Research Article

Historic Fire Regime of an Upland Oak Forest in South-Central North America

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ABSTRACT

Prescribed burning is used in upland oak forests of south-central North America to improve wildlife habitat, reduce fire hazard, restore ecosystem integrity, and maintain biological diversity. However, little is known about the frequency, seasonality, and ignition source of historic fires that shaped these forests. In general, it is believed that fire frequency in upland oak forests of south-central North America was influenced by climate and humans, and decreased since Euro-American settlement; yet there is a dearth of scientific evidence to support this conclusion. The objective of this study was to link the fire history of an upland oak forest in east-central Oklahoma with factors controlling the fire regime. We removed cross-sections from 69 dead post oak (*Quercus stellata* Wangenh.) trees in a 1 km^2 area of old-growth post oak and blackjack oak (*Q. marilandica* Münchh.) forest, and determined the tree-ring record and exact dates of fire scars from 1750 to 2005, using standard dendrochronological methods. An increase in fire from the eighteenth to early twenty-first centuries appeared to be associated with changes in human occupation, and there was little evidence linking the frequency, severity, or extent of fires to climate factors including drought, lightning, and late-spring frosts. These findings appeared to contradict the belief that fire decreased from the eighteenth to early twenty-first centuries and appeared to emphasize the importance of anthropogenic ignition to the local fire regime.

Keywords: anthropogenic ignition, Cross Timbers, dendrochronology, fire history, oak forest, Oklahoma, post oak, prescribed burning, *Quercus stellata* Wangenh.

Citation: DeSantis, R.D., S.W. Hallgren, and D.W. Stahle. 2010. Historic fire regime of an upland oak forest in south-central North America. Fire Ecology 6(3): 45-61. doi: 10.4996/fireecology.0603045

INTRODUCTION

Anthropogenic fire has long played an important role in the ecology of south-central North American oak forests (Pyne 1982, Frost 1998, Bowman *et al.* 2009). Generally, local fire histories corresponded to human settlement patterns or transitory land use (Guyette *et al.* 2002). Indigenous tribes used fire for a variety of reasons, including pest management, tree felling, insect collection, pasturage improvement, warfare, communication, and to facilitate hunting (Day 1953, Moore 1972, Pyne 2001, Omer 2002). Euro-American settlement (EAS) often displaced or replaced indigenous tribes, changing local- and sometimes large-scale impacts on land use (Williams 1989). Fire traditionally played a role in pre-EAS land management techniques used by indigenous tribes but was subsequently reduced or suppressed in south-central North America (Abrams 2005, Courtwright 2007). Often, decreased fire frequencies dramatically and rapidly transformed vegetation types, changing forest structure and composition (Nowacki and Abrams 2008). While some literature suggests that fire frequency decreased in oak forests of south-central North America throughout the nineteenth and twentieth centuries (Abrams 1986, 1992; Van Lear and Watt 1992; Nowacki and Abrams 2008), there is evidence to the contrary (Clark *et al.* 2007). In addition, the importance of non-anthropogenic ignitions to fire regimes in North American deciduous forests is relatively unknown (Frost 1998, Peterson and Drewa 2006, Aldrich *et al.* 2010).

Knowledge of the frequency, seasonality, and ignition sources of historical fires in oak forests is important for present-day fire and vegetation management, yet is usually unavailable (Wadleigh *et al.* 1998, Peterson and Reich 2001, McShea and Healy 2002). Often lacking this information, land managers attempt to maintain biodiversity, restore ecosystems, reduce fire hazard, and improve wildlife habitat through prescribed burning (Guyette *et al.* 2002, Hutchinson *et al.* 2005, Blankenship and Arthur 2006). Our main objectives were to reconstruct the fire history of an upland oak forest in south-central North America currently being managed with fire, and to link the fire history to factors controlling the fire regime. Specifically, our goals were to determine the seasonality, extent, frequency, and ignition sources of historical fires in order to reveal whether climate or humans controlled fire frequency, and to determine how modern prescribed burning related to the historical fire regime.

METHODS

Study Site

The study site was located in Okmulgee Game Management Area (OGMA) administered by the Oklahoma Department of Wildlife Conservation (ODWC) in east-central Oklahoma, USA (35°38'N, 96°02'W; Figure 1). Mean annual temperature is 15 °C and mean annual precipitation is 108 cm but highly variable, ranging from 55 cm to 156 cm (Oklahoma Climatological Survey 2005). Elevations range between 193 m to 290 m with 5% to 30% slopes; parent materials are primarily sandstone and shale; and soil types are stony and gravelly fine sandy loam and silty clay (Soil Survey Staff 2009). The OGMA is composed primarily of upland post oak (*Quercus stellata* Wangenh.) (89% of woody species basal area) and blackjack oak (*Quercus marilandica* Münchh.) forests (Duck and Fletcher 1945). These relatively xeric forests are located on broken, rocky terrain inaccessible to logging equipment, and trees are usually not merchantable as timber because of low productivity and poor growth form (Therrell and Stahle 1998). Due to these limitations and the longevity of post oak, a substantial portion of OGMA is relatively undisturbed and may comprise one of the largest contiguous old growth

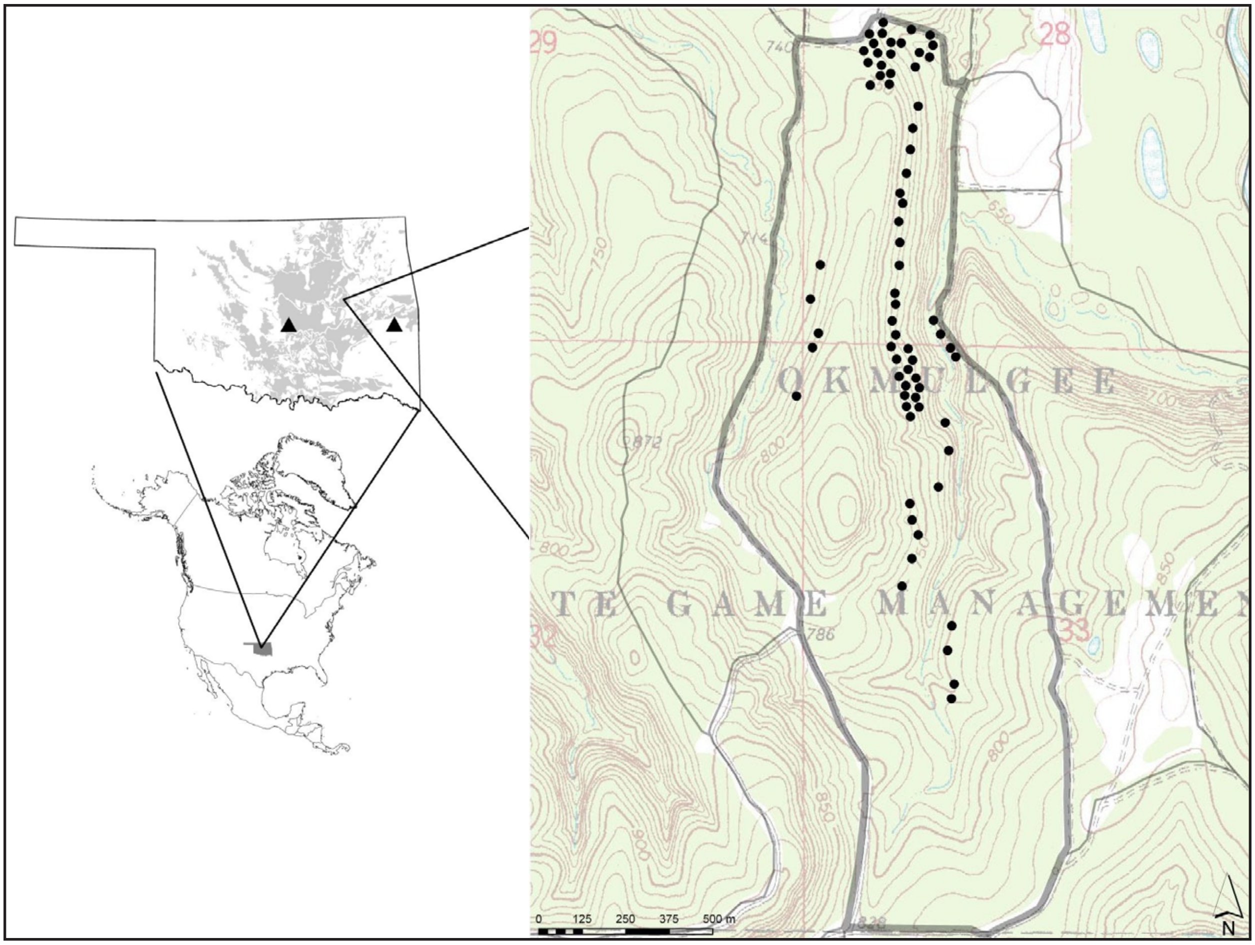

Figure 1. Location of fire history sample collection within the study site, Okmulgee Game Management Area, the Cross Timbers region of Oklahoma, USA, and North America. Sample collection locations are approximate and were not mapped with a global positioning system. Triangles represent locations of PDSI grid points 179 and 193. Map contour lines are in 3.05 m increments.

oak forests in the region (Stahle and Hehr 1984, Stahle 2007); therefore, it provides an excellent opportunity for long-term fire history reconstruction.

Starting in 1989, the OGMA was divided into management units varying in size from 30 ha to 460 ha and burned at different fire intervals (from 1.8 yr to 8 yr) by low intensity dormant season prescribed burning (Figure 2). All prescribed burns were conducted in February and March; relative humidity was between 30 % and 50 %; temperature was less than 27 °C; and winds were less than 25 km h^{-1}. There are no records of fire occurrences prior to 1989.

We chose to take our sample collection from the management unit most frequently prescribed burned in order to assess the likelihood of finding fire scars from known fire dates (Clark *et al.* 2007). The study site was approximately 1 km^2, which is a common size for local fire history reconstruction. This size has been successfully applied in various forest ecosystems, is large enough to encompass variable topography and enable collecting adequate numbers of samples, and shows promise in landscape models depicting spatio-temporal variability in fire frequency (Falk and Swetnam 2003; Fulé *et al.* 2004; Falk *et al.* 2006; Falk *et al.* 2007; M. Stambaugh, University of Missouri-Columbia, personal communication).

Figure 2. Prescribed burn on 4 March 2010 at Okmulgee Game Management Area, Oklahoma, USA. Air temperatures ranged from 7 °C to 13 °C, relative humidity 30 % to 40 %, and wind speeds ranged from 3 km h^{-1} to 16 km h^{-1}. Fire observations indicated slow rates of spread and flame lengths <0.3 m in forested areas and 0.9 m to 1.8 m in areas dominated by herbaceous plants. Photo courtesy of John Polo, Oklahoma State University.

Sampling Scheme

In May 2007, we removed cores from 20 live post oak trees within 30 cm of the root collar. These cores were used to build a master chronology from which subsequent cross-sections could be cross-dated (Douglass 1941, Stokes and Smiley 1968). From May 2007 to November 2009, we used a chainsaw to remove cross-sections from 69 dead post oak trees within 30 cm of the root collar. Because previous literature showed relationships between diameter, growth rate, and the likelihood of post oak trees to exhibit fire scars (Guyette and Stambaugh 2004), we made an effort to collect cross-sections from trees with a range of diameters. We sanded all cross-sections with progressively finer grits of sandpaper in order to distinguish tree rings and fire scars under a microscope, and measured the cross-sectional diameter of each disk.

Analysis

Dendrochronology uses synchronous time series of annual growth ring widths across a geographical region influenced by the inter-annual variability of climate and growth limiting factors (e.g., soil moisture). It is based on the principal of cross-dating, which uses patterns of wide and narrow rings induced by climate variability (Douglass 1941). We cross-dated all cross-sections using standard dendrochronological methods (Stokes and Smiley 1968) and measured annual growth ring widths to the nearest 0.001 mm with a stage micrometer. In cases where cross-sections did not exhibit circuit uniformity we measured them along a radius of intermediate ring width.

We used COFECHA (This and subsequent programs are available at the University of Arizona Laboratory of Tree-Ring Research [http://www.ltrr.arizona.edu/pub/dpl/A-INFO.HTM]) software (Holmes 1983) to statistically verify the cross-dating of each cross-section and indicate any possible measurement or dating problems. We developed a master chronology from OGMA cross-sections that is now archived in the International Tree-Ring Data Bank (DeSantis *et al.* 2010*a*).

Fire kills living tissue in woody plants and creates both conductive heat-caused injuries extending around a substantial portion of tree circumference and extremely localized injuries from radiative heat (Smith and Sutherland 1999). Vegetative response to fire includes cambial production of wound ribs or bark fissure patterns unique anatomically from other cambial wounds. These wounds are fire scars (Figure 3) that are often possible to date to a particular season within a year using standard dendrochronological methods, and they provide valuable information on ecological, spatial, and temporal historic fire conditions (Baisan and Swetnam 1990, Guyette *et al.* 2002). We identified and assigned the exact date of each fire scar corresponding to the first year in which the tree exhibited a growth response to the wound (Guyette and Cutter 1991). These fire scars represent the fires recorded by our sample collection and are therefore a minimum estimate. It is possible that additional fires consumed trees, did not leave any scars in the sample collection, or were recorded in non-sampled trees. We were able to identify the season of response for the majority of fire scars by assessing the scar position within each annual growth ring (Dieterich and Swetnam 1984, Guyette *et al.* 2002). However, many scars could not be identified to season. Growing season scars were tree growth responses to injuries from fires that occurred between approximately March and July, and dormant season scars were tree growth responses to injuries from fires that occurred between approximately July and March (Stahle 1990, Guyette and Spetich 2003, Guyette and Stambaugh 2004). We estimated the season of fire occur-

Figure 3. Fire scars in tree scarred by 22 unknown origin fires and 1 prescribed burn, Okmulgee Game Management Area, Oklahoma, USA.

rence by classifying specific scar positions as early-earlywood, middle-earlywood, late-earlywood, latewood, dormant, or undetermined (Grissino-Mayer 2001).

A fire index (Guyette and Cutter 1991) and program SSIZ (Holmes 1995) were used to determine the effect of sample size on fire frequency estimates. The number of cross-sections is usually greatest for the most recent years and declines with time; consequently, the number of fire scars may be greatest for the recent past simply due to a greater sample size. Both the fire index and program SSIZ reveal bias in fire frequency estimates through time. Program SSIZ computes mean and 95% confidence interval curves for the estimated number of fires for randomly chosen groups of sampled trees. The point at which the mean curve flattens indicates that increasing sample size of the randomly chosen groups of sampled trees no longer increases the number of fire years detected. We calculated the fire index by dividing the number of trees scarred in each one-year time interval by the number of cross-sections we collected that contained the same time interval. In order to identify relationships between the spatial extent of fires and topography and climate, we mapped the approximate location of each fire scar as in Figure 1 and compared the spatial extent of each fire with aspect and Palmer Drought Severity Index (PDSI; Palmer 1965, Cook *et al.* 2004).

Previous literature showed relationships between the diameter and age of trees and PDSI and the likelihood of post oak trees to exhibit fire scars (Guyette and Stambaugh 2004, Clark *et al.* 2007). Therefore, we used correlation analysis to determine significance of the following relationships: 1) cross-sectional diameter and the percent of cross-sections scarred, 2) percent scarred and Palmer Drought Severity Index, 3) pith dates and PDSI, and 4) pith dates and percent scarred.

We used program FHX2 (Grissino-Mayer 2001) to determine differences in means, variances and distributions of fire intervals, and percent of cross-sections scarred between time periods using Student's *t*-tests, F-tests, and Kolmogorov-Smirnov Goodness-of-Fit (KS) tests. The time periods we analyzed corresponded to the predominant culture or population occupying the area or the predominant land use: Osage (1750-1836), Creek (1837-1899), Pre-EAS (1750-1899), Post-EAS (1900-1988), and Prescribed Burning (1989-2005). From approximately 650 to 1550, the indigenous Caddo inhabited land east of Okmulgee, but subsequently abandoned the area and gradually moved south (Wyckoff 1980). In the mid-1700s, the Osage began to expand their territory for hunting purposes and may have occasionally passed through the Okmulgee area (Bailey 1973; B. Bays, Oklahoma State University-Stillwater, personal communication). The Creek arrived following the Indian Removal Act and comprised more widespread permanent settlements in the area by 1837 (Okmulgee Historical Society 1985). From 1900 to 1907, the nearby town of Okmulgee was incorporated, oil was discovered nearby, the railroad was completed, and Oklahoma was established as a state. These events made the area more accessible and more attractive to Euro-American settlers, and Okmulgee quickly increased in population. From the 1910s to 1950s, OGMA was privately owned by Euro-American settlers and was subsequently sold to the ODWC in the 1950s (B. Burton, ODWC, personal communication). Although the human population density of the Okmulgee area steadily increased throughout the nineteenth century, it was not until Post-EAS at the turn of the twentieth century that a substantial population base was established within proximity (Martin 1936, Wyckoff 1980, Okmulgee Historical Society 1985). At the onset of the twentieth century, there was a larger variety of land use due to oil exploration and settlement (Martin 1936, Okmulgee Historical Society 1985). Euro-American influence in the area prior to 1900 was not as substantial as Creek influence but steadily increased until Euro-American influence eventually overwhelmed Creek influence, especially when the nearby town of Okmulgee was incorporated in 1900 (Okmulgee Historical Society 1985; B. Bays, personal communication).

We use Post-EAS here to describe a period of time but note that after 1900, Euro-American settlement continued for decades. While there was likely prescribed burning prior to 1989 (B. Burton, personal communication), the only fires of known origin occurred after 1988; thus, we refer to the 1900-1988 period as Post-EAS and the 1989-2005 period as prescribed burning. We computed mean and median fire intervals for the composite fire history and used KS tests to determine whether a Weibull distribution fit the data better than a normal distribution and whether mean, median, or Weibull means or medians described the historical fire interval better (Table 1).

We used FHX2 to produce a fire scar history chart (Figure 4) and to determine the relationship between climate and fire using superposed epoch analysis (SEA; Grissino-Mayer [2001]). The SEA analyzes climate and fire history data to determine if climate was significantly different than normal during an eleven-year window of time bracketing each fire event. We conducted SEA using all fires (including those that scarred only one tree) and reconstructed summer PDSI (Cook *et al.* 2004) for the averaged central (grid point 179; 97.5°W, 35.0°N) and eastern (grid point 193; 95°W, 35°N) Oklahoma grid points from 1750 to 2005. In addition, we conducted SEA using fires that scarred at least two trees. We also analyzed differences in fire intervals and percent of cross-sections scarred between time periods using fires that scarred at least two trees.

RESULTS

Our sample collection contained 69 cross-sections taken from one management unit of OGMA (Figure 1). We identified 181 scars from 83 fires for the time period 1750 to 2005, including all but one (1999) of the ten documented prescribed burns (Figure 4). Although we determined the tree-ring record from 1691 to 2008, we chose to analyze fire history from the period 1750 to 2005 due to settlement history and sample size, but our sample collection did not record any fires before 1750 or after 2005.

Forty-three percent of fires scarred only one tree and on average there were 2.6 scars per cross-section. The standard deviation and range for the average number of scars per cross-section were 3.17 and 1 to 23, respec-

Table 1. Descriptive fire history statistics for Okmulgee Game Management Area, Oklahoma, USA. Abbreviations: EAS = Euro-American Settlement, MFI = mean fire interval, Median = median fire interval, SD = standard deviation.

Time period	MFI (yr)	Median (yr)	SD (yr)	Range (yr)	Number of intervals	Years with ≥7% cross-sections scarred (percent)	Years covered
Pre-EAS	4	3	2.8	1-12	28	1877 (7)	1750-1899
Osage	5.9	5.5	3.5	2-12	8	none	1750-1836
Creek	3	3	1.6	1-7	19	1877 (7)	1837-1899
Post-EAS	2	2	1.1	1-5	44	1957 (7), 1975 (12), 1979 (13)	1900-1988
Prescribed burning	1.8	2	0.5	1-2	8	1989 (11), 1993 (9), 2003 (9)	1989-2005
Total	2.7	2	2.1	1-12	82		1750-2005

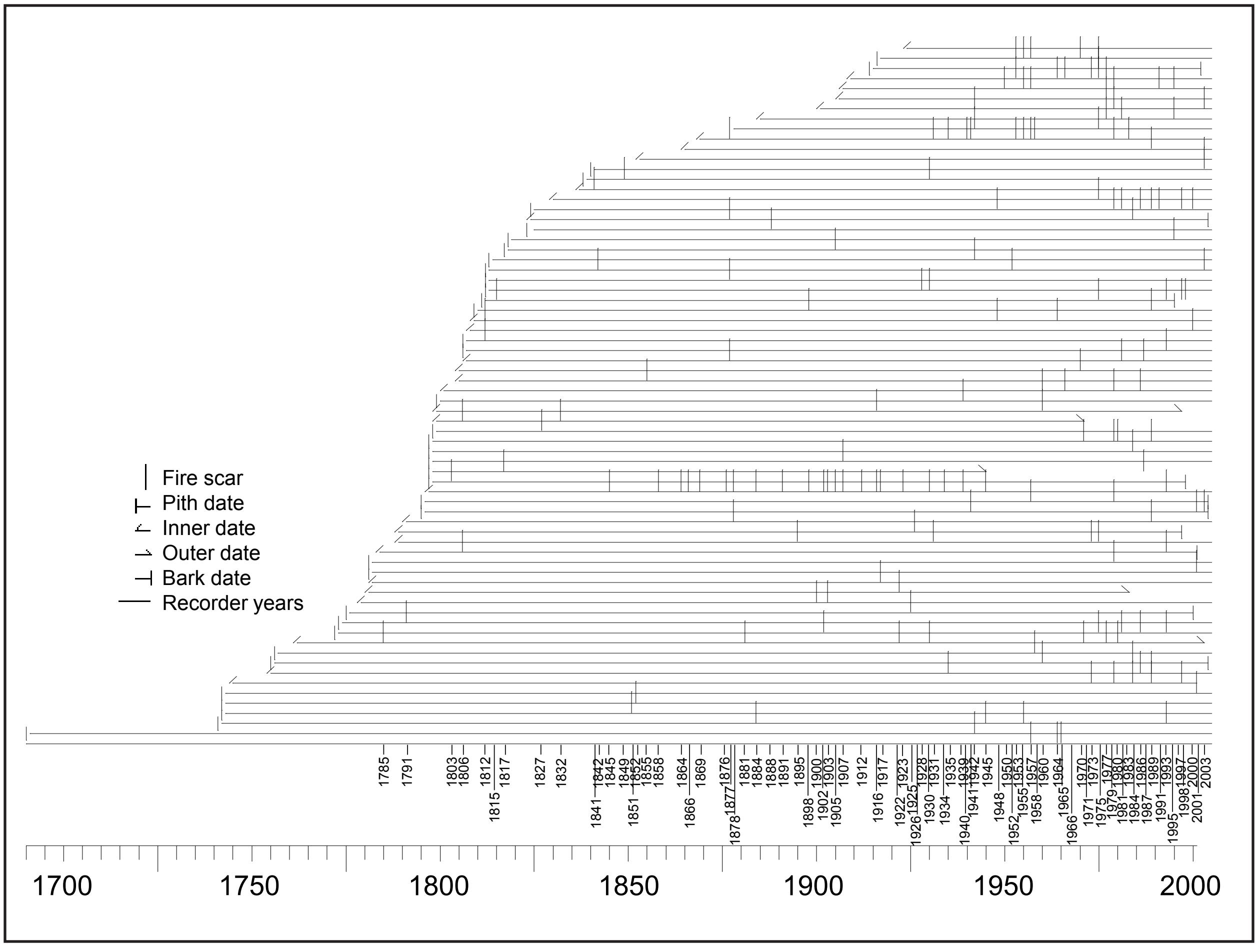

Figure 4. Fire scar history chart, Okmulgee Game Management Area, Oklahoma, USA.

tively. Of the 62 % of scars that we could identify to season, 95 % were in the dormant season, 3 % in the latewood growing season, and 2 % in the early-earlywood growing season. Trees ranged in age from 85 yr to 318 yr with a mean age of 208 yr. However, this estimate excludes 46 % of our sample collection due to their hollow interiors.

The mean curve produced by program SSIZ flattened out at a lower sample size than we collected, indicating that we had an adequate sampling intensity (data not shown). Likewise, the results of the fire index suggested that we had an adequate sampling intensity; as shown in Figure 5. The tree-ring record of 87 % of our sample collection dated earlier than 1877 yet we detected only two fires prior to 1877 and 45 fires after 1877 that scarred more than one tree. Additionally, over 50 % of the 69 cross-sections were older than all but the four earliest fire scars recorded by our sample collection, 28 % were older than the earliest fire scar, and 19 % were more than ten years older than the earliest fire scar.

We did not detect significant relationships between topography or climate and the spatial extent of fires ($r < 0.1$ and $P > 0.05$ in all cases). However, there was a substantial increase in percent of cross-sections scarred between the Pre-EAS and Post-EAS time periods, with no substantial increase in sample size (Table 1 and Figure 5). We did not detect a significant relationship between tree diameter and percent of cross-sections scarred, percent scarred and PDSI, pith dates and PDSI, and pith dates and percent scarred ($r < 0.1$ and $P > 0.05$ in all cases).

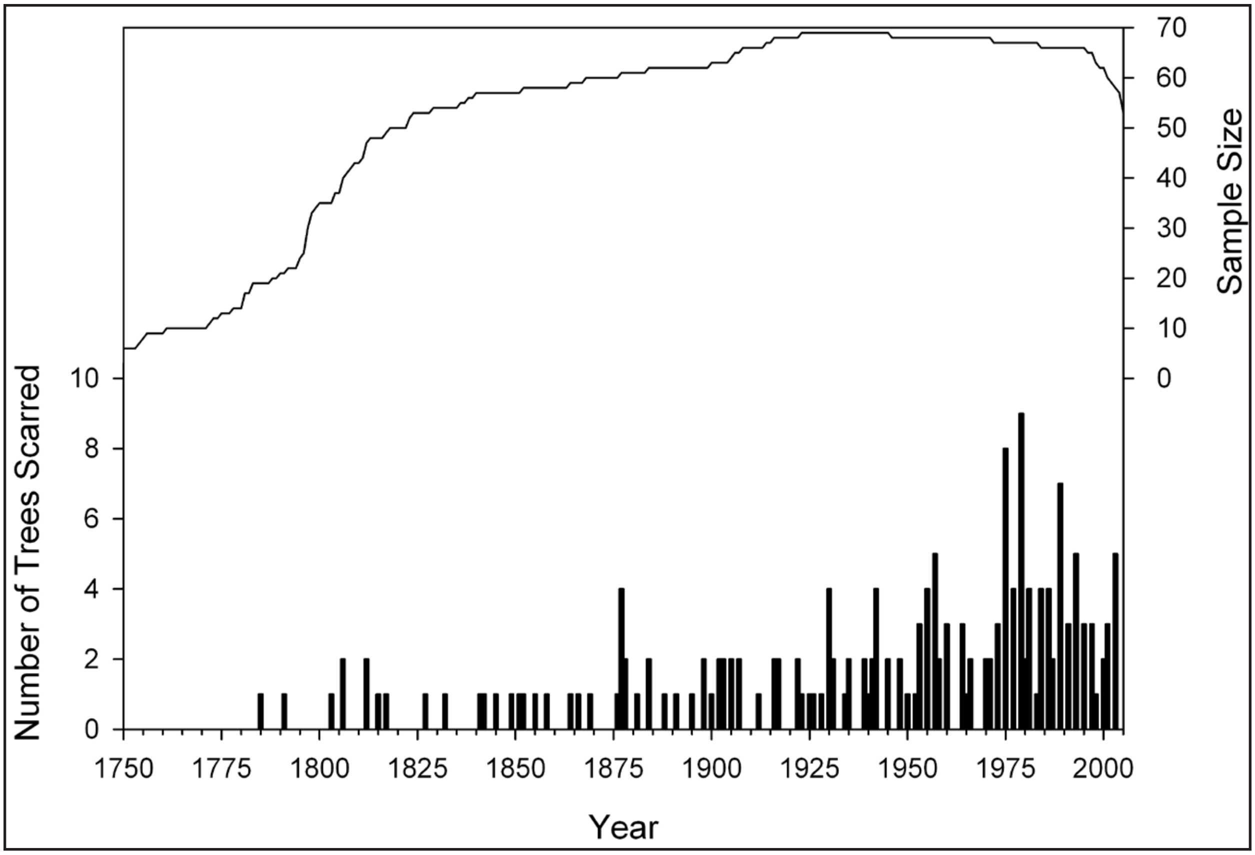

Figure 5. Number of trees scarred and sample size per year, Okmulgee Game Management Area, Oklahoma, USA.

There were significant decreases in mean fire intervals (MFI) and significant increases in percent of cross-sections scarred between the Osage and Creek, Creek and Post-EAS, and Pre- and Post-EAS time periods ($P < 0.05$ in all cases; Table 1, Figures 4 and 5). The KS tests determined that the Weibull distribution did not fit the fire interval data and that fire intervals were not normally distributed, so we report median fire intervals here because they are a better descriptor of central tendency than means with non-normally distributed data: 5.5 yr for the Osage time period, 3 yr for each of the Creek and Pre-EAS time periods, and 2 yr for each of the Post-EAS and Prescribed Burning time periods. We also report the widely used MFI in Table 1.

The superposed epoch analysis component of FHX2 did not detect a significant relationship between climate and fire (Figure 6). Using only fires that scarred two or more trees, we did not detect significant differences in MFI or percent of cross-sections scarred between time periods, or between drought and fire frequency.

DISCUSSION

Our findings provided strong support for an ignition-dependent anthropogenic fire regime in the Okmulgee area over the past 250 yr (Guyette *et al.* 2002). Increasing human population corresponded with decreasing MFI and lightning ignition did not appear to be a major factor. These findings contradicted the common belief that MFI increased Post-EAS throughout south-central North America (Martin 1936, Wyckoff 1980, Okmulgee Historical Society 1985). Only one other study in this area found a decrease in MFI continuing

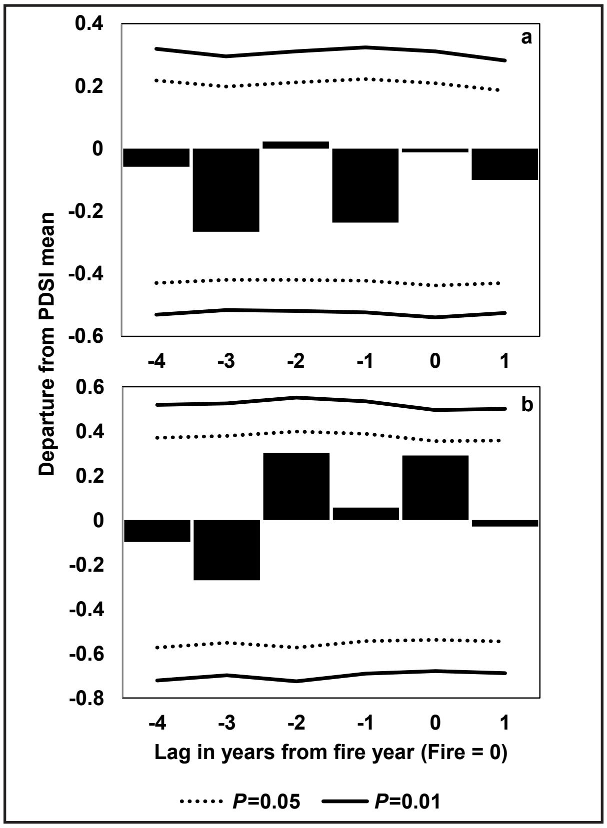

Figure 6. Superposed epoch analysis of all fires (a) and all fires scarring two or more trees (b) compared with the average of reconstructed summer PDSI grid points 179 and 193, Okmulgee Game Management Area, Oklahoma, USA.

through the Post-EAS period (Clark *et al.* 2007). The OGMA fire regime contrasts with other studies in the region that found that climate played a major role in the fire regime (Clark *et al.* 2007, Stambaugh *et al.* 2009).

Oak-dominated forests in the Okmulgee area are part of a broad forest-prairie transition zone locally referred to as the Cross Timbers (Hoagland *et al.* 1999). Geochronological studies suggest that the Cross Timbers ecotone formed between the margins of the North American Great Plains prairie and eastern deciduous forest ecosystems more than 8000 years ago (Albert 1981, Bryant and Holloway 1985, Delcourt 2002). Soil type and a longitudinal moisture gradient strongly influenced woody and herbaceous vegetation, but fire helped shape this ecotone by altering vegetation composition and structure for the past 5000 years (Albert 1981, Hoagland *et al.* 1999, Anderson 2006). Lightning-initiated fires probably influenced the forest-prairie transition zone on a broader scale while anthropogenic ignitions may have maintained a patchwork of oak-dominated forests on a smaller scale (Pyne 1982, Frost 1998, Petersen and Drewa 2006). Therefore, the fire history of the Cross Timbers may be linked to the regional human history.

The progressive decrease in MFI on the OGMA during successive Pre-EAS and Post-EAS cultural periods suggested trends in human interaction with vegetation and fire similar to those reported for the nearby Missouri Ozarks (Guyette *et al.* 2002). There, fire occurrence was dependent on human ignition at low population densities and MFI declined with increasing population. Post-EAS population increases led to ignition saturation when fire eventually became fuel-limited. Periodic fire was limited by the rate at which the site could produce new fuel for future fires. In the Missouri Ozarks, MFI declined to a minimum of 1.4 yr (Guyette and Spetich 2003), compared to 2 yr at OGMA prior to the current prescribed burning period. The OGMA fire history did not include the last two fire regime phases of the Missouri Ozarks, where continuous increases in population density led first to fuel fragmentation and finally to fire exclusion as MFI increased (Guyette *et al.* 2002). The OGMA may never experience fuel fragmentation from roads and development because the ODWC controls over 4400 ha in and around OGMA. Therefore, the future MFI will likely be set by ODWC management plans. In a nearby fire history study on private land, the MFI declined to 2.1 yr in the most recent period (Clark *et al.* 2007), similar to our findings from OGMA.

The OGMA fire history suggested that fires were larger Post-EAS, contrary to the findings of Clark *et al.* (2007). The increase in percent of cross-sections scarred between the Osage and Creek time periods appeared to be linked to the OGMA settlement history. Prior to Creek settlement of the area, ignitions may have been from transient hunting parties, whereas permanent settlements and fire frequency increased during the Creek occupation (Martin 1936, Hudson 1976). The increases in percent scarred between the Creek and Post-EAS and between the Pre- and Post-EAS time periods may be explained by an increase in human occupation and, later, changes in fire management following the acquisition of OGMA by the ODWC; six of the seven fire years with the highest percent of cross-sections scarred occurred after the ODWC acquisition of OGMA (Table 1). The ODWC probably had more resources available and may have initiated prescribed burning on a scale larger than that of fires set by previous private landowners.

Our results suggested a dominant role for anthropogenic fire at OGMA. Similar to other studies indicating the importance of anthropogenic ignitions in south-central North American oak forests, the OGMA MFI declined as settlement population and activity increased (Guyette *et al.* 2002, Guyette and Spetich 2003, Clark *et al.* 2007). Additionally, our results and previous research showed a prevalence of dormant season fire scars (Guyette and Cutter 1991, Guyette and Spetich 2003, Stambaugh *et al.* 2006, Clark *et al.* 2007, Stambaugh *et al.* 2009). Although lightning can occur at any time of the year, in the Okmulgee area, lightning was probably much less frequent during the dormant season when typically cooler and moister conditions are less conducive for ignitions (Bragg 1982, Orville and Silver 1997, NOAA 2010). Lightning fires were of minor importance in an old-growth oak-pine forest 200 km southeast of OGMA, where only 24 % of the fires accounting for only 3 % of the total area burned were due to lightning ignitions between 1939 and 1992 (Masters *et al.* 1995). Moore (1972) attributed 100 % of documented historical fires in south-central North America to humans during the period 1535 to 1890. Although lightning certainly occurred, it was not likely to be the major source of ignitions during the dormant season and probably played a minor role in the OGMA fire regime compared to anthropogenic ignition.

Previous fire history studies in Cross Timbers forests found links between fire and drought. Clark *et al.* (2007) found that the percent of scarred trees increased with drought, and Stambaugh *et al.* (2009) found that MFI decreased during a severe nineteenth century drought. Although we found little evidence that climate affected the OGMA fire regime, two of the seven years with 7 % or more cross-sections scarred were associated with extreme weather. The 1877 fire occurred in the dormant season immediately following a local, severe late-spring frost that may have killed a substantial amount of live vegetation, fueling fires in the following dormant season (Stahle 1990). Similarly, the 1957 fire occurred in the dormant season immediately following a local, severe southern plains drought, which also may have killed vegetation and increased fuel (Rice and Penfound 1959; Cook *et al.* 2004, 2007). However, neither the local, severe "Civil War drought" of the 1850s to 1860s (Cook *et al.* 2004) nor other documented late-spring frosts (Stahle 1990) were associated with decreased MFI or increased percent scarred. In addition, we did not detect a significant relationship between MFI and PDSI or percent of cross-sections scarred and PDSI.

Our findings are important for understanding the nature of south-central North American oak forests. Research has shown that fire frequency and seasonality influence plant community composition, structure, and dynamics over time. For example, woody deciduous species can eventually be reduced by long-term annual winter burning, quickly removed by summer burning, and stimulated to regenerate by periodic burning; and frequent fires can favor herbaceous over woody species (Waldrop *et al.* 1992; Peterson and Reich 2001, 2008; Burton *et al.* 2010). Varying fire frequency can have differential effects on the survival and regeneration of relatively fire-tolerant and fire-adapted species like oaks (Huddle and Pallardy 1996). Fire ignition sources have implications for both the frequency and seasonality of fire. For example, non-anthropogenic ignitions are more likely to occur during dry periods and periods of higher lightning strike densities (Komarek 1968, Frost 1998). Without a substantial lightning fire regime, anthropogenic fire can help maintain dominance by fire-tolerant and fire-adapted species such as oaks, and the absence of fire can encourage the eventual replacement of oaks by fire-intolerant species (Abrams 1992).

While fire scars in ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forests of the southwestern US have been used to accurately reconstruct the extent of fires (Farris *et al.* 2010), the accuracy of using fire scars for reconstructing fire extent in oak forests has not been established. For this reason we limited inferences and discussion concerning the historical spatial extent of fires and focused more on the temporal aspects of the OGMA fire history. The use of fire scars to accurately reconstruct temporal aspects of fire in oak forests has been well established (Guyette and Stambaugh 2004).

Our findings appeared to suggest that anthropogenic ignitions were crucial to the OGMA fire regime. The fire frequency of the current prescribed burning regime at the study site appears to be higher than at any time during the past 250 yr. Although our sample collection was taken from the management unit most frequently prescribed burned, the fire frequency for the earlier Post-EAS period was only slightly lower (MFI of 2 yr compared to 1.8 yr). The absence of anthropogenic fire at OGMA could result in an infrequent fire regime and the eventual replacement of fire-adapted and fire-tolerant species like oaks by mesophytic, fire-intolerant, shade-tolerant species (Nowacki and Abrams 2008, DeSantis *et al.* 2010*b*). Recent research at OGMA suggested that the current fire frequency and intensity will not reduce the overstory, but will suppress mesophytic woody plants and favor fire-tolerant oaks (Burton *et al.* 2010). This may be evidence that the maintenance of oak-dominated forests like OGMA necessitates human intervention in the fire regime.

ACKNOWLEDGEMENTS

S. Clark and M. Stambaugh provided valuable advice. We thank M. Allen, J. Beale, B. Burton, J. Burton, K. Hesse, L. Karki, E. Lorenzi, J. Polo, and R. Williams for field and laboratory assistance. Thanks to the Oklahoma Department of Wildlife Conservation and Okmulgee Wildlife Management Area for cooperation and access to the study site. We thank J. van Wagtendonk and two anonymous reviewers for their helpful comments on an earlier draft of this manuscript.

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