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Fire history of oak–pine forests in the Lower Boston Mountains, Arkansas, USA

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Abstract

Perspective on present day issues associated with wildland fire can be gained by studying the long-term interactions among humans, landscape, and fire. Fire frequency and extent over the last 320 years document these interactions north of the Arkansas River on the southern edge of the Lower Boston Mountains. Dendrochronological methods were used to construct three fire chronologies from 309 dated fire scars that were identified on 45 shortleaf pine (*Pinus echinata*) remnants. Fire frequency increased with human population density from a depopulated period (the late 1600s and early 1700s) to a peak in fire frequency circa 1880. Fire frequency then decreased as human population continued to increase. Fire frequency and human population density were positively correlated during an early period (1680–1880) with low levels of population, but negatively correlated during a later period (1881–1910) with high levels of population. We hypothesized that this difference is due to limits on fire propagation and ignition caused by land use and culture, as well as human population density. Relatively high human population densities (>5 humans/km^2) were associated with a peak in the maximum number of fires per decade in this highly dissected, 'bluff and bench' landscape compared to less dissected regions of the Ozarks.

Keywords: Ozarks; Dendrochronology; Human population; Fire scar; Arkansas River

1. Introduction

Relationships between humans and wildland fire are becoming increasingly important. In much of the South Central US, fuel and ignition characteristics remain an import factor influencing forest processes (Rudis and Skinner, 1991). Fuel accumulation at regional and local scales can dramatically affect fire frequency, intensity, and the effects of fire on forests. Human population density is a master variable in understanding temporal changes and interactions in fire regimes. Fire regimes can undergo a number of changes due to changes in anthropogenic ignitions based upon human population density and culture. In addition, topography, land use, and fuels interact with ignitions to mitigate the propagation of fire across the landscape. Based on a study area 270 km northeast of the study sites (Guyette and Dey, 2000; Guyette et al., 2002), four fire regime stages were hypothesized which may apply to the present study sites. These include: (1) an ignition-limited stage, (2) a fuel-limited stage, (3) a fuel-fragmentation stage, and (4) a culturally limited stage. During Stage 1, fire frequency increases as the human population and number of potential ignitions increases. In later stages, as human

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population density increases, fuel, landscape artifacts, and finally culture limit fire frequency.

Anthropogenic ignitions have overwhelmed the influence of natural ignitions in much of the central hardwood region including the Ozarks (Dey and Guyette, 2000a). 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). Spatial and temporal differences in the frequency of fire in landscapes dominated by anthropogenic ignitions reflect changes in human populations and culture caused by war, migration, and disease (Weslager, 1978; Wiegers, 1985). Europeans introduced diseases that decimated the Native American population. Depopulation caused by disease (Dobyns, 1983; Ramenofsky, 1987; Rollings, 1995), warfare, and migration occurred throughout much of North America (DeVivo, 1991) and has been linked with abrupt changes in fire history (Cutter and Guyette, 1994; Guyette and Dey, 1995; Dey and Guyette, 2000b). Thus, humans are by far the most important factor influencing the frequency of ignitions.

The general goal of this study is to describe the frequency and extent of fire during the last 320 years in oak–pine forests along the northern edge of the Arkansas River Valley and to relate this to factors which control the frequency of fire. Specifically the objectives are (1) to establish an association between increases in human population density and increases in fire frequency during periods of low human population, (2) to establish an association between increases in human population density and decreases in fire frequency during periods of high human population, (3) to identify stages within the fire regime based on historic changes in frequency and controlling variables, (4) and to examine the nature and significance of variables that affect changes in the fire regime.

2. Methods

2.1. Sites

The three study sites are located in Pope County, Arkansas, in the mid section of the Lower Atoka Hills and Mountains Land Type Association (Table 1) in the Boston Mountains. The sites are adjacent to the north border of the Arkansas River Valley. The study sites are located on steep forested hills which border the gently rolling agricultural lands and flood plains along the Arkansas River. The hills are highly dissected with more than 350 m of relief from lowlands to hill top. Forest vegetation is mixed oak (*Quercus* spp.) and shortleaf pine (*Pinus echinata*). 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. Southwesterly winds make the study sites sensitive to ignitions originating in Arkansas River Valley. During the fall, winter, and spring of most years, dry warm weather of only a few days is sufficient to dry ground fuels and permit the spread of surface fires in and around the study sites.

Logging occurred at two of the study sites in the early 1900s. At both the White Oak Mountain site and the Chigger Road site most of the cut pine stumps had outside rings that dated between 1910 and 1920. These dates, along with the abundance of pine trees aged less than 100 years, indicate that these sites were probably

Table 1
Characteristics of three fire history sites in the Lower Atoka Hills and Mountains on the northern edge of the Arkansas River

Site name	Granny Gap	Chigger Road	White Oak Mountain
Location	35°31′N, 93°05′W	35°29′N, 93°03′W	35°28′N, 92°53′W
Site area	0.5 km^2	1.5 km^2	2.0 km^2
Elevation	280–366 m	225–313 m	304–425 m
Land type association	Lower Atoka hills	Lower Atoka hills	Lower Atoka mountains
Forest type	Oak and pine	Pine and oak	Oak and pine
Distance to Arkansas River Hills LTA	2.2 km	4.0 km	3.5 km
Site aspect	SE and E	SE and SW	SW

logged in the 1920s. No cut pine stumps were found at the Granny Gap site, and all samples from this site were taken from natural snags, down wood, and live trees. In addition, there were many older, unscarred pine trees at the Granny Gap site that ranged in age from 160 to 230 years indicating that the site has not been logged for pine.

2.2. Fire scar identification and formation

Fire scars were identified by callus tissue, traumatic resin canals, and cambial injury. All samples had charcoal present on the surface of the scars. More than 90% of the fire scars were located on the uphill side of the bole as has been documented in other studies (Gutsell and Johnson, 1996; Guyette and Cutter, 1997). Fire scars were dated to the first year of cambial injury. The initial scarring of the bole requires considerable heat to penetrate the bark (Hengst and Dawson, 1994; Splat and Reifsnyder, 1962). The bark of one old shortleaf pine, which had no scar, measured 15 cm thick at ground level. Lowery (1968), studying cambial injury in shortleaf pine, showed that 15–20 min exposure was required to kill the cambium under 4 cm of bark when exposed to air temperatures of 532 °C. The high temperature differences within a fire indicate that initial scarring of trees can be highly variable. Evidence for this variability and the resistance of shortleaf pine to initial scarring comes from old trees and stumps without scars growing adjacent to pine remnants with multiple (>10) scars. Thus, although the presence of a scar dates a fire, non-scarred trees do not necessarily indicate the absence of fire.

2.3. Dating fire scars and statistical analysis

Cross-section radii with the least amount of ring-width variability due to reaction wood, injury, or ring-width suppression were chosen for measurement and cross-dating. Two radii were measured on the same sample when ring-width series were highly variable due to injury, release and reaction wood. Ring-widths series from each sample were measured and plotted. Plots were used for visual cross-dating (Cutter and Guyette, 1994; Guyette and Cutter, 1991; Stokes and Smiley, 1968). Visual matching of ring-width patterns allows the weighing of important signature years (sequences with distinctive ring patterns) over years with low common variability among trees. Plots also aid greatly in identifying errors in measurement or missing and false rings associated with injury or drought. Fire scar data was collected from three sites (Table 1) separated by as much as 16 km. Cross-sections from 45 shortleaf pine trees, cut stumps, and natural remnants were surfaced, measured, and cross-dated. Cross-sections were surfaced with a electric hand planer with a sharp carbide blade. Where rings were very narrow or indistinct, the ring structure and cellular detail was revealed with sandpaper (220–600 grit), fine steel wool, or razor cuts. A dating chronology was constructed from the tree-rings. The samples and dating chronologies were cross-dated and verified with shortleaf pine chronologies from Missouri (Guyette, 1996) and Arkansas (Dewitt and Ames, 1978). Computer programs were used to insure the accuracy of cross-dating (COFECHA, Holmes et al., 1986) and to graph tree and composite fire scar chronologies (FHX2, Grissino-Mayer et al., 1996). SAS/STAT (2002) system was used for the summary and analysis of means, population differences, and the calculation of statistical significance among populations and periods.

2.4. Human population

Human population data were derived from Pope County and Arkansas census data for the modern period (1810–2000). Historic (1520–1820) Native American population estimates, trends, and density were derived from many sources (Bailey, 1973; Marriott, 1974; Pitcaithley, 1978; Baird, 1980; Stevens, 1991; Hudson, 1995; Rollings, 1995). The population density of groups in the vicinity of the Arkansas River was calculated by dividing their historical population estimates by the area of their lands or by a circle whose radius was the distance between their population center and the study sites. For example, the changes in the population and location of the Cherokee are documented in the historical literature and were used to estimate population density at the study sites. Historical estimates of Cherokee population west of the Mississippi are between 3500 and 6000 in Southeast Missouri and Northwest Arkansas in 1803 (Royce, 1899; Gilbert, 1996). During the winter of 1811–1812, many Cherokee moved from Missouri to

Arkansas and their population along the Arkansas River increased to about 3000 (Stevens, 1991). By treaty, they occupied about 28,322 km^2 (7,000,000 acres) in Arkansas (Royce, 1899) and settled along the Arkansas River (Pitcaithley, 1978). After 1828 the Cherokee moved west to Oklahoma. Thus, peak population density of the Cherokee in the region of the study sites probably occurred circa 1820 and was about 0.16 human/km^2 (4500 humans/28,322 km^2) regionally. Although estimates by this method do not take into account the great variation of population density within a region, they do provide for rough density estimates and changes in population through time. These population density estimates are, however, within the range of population densities (0.07–6 humans/km^2) given for many areas of eastern North America (Dobyns, 1983; Ramenofsky, 1987; Thornton, 1987). Linear interpolation was used to calculate annual population density from census data estimates taken by decade.

Sample size can be a problem in determining the time series of fire events in the composite fire scar chronologies since more sample trees represent more area and sometimes different areas. At our sites the major periods of concern are before 1750 at the White Oak Mountain site and before about 1760 at the Chigger Road site. Diminishing sample size before these dates may be affecting the composite fire scar chronologies. That is, longer fire intervals may be the result of the decreased number of sample trees. The intervals and frequencies derived from the composite fire scar chronologies represent the occurrence of fire somewhere in the study area and do not estimate an interval for the complete burning of the site by surface fires.

3. Results

3.1. Fire scars

Three hundred and nine fire scars were identified and dated to the calendar year at the three study sites (Figs. 1–3). Between 1670 and 2000, fire years ranged from 1679 to 1938. The fire scar record and the evidence of fire extended to before 1700 at all of the sites. There were 7692 years of tree-ring record on the 45 dated tree-ring series. There was an average of one scar for every 25 years of tree growth for all ring series. There was no fire scar evidence of fires after 1920 at any of the sites or during visual inspection for recent fire scars on the many live young and old pines at the sites. One exception was a single fire scar dating to 1938 at the White Oak Mountain site. Live younger trees without fire scars or bark char were evidence for the abrupt and complete cessation of fire at the sites that marked the beginning of active fire suppression. This indicates that the near absence of fires in this

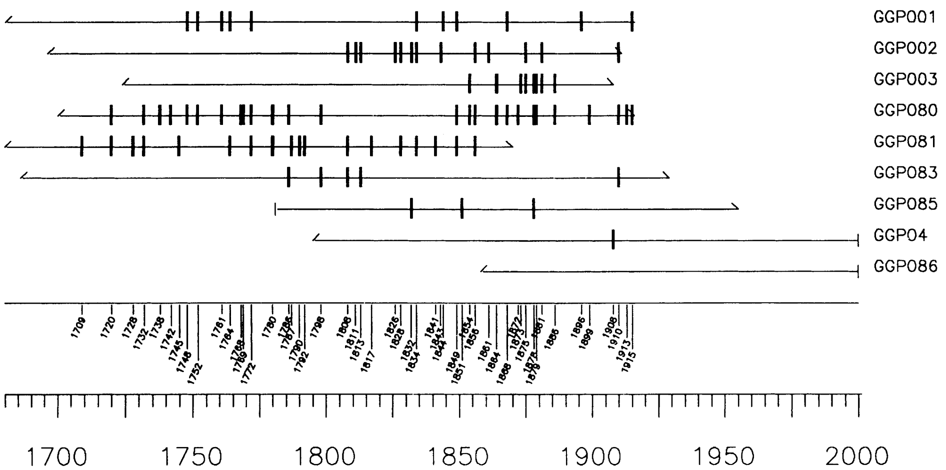

Fig. 1. The Granny Gap fire history showing the fire scar dates of nine individual trees and a fire scar composite chronology for the site. Each horizontal line represents the length of the fire scar record of a shortleaf pine tree or remnant. The composite fire scar chronology with all fire scar dates is shown at the bottom of the figure.

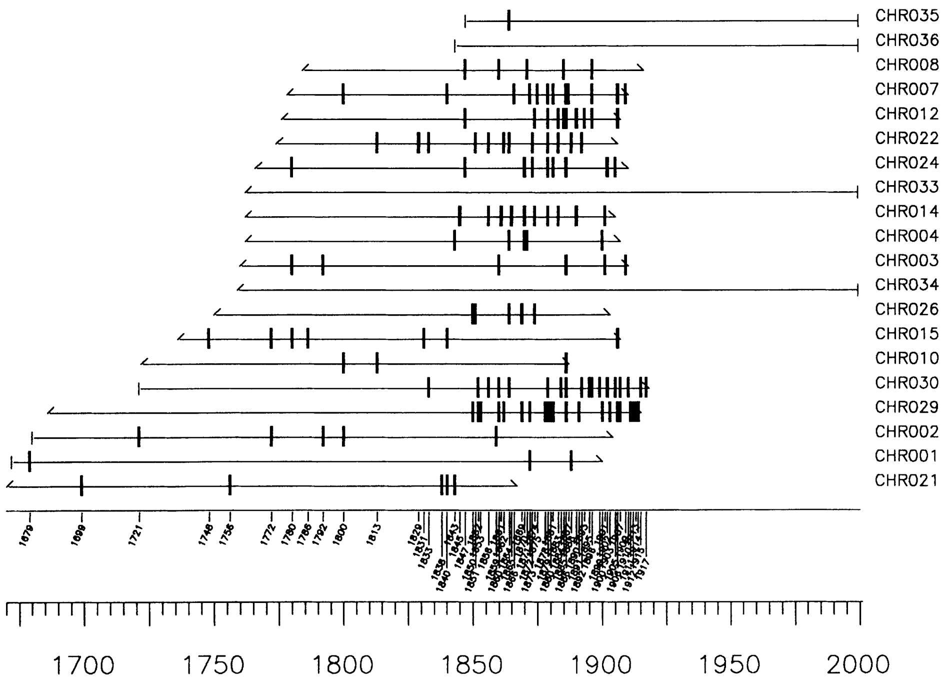

Fig. 2. The Chigger Road fire history showing the fire scar dates of 20 individual trees and a fire scar composite chronology for the site. Each horizontal line represents the length of the fire scar record of a shortleaf pine tree or remnant. The composite fire scar chronology with all fire scar dates is shown at the bottom of the figure.

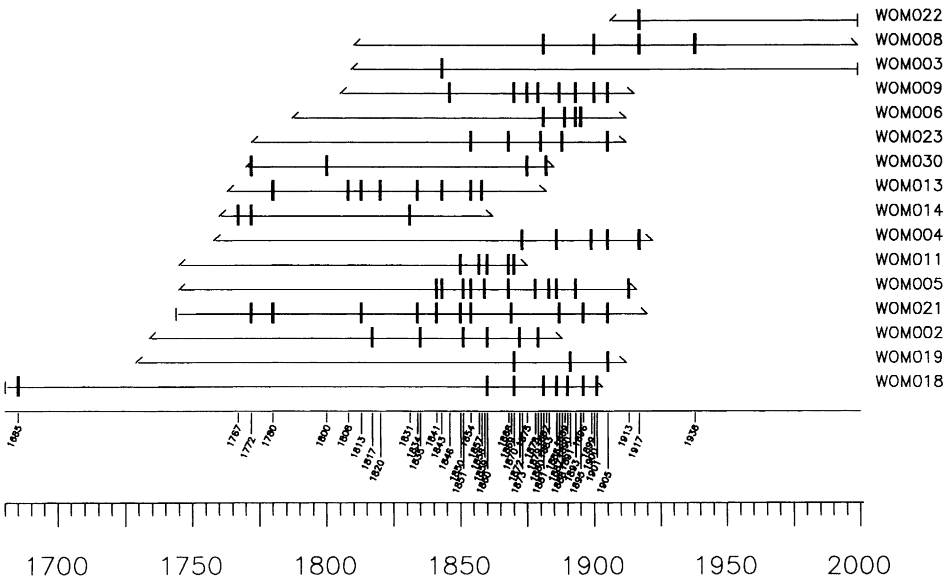

Fig. 3. The White Oak Mountain fire history showing the fire scar dates of 16 individual trees and a fire scar composite chronology for the site. Each horizontal line represents the length of the fire scar record of a shortleaf pine tree or remnant. The composite fire scar chronology with all fire scar dates is shown at the bottom of the figure.

Table 2
Fire chronology and frequency data at the study sites

Site name	Granny Gap	Chigger Road	White Oak Mountain
Number of sample trees	9	20	16
Total years of record	1814	3478	2400
Total years with fire	51	70	50
Total number of fire scars	85	137	87
Native American MFI (1680–1820)	4.6 years	13 years	16 years
Euro-American settlement MFI (1821–1880)	3.1 years	2.0 years	3.0 years
Regional development MFI (1881–1920)	5.0 years	1.4 years	2.4 years
Fire suppression			
MFI (1921–2000)	>80 years	>80 years	>62 years

more recent section of the record (1920–2000) is not a function of sample size and is consistent with the memory of local resource specialists.

3.2. Individual tree fire intervals

There were fewer and generally longer fire intervals on individual trees before 1820 than after. However, the longest fire intervals occurred after 1920 as is evidenced by the hundreds of young and old trees we did not sample because there was no evidence of fire scarring. The most frequent fire interval for the sample trees at all the sites was 5 years for the period before 1930. The most frequent interval before 1820 was 8 years, while the most frequent interval after 1820 was 5 years. The length of fire scar intervals on individual trees decreased from the late 1600s to the 1920s at the Chigger Road and White Oak Mountain sites, but not at the Granny Gap site.

3.3. Composite fire intervals

Fire scar dates were combined into composite fire scar chronologies for each site. Mean fire intervals (MFI) based on the site composite fire chronologies are given for four periods (Table 2). These intervals document the presence of a fire in at least one location that was of sufficient intensity to scar at least one tree. Fire intervals ranged from less than 2 to about 80 years. The MFI for the Native American Period (1680–1820) at the Chigger Road and White Oak Mountain sites was longer than the two later periods of Euro-American settlement (1821–1880) and Regional development (1881–1920). The MFI for the Native American Period (1680–1820) at the Granny Gap site was shorter than that at the Chigger Road and White Oak Mountain sites. The MFI during the Native American Period at the Granny Gap site was slightly longer than the MFI (3.4 years) during Euro-American settlement (1821–1920), but was not significantly different ($P = 0.08$).

3.4. Site level fire intervals versus individual tree fire intervals

Frequency distributions of fire scar intervals at the site level (area about 2 km^2) and for individual tree sites (area about 1 m^2) were compared in order to assess differences in fire intervals associated with differences in sample area (Fig. 4). The length of fire intervals recorded in composite fire chronologies (many individual tree sites, Fig. 4a) are proportionally shorter than those resulting from individual trees (Fig. 4b). About 92% of the intervals in the composite fire chronologies were less 10 years in length, whereas 70% of the individual tree intervals were less than 10 years. The largest difference between the two interval distributions was in the number 1-year fire intervals. The composite distribution had a proportionally greater (37%) number of 1-year fire intervals than did the individual trees (7%).

3.5. Seasonality

The majority of the scars at the sites were from injuries received during the dormant season or were undetermined as to seasonality. The season of burning was not determined for many of the fire scars because outer sections of the scar had been burned off or

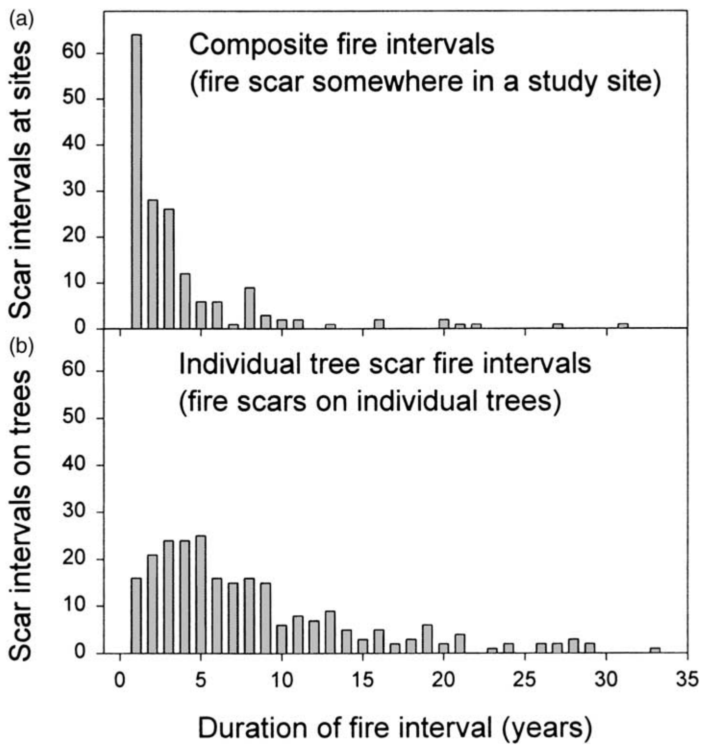

Fig. 4. A comparison of the minimum frequency of fire somewhere in a study site (the study site composite fire intervals) versus the minimum occurrence of fire at a point location (individual tree scar fire intervals).

decayed. There was some evidence of a change in the season of burning from the growing season (April–August) during the Native American Period to the dormant season during the Euro-American Period at the Granny Gap site. This was indicated by a greater percentage (73%) of growing season fires (scarring during the period of cambial expansion) before 1820 compared to the percentage of growing season fires (5%) after 1820.

3.6. Fire frequency and human population

Fire frequency was found to be positively related to human population density (Fig. 5) at low levels of human population density and negatively related at high levels of human population density. The hypothesis that human population density is the major factor affecting fire frequency prior to 1910 is supported by correlation analysis (Table 3, last row). After population density

Table 3
Periods and characteristics of the fire regime of the Lower Atoka Hills and Mountains

Period	Native American	Euro-American settlement	Regional development	Fire suppression
Factors most limiting fire	Ignitions	Ignitions	Fuel mass and continuity	Value of wood versus protein
Dates	<1680–1820	1821–1880	1881–1910	1911–2000
Economic activities	Subsistence and trade	Grazing	Regional trade in forest resources	Industrial forestry
Mean population density	0.08 human/km^2	2.4 humans/km^2	9.6 humans/km^2	12.6 humans/km^2
MFI	11.2 years	2.7 years	2.9 years	>80 years
r (population × MFI)	+0.64 ($P < 0.01$)	+ 0.91 ($P < 0.01$)	−0.88 ($P < 0.01$)	−0.16 ($P = 0.18$)

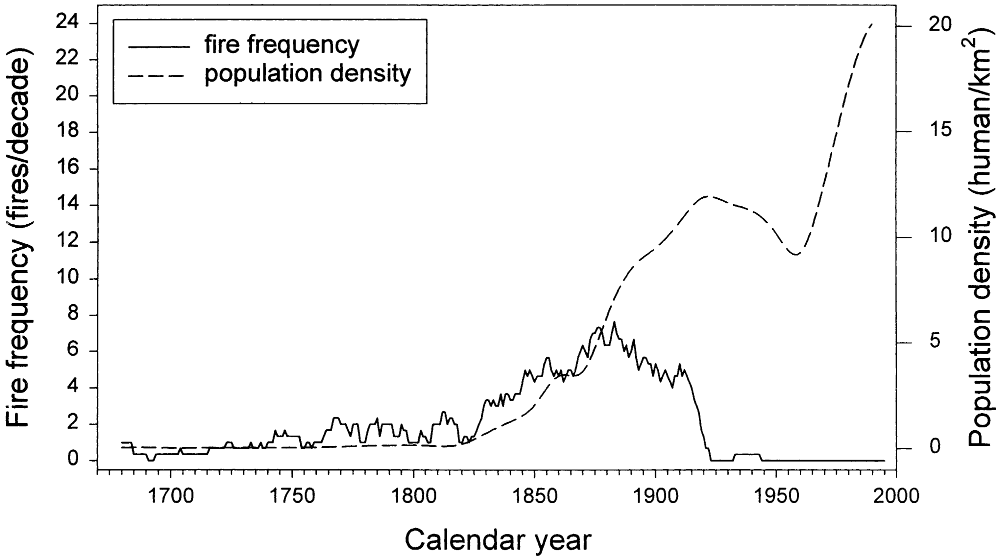

Fig. 5. Trends in population density and the frequency of fire. Population density data after 1900 are for Pope County, Arkansas.

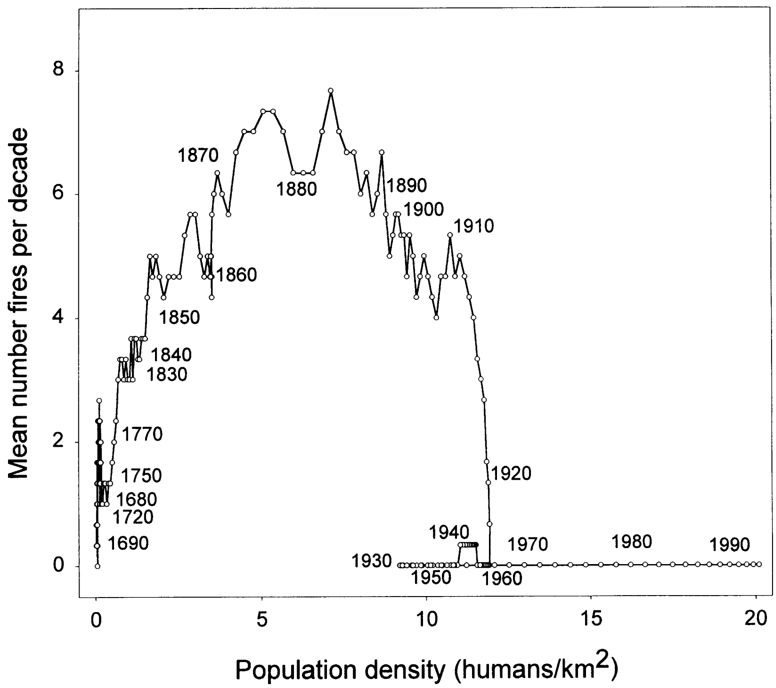

Fig. 6. Changes in the relationship between population density and fire frequency through time. Increases in human population and ignitions are positively and significantly correlated before 1880, while increases in population are negatively correlated between 1881 and 1920. Numbers in plot data are calendar years.

Table 4
Two top-ranked fire years in the Lower Atoka Hills and Mountains (AHM) that are coincident with top-ranked fire years at 26 sites in Current River watershed (CRW) during the 1700s (the average of the mean percent of trees scarred at each site is given)

Fire year	AHM percent scarred (%)	AHM rank	CRW percent scarred (%)	CRW rank	CRW acres burned
1772	31	1	29	6	152879
1780	23	2	44	1	274091

reaches a threshold of about 6 humans/km^2 (at the county level population data, inclusive of urban areas), the relationship between fire frequency and population reverses (Fig. 6).

3.7. Co-occurrence of fire years

The sites had several fire years in common during the 1700s. These were fire years in which extensive burning occurred elsewhere in the Ozarks. In the 1700s, several fire years at the study sites (Table 4) were coincident with the top-ranked fire years in the Current River watershed (270 km northeast of the study sites). All three study sites had fire scars that dated to the year 1780 during which fires burned at more than half of all Missouri Ozark sites. The percentages of stems scarred in 1780 at the study sites in the Boston Mountains was not great (GGP = 33%, WOM = 18%, CHR = 18%).

4. Discussion

4.1. Hardwood–pine complex

The fact that shortleaf pines grow in a matrix of hardwoods in this forest allows us to examine fire frequency throughout the complex. Once a fire starts, it burns through both hardwood and pine. However, significantly scarred hardwoods often continue to decay, do not readily record subsequent fires, and eventually die due to the combination of decay and other stresses, leaving few remnants. This makes deriving fire histories from hardwoods more problematic than for shortleaf pine. Shortleaf, once scarred, is predisposed to recording subsequent fire events through scarring, due to resin secretions at the injury site. This resin also impregnates wood, significantly reducing decay. Historic evidence of this hardwood–pine complex is documented in research notes by Harvey who studied Arkansas vegetation from 1875 to 1885. Harvey (1883) noted that “North of the Arkansas River a great many deciduous trees grow with pines. The percentage of pine increases as you go South, but there are no forests exclusively in pine...”.

4.2. Seasonality

The majority of scarring at the study sites took place during the dormant season (September–March). This is consistent with the timing of fire scars formed during the dormant season at other sites in Missouri (Guyette and Cutter, 1991, 1997). There was, however, evidence of a change in the season of burning from the growing season (April–August) during the Native American Period to the dormant season during the Euro-American Period at the Granny Gap site. Authors have speculated on the season of aboriginal and Euro-American burning. Early accounts of burning in the northern Great Plains by aboriginal people document that many fires took place in April, May, July, and August (Higgins, 1986). A shift from fall to spring burning occurred with the displacement of Native Americans by Euro-American settlers in the prairies and forests of Illinois (McClain and Elzinga, 1994).

4.3. Spatial and temporal interpretations of fire intervals

The distributions of fire intervals recorded at individual tree sites by each sample tree are skewed to fire intervals that are longer than those of the composite fire interval (Fig. 4). This is expected since not every fire recorded at a study site burned the entire site, or if it did, the fire may not have been hot enough to scar every tree. Low-intensity surface fires do not always completely burn a site. Differences in fuel moisture, aspect, wind, and fuel loading often result in unburned areas within a site. Some of these unburned areas may be reflected in the non-scarring of sample trees. However, non-scarring is much more likely to occur due to the resistance of trees to scarring in a fire. We know that fire scarring is highly variable even among trees growing only a few meters apart on similar sites. Often, trees with 10 or more fire scars are growing next to trees with no fire scars. Thus, the underestimation of the length of fire intervals at point locations (individual tree fire intervals) relative to the composite fire intervals is greatly mitigated by the resistance of trees to scarring in low-intensity surface fires, which greatly reduces the number of fire scars and the number of trees scarred.

4.4. Fire frequency and human population density

In many ways, fire history in much of eastern North America is a history of anthropogenic ignitions. Human life and culture have long been dependent on fire on a daily basis (Pyne, 1982). The vast majority of fires result from anthropogenic ignitions, whether accidental or with intent. The idea that human population density is a measure of ignition potential is supported by the significant and positive correlations between these variables at low population densities. Thus, the variation of low population densities over the last millennium is the major factor affecting fire history. Human population in the Arkansas River Valley has varied greatly over the last 1000 years (Rollings, 1995). Fire frequency has probably changed with the flux of human population density. The Arkansas River Valley was densely populated at the time of first European contact in 1541 (Rollings, 1995). At least five tribes are mapped along the Arkansas River route of the Hernando de Soto expedition (Sloan, 1995). Depopulation of the region occurred rapidly after the First European contact (Hudson, 1995) and lasted well into the first part of the study period (1675–1770). Explanations of this decline include droughts and disease (Hoffman, 1995). After initial European contact, Native American population did not begin to increase until the migration of eastern tribes into the Arkansas River Valley in the late 1700s and early 1800s.

Anthropogenic ignitions were probably frequent along the fertile bottom lands of large rivers, including the Arkansas River, during pre-European contact. During the Mississippian Cultural Phase, agricultural communities have been identified in riparian areas of Arkansas River that would have been a source of many ignitions. An early source of anthropogenic ignitions may have been the 6000 Quapaw (Baird, 1980) that lived near the confluence of the Arkansas, White, and Mississippi Rivers before 1680. Disease came first to large riverine cultures such as the Quapaw because of their location and population density (Dobyns, 1983) and reduced the Quapaw population by two-thirds in 1698 and again reduced their population in 1747 and 1751 (Baird, 1980). There were only about 700 Quapaw by 1763. Rollings (1995) discusses in detail the low population density in the Arkansas River Valley at the time of post-DeSoto European contact. In the late 1700s, eastern Native American groups had begun to arrive in the Ozarks (Pitcaithley, 1978; Gilbert, 1996). In the early 1800s, Euro-Americans began agricultural settlements and wildland burning (Bass, 1981). Active fire suppression began in the 1920s.

There are several geographic factors that may be relevant to the fire history of these sites. The sites lie along the major east–west travel corridor of the Arkansas River and are adjacent to the fertile agricultural lowlands of the Arkansas River where humans and ignitions may have been common. The sites are near the North Fork Illinois Bayou which may have been visited by the members of the Illinois confederation in the 1700s (Dickinson, 1995). There are at least three sites along the Arkansas River in Pope County with protohistoric phases (Hoffman, 1995). All these factors may have increased the frequency of anthropogenic ignitions. In addition, the Granny Gap site is along a possible local human travel corridor (the "Gap") that may have been used by both historic Euro-American and Native American populations in moving between Tag, North Fork Illinois Bayou and points southwest. During the pre-European settlement period, the Granny Gap site differed from the White Oak Mountain site in the duration of fire intervals and the number of scars per period of record. This was not expected given their landscape positions. However, this might be expected if the Granny Gap site was adjacent a historic travel corridor.

One factor that mitigates the spread and frequency of fire, anthropogenic and natural, is topographic roughness (Guyette and Dey, 2000; Guyette et al., 2002).

Topographic roughness is the ratio of 'actual' surface area (measured by 30 m pixels) of a landscape to a the surface area measured by a large, single, planimetric surface. Indices of topographic roughness for sites and landscapes are calculated by dividing the more finely measured surface area by the area of a planimetric surface. Topographic controls on the frequency of fire become less and less important as population density and the frequency of anthropogenic ignitions increases. This theory is supported by the trends in the interactions between fire frequency and human population density in the very rough terrain of the Lower Atoka Hills and Mountains. The resistance of some ecosystems to fire propagation and frequency via anthropogenic ignitions is very low. For instance, it might take only a handful of humans on horseback or foot to keep a topographically smooth ecosystem, such a large prairie of tens of thousands of square kilometers, burning frequently. On the other hand, many topographically rough ecosystems, such as those in the rough terrain of the Lower Atoka Hills and Mountains, require a high human population density to reach and maintain a high frequency of burning. The population density required to reach a MFI of less than 2 years in the Lower Atoka Hills occurred later (about 30 years) and at a population density (6 humans/km^2) that is 10 times greater than the population density (0.64 human/km^2) that was required to achieve this MFI in the Current River Hills, a less topographically rough landscape (Guyette and Dey, 2000). This may result from the Current River Hills having only about a third of the topographic relief (difference in elevation) of the Lower Atoka Hills.

Rivers may act as fire breaks as well as corridors for human travel and ignition (Batek et al., 1999). The presence of the Arkansas River flowing west to east about 30 km south of the study sites may have provided a fire break. Fires spreading from south to north and any ignition on the south side of the river would have been blocked by the waters of the Arkansas River. Later as the river lowlands were developed for agriculture, fields, heavy grazing, and roads would have acted as additional impediments to the propagation of wildland fires.

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