Ridgetop Fire History of an Oak-Pine Forest in the Ozark Mountains of Arkansas

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Abstract - A total of 53 fire-scarred *Pinus echinata* (shortleaf pine) trees were examined to reconstruct a ridgetop fire chronology of an oak-pine forest in the Ozark Mountains of north-central Arkansas. This process yielded 104 fire scars dating to 61 separate fire years. Fire frequency was greatest during the Euro-American Settlement Period (1820–1900), when the median fire interval (MFI) was 1.9 years. Most of the sample trees established during this period. Fire remained prevalent through the Regional Development (1901–1930) and Modern (1931–2003) Periods, when the MFI was 2.1 and 2.6 years, respectively. Palmer Drought Severity Index mean values from 1823–2003 did not differ ($p = 0.76$) between fire years and non-fire years, suggesting that fires in the study area were predominantly anthropogenic in origin.

Introduction

Fire has been a dominant force in establishing and maintaining forested ecosystems throughout North America (Pyne 1982). As the importance of fire-disturbance ecology becomes more apparent, a shift in land-management philosophy is occurring from total fire suppression to fire prescription. Increasingly, prescribed burning is being used to restore and maintain forest structures that resemble pre-European settlement conditions (Guyette and Dey 2000). The importance of fire in the development of these pre-settlement forests can be inferred by reconstructing historical fire regimes. Dendrochronological analysis of fire scars found in tree rings is effective in reconstructing both spatial and temporal characteristics of historic fire events. This technique provides information about the frequency, intensity, and geographic extent of historic fire events (Cutter and Guyette 1994).

There is growing acceptance that many *Quercus* (oak) and *Pinus* (pine) forest types of the southern and eastern United States have evolved under a fire regime characterized by frequent, low-intensity, surface fires and infrequent, high-intensity, stand-replacing fires (Abrams 1992, 2003; Arthur et al. 1998; Brose et al. 2001). In the Ozark Mountains of Missouri, for example, fire-scar analysis suggests that oak forests and savannahs have burned repeatedly for hundreds of years. Fire-return intervals of 3–5 years from 1710–1830 and 7–13 years from 1831–1980 have been reported by several investigators (Cutter and Guyette 1994, Dey et al. 2004, Guyette and Cutter 1991). An old-growth oak-*Pinus echinata* Mill. (shortleaf pine) forest

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examined by Stambaugh et al. (2005) in Missouri had a fire-return interval of about 2 years from 1780–1930. Another Missouri study in an oak-pine forest found fire-return intervals of 18 years from 1580–1700, 12 years from 1701–1820, and 4 years from 1821–1940 (Guyette and Cutter 1997).

There is less information available concerning historical fire regimes in the Ozark Mountains of Arkansas. In fact, only in the past several years has the fire history of this region been investigated. In three oak-shortleaf pine forests in northwest Arkansas, Guyette and Spetich (2003) reported mean fire-return intervals of 5–16 years from 1680–1820; 2–3 years from 1821–1880; 2–5 years from 1881–1920; and >62 years (one study site) to 80 years (two study sites) from 1921–2000. Recent work from three additional sites in northwest Arkansas revealed mean fire-return intervals of 1.4–5.4 years from 1810–1920 (Guyette et al. 2006). The reduced fire frequency beginning in the 1920s reflects the implementation of effective fire suppression and prevention in Arkansas (Bass 1981, McGuire 1941, Strausberg and Hough 1997). In the Lower Buffalo Wilderness Area in northern Arkansas, Stambaugh and Guyette (2006) found mean fire-return intervals of 8 years from 1670–1821 and 2 years from 1821–1920. Fire frequency generally decreased during the mid- to late 1900s, and no fires occurred since 1972.

In 1934, the US Forest Service established the 1736-ha Sylamore Experimental Forest (SEF) in north-central Arkansas. The area supports oak and oak-shortleaf pine stands representative of the greater Ozark region (McGuire 1941). Shortleaf pine is an ideal species to sample for fire scars due to its flammable resins and ability to preserve scars (Guyette and Cutter 1991, Guyette and Spetich 2003). The abundance of pine on the SEF, particularly on mid- to upper slopes and ridges (Heitzman et al. 2006), presents an excellent opportunity to examine the long-term fire history of a typical Arkansas Ozark upland forest. The objective of this study was to utilize dendrochronological methods to reconstruct a ridgetop fire history of the Sylamore Experimental Forest.

Field Site Location

The SEF is located on the Springfield Plateau subsection of the Ozark Mountains in Stone County, AR (36.1°N, 92.2°W). Administratively, it is within the Sylamore Ranger District of the Ozark-St. Francis National Forest. Local topography is steep and highly dissected with elevations ranging from 121 to 304 m. The moderately to excessively well-drained soils are low in organic matter and fertility. Ridgetop soils primarily consist of the Clarksville-Nixa complex while side slopes are generally Clarksville very cherty silt loam. The climate is temperate, with an average growing season of 180–200 days and a mean annual precipitation of 122 cm (Ward 1983). The SEF functioned as the center of a US Forest Service silvicultural research program from the 1930s through the 1950s. Since that time, little research has been conducted on the forest due to reductions in research funding and the closure of on-site research facilities.

Methods

Data collection

From May to August 2004, a total of 94 living shortleaf pine trees on the SEF were sampled for fire scars to reconstruct the fire chronology of the forest. The samples were located primarily on or near ridgetops adjacent to US Forest Service roads that provided access to the study area. Because we wanted to select old, fire-scarred trees, samples were not chosen randomly, but were targeted based on the presence of external fire scars and other defects, tree size, and topographic position. Cat-faced trees had the highest sampling priority, followed by large (and presumably old) trees displaying cambial anomalies such as bark seams that can indicate healed-over fire scars (Arno and Sneck 1977). We also sampled large trees free of external defects that were located at the head of hollows and/or on southern aspects where fire occurrence and intensity are generally the greatest. Once a tree was selected for sampling, its diameter at breast height (dbh) was measured. To describe ridgetop forest characteristics, one 2.3 basal area factor prism point was established 30 m to the north or south of every other sample tree. At each point, all living trees larger than 10 cm dbh were tallied by species and dbh to calculate stand density (trees/ha) and basal area (m^2/ha).

The sample trees were felled with a chainsaw at ground level and cross-sections were removed from the stumps. Fire scars were identified by basal cambium injury, callus tissue, traumatic resin canals, and the presence of charcoal (Guyette and Spetich 2003). Fire-scar characteristics from known prescribed burns on the SEF conducted by the Forest Service in 1998 and 2002 were used for comparison in the identification of fire scars from earlier fire events. Cross-sections that clearly were not scarred were left in the forest. The scarred cross-sections were transported to the University of Arkansas - Monticello, where they were planed and sanded to better reveal the annual growth rings and scars. Undistinguishable injuries examined under a dissecting microscope were discounted as fire scars. A total of 53 trees contained genuine fire scars, all of which were used to reconstruct the fire chronology.

Dating fire scars and statistical analysis

Skeleton plots (the ring-width record of individual trees) were created from the cross-sections of 11 shortleaf pine trees from the study area. Signature years from the skeleton plots were identified to visually cross-date the remaining samples. Signature years are distinct patterns of wide or narrow growth rings due to a common limiting environmental factor (Stokes 1980). By matching signature years, false and missing rings were identified. Fire scars were dated to the first calendar year of cambial injury. The piths (i.e., total tree age) of 49 fire-scarred trees were successfully dated. Due to illegible growth rings and/or rotten heartwood, the remaining 4 samples were dated to the innermost available ring. The ground-line diameter of a tree when first scarred was determined by doubling the radial distance from the pith to the initial fire scar.

Fire years and pith dates from each sample were compiled into a master fire chronology using FHX2, a software program that analyzes spatial and temporal patterns in fire regimes from tree rings (Grissino-Mayer 2001). The master fire chronology displays how far back in time the composite fire record extends. To better describe the historical fire frequency, the master fire chronology was divided into 3 time periods based on the work of Guyette and Spetich (2003) in northwest Arkansas: the Euro-American Settlement Period (1820–1900), Regional Development Period (1901–1930), and Modern Period (1931–2003).

Statistics describing the fire frequency were computed using FHX2. Fire intervals (the number of years between fire events that scarred at least 1 tree) were analyzed using the two-parameter Weibull distribution (Grissino-Mayer 2001, Schuler and McClain 2003). Statistics included the minimum, Weibull median, and maximum fire intervals for each of the three time periods. The Weibull median fire interval (MFI) is a measure of central tendency analogous to the mean of a normal distribution.

To examine the influence of climate on fire occurrence, the master fire chronology was compared to summer Palmer drought severity index (PDSI) values for Arkansas from 1823–2003. PDSI values were obtained from the National Climatic Data Center (Cook 2005) for north-central Arkansas (grid point 202). A PDSI value of zero represents normal climatic conditions, -2 is moderate drought, and -4 is extreme drought, while positive values indicate wetter than normal conditions. We compared PDSI values for the 61 fire years and 120 non-fire years from 1823–2003 using a two-sample t-test with equal variances. Significance was accepted at $p \leq 0.05$.

Results

Forest characteristics

For trees larger than 10 cm dbh, the ridgetop forest composition was dominated by white oaks (including *Quercus alba* L. [white oak] and *Q. stellata* Wangenh [post oak]), red oaks (including *Q. velutina* Lam. [black oak], *Q. rubra* L. [northern red oak], and *Q. falcata* Michx. [southern red oak]), and shortleaf pine. Combined, these species accounted for 77% of the total tree density and 86% of the total basal area. Total density was 531 trees/ha, and total basal area was 29 m^2/ha. White oaks had the highest density with 194 trees/ha, followed by red oaks (111 trees/ha) and shortleaf pine (104 trees/ha). The basal area was 9 m^2/ha for white oaks, 8 m^2/ha for red oaks, and 8 m^2/ha for shortleaf pine. An additional 14% of tree density and 6% of basal area was comprised of *Carya* spp. (hickory). Other associated ridgetop species included *Prunus serotina* Ehrh. (black cherry), *Nyssa sylvatica* Marsh (blackgum), *Robinia pseudoacacia* L. (black locust), *Juglans nigra* L. (black walnut), *Cornus florida* L. (flowering dogwood), *Diospyros virginiana* L. (persimmon), *Acer rubrum* L. (red maple), *Sassafras albidum* (Nutt.) Nees (sassafras), *Amelanchier arborea* Michx. (serviceberry), and *Liquidambar styraciflua* L. (sweetgum).

Sample tree diameters

The dbh of fire scarred shortleaf pine ranged from 35 to 65 cm dbh. Most trees (81%) were 45 to 60 cm dbh. Sample tree ground-line diameters ranged from 5 to 65 cm when the trees were first scarred (Fig. 1). Initial fire scarring occurred most frequently when the trees were relatively small in size. Fifty-three percent of trees were first scarred when they were ≤10 cm in ground-line diameter, and 74% of trees were first scarred when their diameters were ≤30 cm. Only 17% of trees were initially scarred when their basal diameter was larger than 40 cm.

Age distribution

Total tree age data indicate that establishment of sampled shortleaf pine began in 1759 and continued until 1932 (Fig. 2). Between these years, the pattern of establishment remained relatively constant (zero to three trees establishing per decade), with the exception of a major pulse of establishment from 1850–1879. During this 30-year period, 64% of shortleaf pine became established. Peak establishment occurred in the 1860s (Fig. 2).

Fire history

The tree-ring record provided by the 53 fire scarred samples spanned 245 years in length (Fig. 3). A total of 104 fire scars were identified and successfully dated to the calendar year. This process yielded 61 fire years with dates ranging from 1823 to 2002. The fire years 1970, 1998, and 2002 were the only years in which fires scarred more than three of the sampled trees. Nine trees were scarred in the 1998 prescribed burn by the Forest

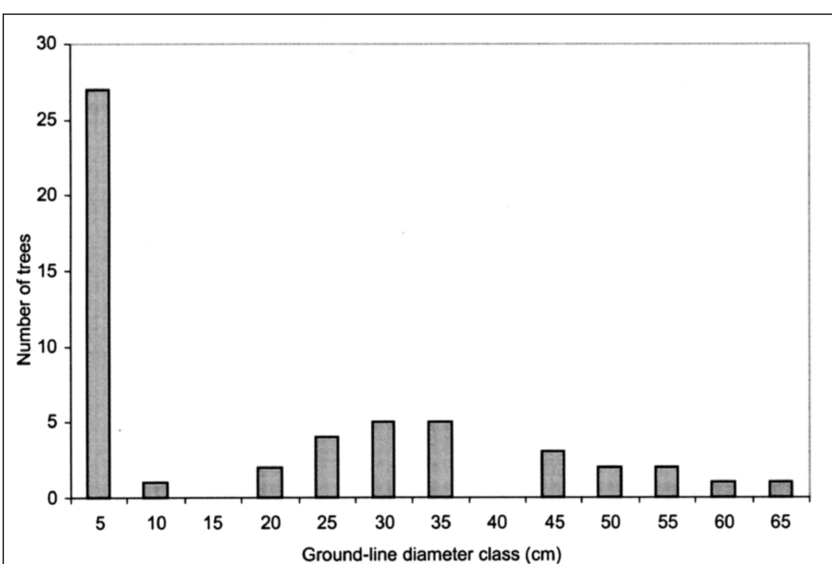

Figure 1. Ground-line diameter of shortleaf pine trees when first scarred on the Sylamore Experimental Forest in Arkansas.

Service, seven trees were scarred in the 2002 prescribed burn, and seven trees were scarred in 1970.

The Euro-American Settlement Period (1820–1900) was characterized by the highest frequency of fire, especially from 1850 to 1887. Fire intervals ranged from 1–13 years with a median fire interval (MFI) of one fire every 1.9 years (Table 1). Seventeen of the 26 samples contained a single fire scar, while one tree was burned 4 times. After 1887, no evidence of fire was observed in the fire record for more than a decade. Fires remained frequent during the Regional Development Period (1901–1930), with fires burning the SEF at intervals of 1–4 years and the MFI increasing slightly to 2.1 years. Half of the samples were fire scarred only once, while a lone tree

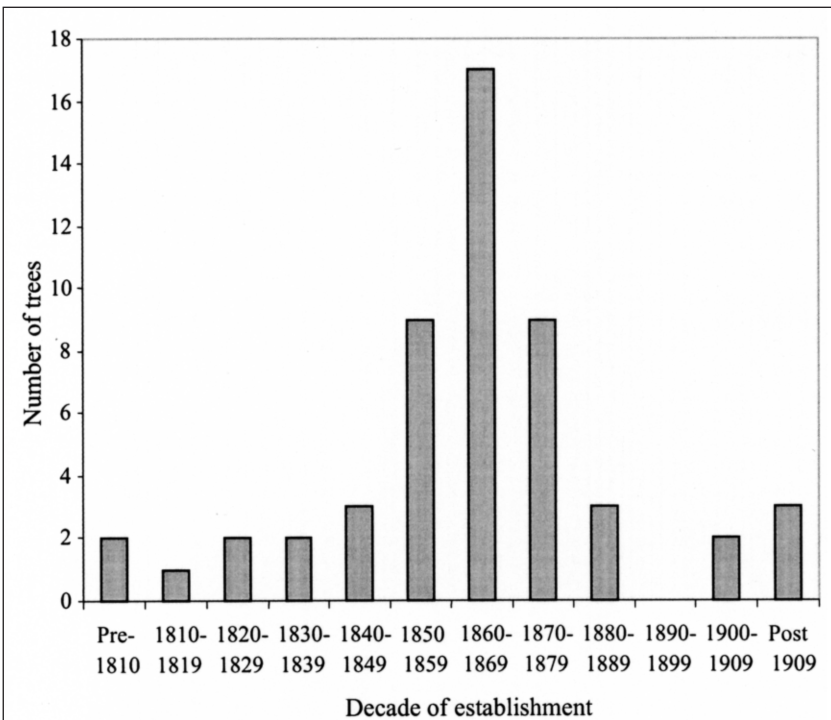

Figure 2. Age distribution of fire-scarred shortleaf pine trees by decade on the Sylamore Experimental Forest in Arkansas.

Table 1. Weibull median fire interval (MFI) and other fire chronology data for fire-scarred shortleaf pine trees on the Sylamore Experimental Forest in Arkansas.

Cultural period	MFI (years)	Range (years)	Total fire scars	Total trees scarred
Euro-American settlement (1820–1900)	1.9	1–13	40	26
Regional development (1901–1930)	2.1	1–4	16	10
Modern (1931–2003)	2.6	1–9	48	31

contained 3 fire scars. Fire continued to remain prevalent into the Modern Period (1931–2003) despite the advent of effective fire suppression throughout much of the region; the MFI was 2.6 years during this time, with fire intervals of 1–9 years (Table 1). Fires were particularly frequent from the late 1950s through the mid-1970s. Fifteen of the 31 trees scarred during the Modern Period were damaged by the two recent prescribed burns. The highest number of scars observed for an individual tree was four. Several groups of two or three adjacent sample trees had a total of five or more fire scars per group.

Climatic influence

In assessing the influence of climate on fire occurrence, the mean PDSI value for fire years during 1823–2003 did not differ significantly from the mean PDSI value for non-fire years (p = 0.76). During fire years, the mean PDSI value was -0.10 (SD = 1.68). For non-fire years, the mean PDSI value was -0.18 (SD = 1.73). The lowest PDSI value over the observation period was -4.17 in 1855, and the highest PDSI value was 3.57 in 1849. There were no fire scars dating to years of extreme wet spells or extreme drought.

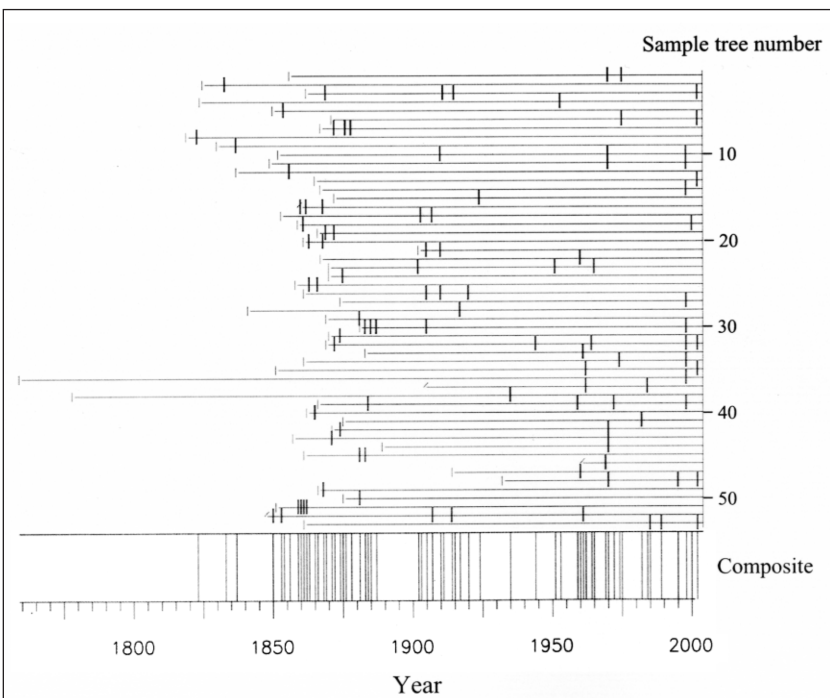

Figure 3. Fire chronology of fire-scarred shortleaf pine trees on the Sylamore Experimental Forest in Arkansas. Each horizontal line represents the annual rings of one sample tree. Bold vertical lines indicate fire scars. The composite fire-scar chronology with all fire scars is shown at the bottom of the figure. Four trees did not have piths; annual rings closest to the pith are represented by a slash.

Discussion

The temporal variation in fire occurrence displayed by the fire chronology on the SEF largely coincides with changes in human populations, human culture, and human land use. Prior to the creation of the Arkansas Territory in 1819, the population remained relatively small due to the presence of the Osage and other remaining tribes of Native Americans (Bass 1981, Sabo et al. 1982). However, the influx of settlers dramatically increased in response to the territorial proclamation. Consequently, Native Americans were gradually forced to exit the region (Guyette and Cutter 1997, McGuire 1941, Strausberg and Hough 1997). The removal of the Cherokee in 1828 marked the opening of the land for Euro-American settlement. By 1836, the year Arkansas achieved statehood, the state population exceeded 30,000 people. Four years later, this had more than tripled (Bass 1981).

During the Euro-American Settlement Period (1820–1900), the greatest influx of settlers into the Arkansas Ozarks arrived between 1820 and 1840. However, the SEF was probably settled later than this due to its rugged topography and inaccessibility (McGuire 1941). Settlement may have coincided with an abrupt increase in fire frequency observed from 1850–1887. In fact, the 1860s were marked by near annual burning. This period of frequent fires coincided with a peak in establishment of the pine trees sampled. Fire, and perhaps other disturbances such as logging and land clearing, most likely resulted in favorable conditions for widespread shortleaf pine establishment. Shortleaf pine has a high regenerative success following frequent large-scale disturbances (Stambaugh and Guyette 2004). It is a fire-adapted species that thrives on burned-over mineral soil seedbeds, can repeatedly sprout from its base when topkilled, and displays rapid juvenile growth (Wade et al. 2000).

After 1887, no fires were recorded for over a decade. A possible explanation is that the annual burning of open range decreased as the Ozarks became settled. Fencing was introduced to denote private property holdings, and the amount of area under cultivation increased. Both of these factors contributed to a substantial reduction in open rangelands (Sabo et al. 1982). Based on archaeological data, Jurney and Stahle (2004) estimated that approximately 90% of the Ozark-St. Francis National Forest in northern Arkansas may have been occupied by farmsteads around the turn of the 20th century. Of this occupied portion, 40% was cleared and cultivated while 60% was used as wooded pasture. The remaining 10% of the national forest area that was left unoccupied could have been utilized as open range.

The increase in fire frequency observed in 1902 coincided with extensive timber harvesting and forest exploitation during the Regional Development Period (1901–1930) (Bass 1981, McGuire 1941, Sabo et al. 1982, Soucy et al. 2005, Strausberg and Hough 1997). An accumulation of slash, ignitions from railroad logging activities, and public indifference to fire suppression provided ideal conditions for widespread fire occurrence. The establishment and expansion of the Ozark National Forest in 1907–1909 may also have contributed to fires. Local people deliberately set "job fires" in hopes of being employed by the US Forest Service in fire-suppression efforts (Strausberg and Hough 1997). In addition, grudge fires were regularly ignited in retaliation against forest officers and the US Forest Service (Bass 1981).

By the 1920s and 1930s, systematic fire protection had been established on US Forest Service and private lands, and fire frequency decreased dramatically (Bass 1981, McGuire 1941, Soucy et al. 2005, Strausberg and Hough 1997). This decrease was observed in the SEF fire chronology, and is consistent with other fire chronologies conducted in the Arkansas and Missouri Ozarks. Guyette and Spetich (2003) reported that fire frequency decreased to greater than 62 years due to fire suppression at three study sites in northwest Arkansas. Fire-scar chronologies from 23 oak-shortleaf pine stands in southern Missouri indicated that effective fire suppression starting in 1930 had reduced the number of sites burned annually from around 25% to less than 1% (Guyette and Cutter 1997).

From 1959–1975, an unexpected increase in fire frequency was observed. A similar increase was recorded from 1955–1972 in a shortleaf pine fire chronology in northern Arkansas (Stambaugh and Guyette 2006), and from 1960–1975 in an oak forest-savannah mosaic in Missouri (Dey et al. 2004). This increase in fire activity may be related to the control of domestic grazing. The Multiple Use-Sustained Yield Act of 1960 directed the US Forest Service to give equal consideration to the management of recreation, range, timber, water, and wildlife (Strausberg and Hough 1997). This restricted some of the grazing practices that were occurring on the Ozark-St. Francis National Forest (although not necessarily on the SEF). Cattlemen and others became angry as the US Forest Service began to auction off some of the 6000 hogs and 8000 head of cattle that were estimated to be grazing illegally on the Ozark-St. Francis National Forest. As a result, incendiary fires were set in retaliation (Strausberg and Hough 1997).

Just over one-half of the sample trees were initially fire scarred when ≤10 cm in ground-line diameter. Small shortleaf pine trees are more susceptible to heat damage because they have a higher surface-to-mass ratio and thinner bark than larger trees (Guyette and Cutter 1991, Guyette et al. 2006). Lowery (1968) reported that exposure to air temperatures of 532 ºC for 15–20 minutes was needed to cause cambial injury in a shortleaf pine tree with bark 4 cm thick. The bark of large shortleaf pine trees can be 15 cm thick at ground level (Guyette and Spetich 2003). Nevertheless, the large, thick-barked trees we sampled clearly recorded the prescribed burns on the SEF in 1998 and 2002. For both burns, backing fires were set from the ridgetops and allowed to burn down slope (Ronnie Anderson, Ozark-St. Francis National Forest, Mountain View, AR, pers. comm.).

Evidence indicates that historic fire events were not associated with years of drought, suggesting a fire regime characterized by anthropogenic ignitions. In fire regimes that are dominated by natural ignitions, fire occurrence shows a strong correspondence to drought (Guyette et al. 2003, Jurney et al. 2004). However, less than 2% of wildland fires originate from lightning strikes in the humid climate of the Ozark Mountains (Bruner 1930, Guyette and Cutter 1991). Furthermore, as human population densities and associated ignitions increase, the influence of climatic conditions on a fire regime decreases. Even during wet periods, a few days of warm and dry weather is sufficient to reduce fuel moistures enough for human-induced fire propagation to occur (Guyette and Dey 2000, Guyette and Spetich 2003).

Conclusions

Results of this study provide further evidence that upland forests in the Ozark Mountains of Arkansas and Missouri have burned frequently over the past 200 or more years. These frequent disturbances have shaped the structure, composition, and distribution of forest vegetation. Indeed, the abundance of fire-adapted oaks and pines in the study area and throughout much of the Ozarks is likely a consequence of long-term recurrent fire. We offer an historical justification for current management activities that restore and maintain fire-dependent ecosystems, and suggest there is a sound ecological basis for reintroducing fire within the region.

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