid-USA *P. echinata* (AR074, MO045). International Tree-ring Data Bank. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2004-083. NOAA/NGC Paleoclimatology Program, Boulder, CO, USA.

Stambaugh, M.C., Guyette, R.P., Putnam, C., 2005. Fire in the pines: a 341-year fire and human history at Big Spring Pines Natural Area, Ozark National Scenic Riverways. Park Sci. 23 (2), 43–47.

Stevens Jr., D.L., 1991. A Homeland and a Hinterland the Current and Jacks Fork Riverways. Historic Resource Study, Ozark National Scenic Riverways, National Park Service, Van Buren, MO, 248 pp.

Stokes, M.A., Smiley, T.L., 1968. Introduction to Tree-ring Dating. University of Chicago Press, Chicago, IL, 78 pp.

Swetnam, T.W., Baisan, C.H., 1996. Fire histories of montane forests in the Madrean Borderlands. In: Ffolliott, P.F., et al. (tech. coords.), Effects of Fire on Madrean Province Ecosystems, A Symposium Proceedings, USDA Forest Service General Technical Report RM-GTR-289, pp. 15–36.

USDA, 1940–1997. Wildfire Statistics. United States Department of Agriculture and Forest Service, Division of Cooperative Forest Fire Control. USDA, Washington, DC.

Westin, S., 1992. Wildfire in Missouri. Missouri Department of Conservation, Jefferson City, MO, 161 pp.