RESEARCH ARTICLE

FIRE, DROUGHT, AND HUMAN HISTORY NEAR THE WESTERN TERMINUS OF THE CROSS TIMBERS, WICHITA MOUNTAINS, OKLAHOMA, USA

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ABSTRACT

Dendrochronological methods were applied to reconstruct the historic occurrence of fires at a Cross Timbers forest-grassland transition site within the Wichita Mountains of southwestern Oklahoma, USA. Sixty fire events occurred within the period 1712 to 2006 (294 years). The mean fire interval (MFI) was 4.4 years for a pre-Euro-American settlement period (pre-1901) and increased to a MFI of 5.2 years after 1901. During the period between 1855 and 1880, which corresponds with the prolonged severe drought called the Civil War drought, the mean fire interval was 1.7 years. Although twentieth century fire frequency has not been significantly decreased, the severity of fires appears to be lessened due to alterations to the fire environment through grazing and fire exclusion. Eastern redcedar (*Juniperus virginiana* L.) expansion now poses significant challenges to forest and range management, particularly its control through prescribed fire. In the future, fire managers throughout the Cross Timbers region are likely to face similar challenges and look toward quantitative and science-based information about the historic fire regime for guidance.

Keywords: drought, fire history, Great Plains, post oak, Wichita Mountains

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INTRODUCTION

The Great Plains is a grass (Poaceae)-dominated biome that occupies roughly one tenth of North America (Licht 1997). Although geology and water availability distinguish broad-scale vegetation patterns (Braun 1947, Axelrod 1985), grazing and fire historically defined finer-scale variability of ecological processes and vegetation communities. For grazing, limited prehistoric information is recoverable; however, it is widely accepted that grazing by herbivores, particularly American bison (*Bison bison*), had important and selective effects on grassland vegetation success and patterning (Larson 1940, Coppedge *et al*. 1998). Much greater potential exists for obtaining paleofire data—information that can be used to develop fire management goals, assess fire risk, and weigh the concomitant role of grazing.

Fires in grasslands are thought to have been historically very frequent (Wright and Bailey 1982) and, depending on grazing and climate, possibly annual (Anderson 1990, Bond and van Wilgen 1996). Although annual burning of grasslands is possible across broad regions, no strong quantitative evidence exists to support that such a frequency occurred over long time periods, and questions remain about the historic range of variability of grassland fire regimes and the scale-dependence of fire frequency estimates. For example, prior to Euro-American settlement, it is improbable that the entire Great Plains region burned on the same day every year (a true annual fire frequency). Instead, fires burned heterogeneous landscapes with varied timing determined by many factors (e.g., weather, vegetation, grazing, time since last fire, topography) and, therefore, it is logical that characterizations of fire regimes and the resulting landscape patterns and ecological processes are scale-dependent (Falk *et al.* 2007, Kerby *et al.* 2007).

The objective of this study was to document long-term changes of a fire regime within the southern Great Plains. In particular, we wanted to add to the relatively sparse body of quantitative fire history studies that represent grassland fire dynamics. We assumed that a site with savanna or woodland characteristics that was surrounded by a grassland expanse would represent grassland fire regime characteristics. In savannas and woodlands, herbaceous fuels constitute the major surface fuel type, and it is possible that changes in fire regimes have occurred and fire-scar records could be used to characterize grassland fire dynamics. We hypothesized that: 1) temporal changes in fire frequency coincided with changes in population and cultures, 2) historic fires were primarily dormant-season events, 3) severe fire events were associated with droughts, and 4) twentieth century fire regime attributes (i.e., frequency, severity, seasonality) were different from those of the pre-Euro-American settlement period.

Fire Scar History of the Great Plains and Cross Timbers

Though broadly characterized as grassland biome, forested areas occur within the Great Plains region and provide potential for recovering multi-century fire history data from fire scars on trees. Forested areas occur at higher elevations, on unique landforms, and in vicinities of fire breaks such as rivers and canyons. Large forested areas include ponderosa pine (*Pinus ponderosa* C. Lawson) forests in the Black Hills and oak (*Quercus* spp. L.)-dominated woodlands in the southern plains (e.g., Cross Timbers, post oak [*Quercus stellata* Wangenh.] savanna). From these areas and others, fire scar history studies have provided evidence for long-term climate forcing of fire (Brown 2006, Stambaugh *et al*. 2008a), spatio-temporal variability in fire frequency (Perryman and Laycock 2000; Guyette *et al*. 2006*a, b*; Clark *et al.* 2007; Stambaugh *et al*. 2008*a*), and the importance of fire for maintaining vegetation communities and forest structures (Brown and Sieg 1999, Clark 2003, Stambaugh *et al*. 2006).

The Cross Timbers is a large forest region within the southern plains of the US that is characterized as a transition zone between forest and grassland. The region extends north to south from southeastern Kansas to central Texas and west to east from western Oklahoma to western Arkansas (Küchler 1964, Francaviglia 2000) (Figure 1). In addition to their occurrence within a grassland biome, forests of the region are unique because of their widespread area of old-growth forest conditions (Therrell

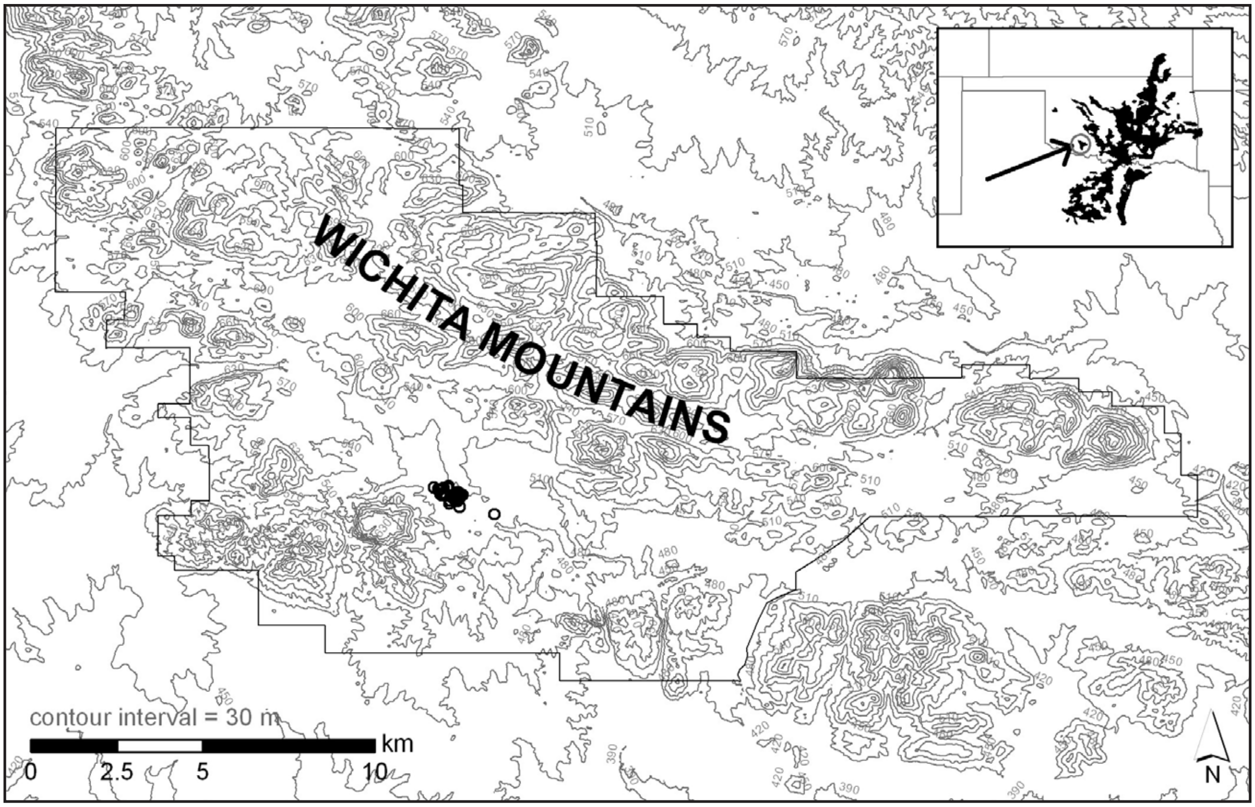

Figure 1. Topographic map of the Wichita Mountains National Wildlife refuge (black line) and vicinity. Cluster of circles represents the locations of trees and extent of area sampled for fire history. Inset: circle represents the location of the Wichita Mountains within the Cross Timbers forest region (black polygon, Küchler 1964).

and Stahle 1998, Clark *et al.* 2005) and associated floral and faunal diversity (Hoagland *et al*. 1999, Masters 2000). Cross Timbers forests are commonly dominated by post oak and blackjack oak (*Quercus marilandica* Münchh.), but can also include significant components of other tree species (e.g., eastern redcedar [*Juniperus virginiana* L.], black hickory [*Carya texana* Buckley], winged elm [*Ulmus alata* Michx.], and sumac [*Rhus glabra* L.] depending on site location and region.

Francaviglia (2000) suggested that prairie fires burned along the edges of Cross Timbers and may have extinguished in their interior due to a lack of fuels. In contrast, Engle *et al.* (1996) emphasized that fire is needed to promote and restore native plant and animal species and reduce woody encroachment. Fire scar history studies have shown that fires were common to Cross Timbers forests, both historically and recently. Clark *et al.* (2007) reported a median fire return interval of 2.0 years (period: 1772 to 2002) for an old-growth Cross Timbers forest north of Tulsa, Oklahoma. Here, fires burned more frequently since settlement than before. In a 20 ha area within the Chautauqua Hills of southern Kansas, fire scars also indicated historically frequent fire (median fire interval = 2.1 years, period: 1850 to 2005; M.C. Stambaugh, University of Missouri-Columbia, unpublished data). At the Tallgrass Prairie Preserve in central Oklahoma, fire scars indicated near-annual burning during the late twentieth century (median fire interval = 1.4 years, period: 1947 to 1992; Shirakura 2006). More information is needed that describes the historic importance of fire to the Cross Timbers and how it relates to the grass-dominated areas of the southern Great Plains. Descriptions of the historic fire regime would aid in designing fire treatments to mimic historic conditions and measuring the effectiveness of prescribed burning treatments used to restore vegetation composition and structure.

METHODS

Study Site

The study site was located in the Wichita Mountains (34˚45'N, 98˚38'W) of southeastern Oklahoma (Figure 1). The Wichita Mountains are an igneous mountain range of rugged and barren peaks with elevations ranging between 420 m and 730 m. The mountains are one of the drier portions of the Cross Timbers with an average annual precipitation of approximately 78.2 cm (period: 1914-2008; NCDC 1999). Less than 5 cm of precipitation occurs each month during the winter (November through February). Parent materials of the mountains are primarily igneous in the form of gabbro and granite (Chase *et al*. 1956) and soil types are cobbly colluvial and rough stony soils. The site is currently owned and managed by the US Fish and Wildlife Service, Wichita Mountains Wildlife Refuge.

The mountains represent the western edge of the Cross Timbers where oak communities abruptly transition to mixed-grass prairie (Küchler 1964) to the west. Eskew (1938) described the Wichita Mountains as an area consisting of groves of mixed-oaks surrounded by hundreds of kilometers of treeless prairie. Mixed-grass prairie and dry oak forests are the largest plant associations (Figure 2), and within forests the most important herbs and forbs include big bluestem (*Andropogon gerardii* Vitman), silver bluestem (*Bothriochloa saccharoides* [Sw.] Rydb.), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), Cuman ragweed (*Ambrosia psilostachya* DC.),

Figure 2. Photograph from the study site representing the typical conditions of post oak (*Quercus stellata* Wangenh.) tree density and grass cover.

purpletop tridens (*Tridens flavus* [L.] Hitchc.), and tall dropseed (*Sporobolus asper* [P. Beauv.] Kunth) (Buck 1964). Buck (1964) listed the most common tree species as post oak and blackjack oak (*Quercus marilandica* Münchh.) with inclusions of eastern redcedar, Arizona walnut (*Juglans major* [Torr.] A. Heller), and netleaf hackberry (*Celtis laevigata* Willd. var. *reticulata* [Torr.] L.D. Benson), with closed forest basal areas ranging from 20.6 m^2 ha^{-1} to 25.3 m^2 ha^{-1} (90 ft^2 ac^{-1} to 110 ft^2 ac^{-1}). Eastern redcedar is encroaching into grasslands and forests throughout the refuge (Buck 1964, Dooley 1983) and, based on locations of old trees (>200 years), we speculate that this species was historically limited to granitic outcrops and sites protected from fires.

Fire is a critical ecological component of the Wichita Mountains and an important management tool. The frequency of fire is believed to have undergone many changes during historic periods and is generally thought to be decreased from the pre-Euro-American period. From about 1938 to 2005, a mean of 880 ha burned annually (wildfires and prescribed fires combined), resulting in an overall fire rotation period (i.e., duration of time until total area of refuge is burned considering mean rate) of 27 years (R. Wood, US Fish and Wildlife Service, unpublished report).

Sample Collection

We chose the Wichita Mountains Wildlife Refuge as a potential study site because there was a lack of fire history information available from the western Cross Timbers and southern Great Plains. In November 2007, we sampled 55 post oak trees to reconstruct the history of fire events from tree-ring dated fire scars. Fire history samples were collected from recently dead trees in a prescribed burn unit located approximately 1 km east of refuge headquarters (N34°43'43", W98°42'13") and immediately north of French Lake, a reservoir constructed on West Cache Creek in the 1930s by the Civilian Conservation Corps. Samples were located within a 1 km^2 area and consisted of cross-sections cut with chainsaws from the bases of trees killed by a prescribed fire in 2006 (Figure 3). Trees were first sounded using a hammer to determine whether the tree was hollow or rotten and were rejected if significant decay was suspected. Tree height and diameter at breast height (dbh) were measured for all trees that had unbroken crowns, and all tree locations were documented using a global positioning system (GPS) unit. In the laboratory, all cross-sections were sanded using progressively finer sandpaper (80 grit to 1200 grit) to reveal the cellular detail of annual rings.

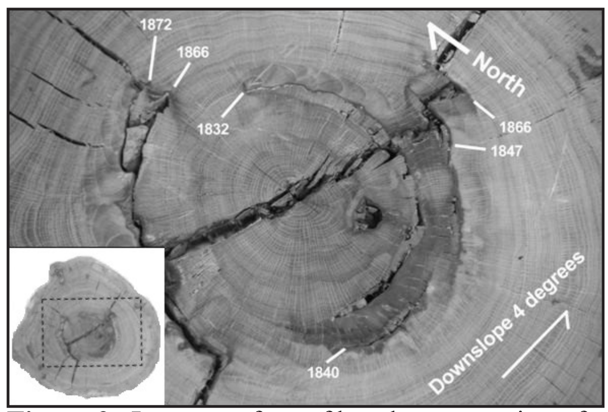

Figure 3. Lower surface of basal cross section of a post oak sample (WCH044). White lines and numbers indicate the locations and calendar years of fire scars. Inset shows the entire section with the area inside the dashed line representing the area of the enlarged photo. The pith of the tree is 1771, the same year as a severe fire. Scars on the sample not indicated were in 1786, 1838, 1864, 1869, and 1958. These scars were either represented on the upper side or as microscopic cell anomalies.

Analysis

All tree rings were measured to 0.01 mm precision, and ring-width patterns were visually crossdated using ring-width plots (Stokes and Smiley 1968). Sample ring-width measurements and dates were verified by crossdating with a post oak master ring-width chronology archived in the International Tree-Ring Data bank (ITRDB) (Quanna Mountain: Stahle *et al*. 1982). Computer program COFECHA (Holmes 1983) was used to ensure accurate dating of samples. A master chronology from the site was developed and archived in the ITRDB (Stambaugh *et al*. 2008*b*). We used program ARSTAN (Cook 1985) to detrend and standardize ring-width series and develop a mean indexed chronology.

Fire scars were identified by the presence of callus tissue, charcoal, barrier zones, and cambial injury (Figure 3). Fire scar dates were assigned to the year and, where possible, season of response to cambial injury (Smith and Sutherland 1999). We used FHX2 software (Grissino-Mayer 2001) to construct the fire chronology, analyze fire scar years, and graph individual tree and composite fire intervals. Fire scar intervals were summarized for a pre- and post-1901 period associated with transition to Euro-American settlement of the region. Mean and median fire intervals and descriptive statistics were computed for both the composite and individual trees. Kolmogorov-Smirnov Goodness-of-Fit (K-S) tests were used to determine whether a Weibull distribution described the fire interval data better than a normal distribution. A *t*-test of sample means ($\alpha = 0.05$) was conducted to determine whether fire intervals were significantly different between the pre- and post-Euro-American settlement periods. Fire severity was defined as the percentage of trees scarred in fire events where sample depth was at least three trees.

Superposed epoch analysis (SEA) was conducted to determine the influence of regional drought on fire events (Fulé *et al*. 2005). Annual drought data were reconstructed Palmer Drought Severity Indices (Cook *et al*. 2004) for southwestern Oklahoma. Data were bootstrapped for 1000 simulated events to derive confidence limits. Fire event years were compared to climate parameters to determine if drought was significantly different from average during the six years preceding and four years succeeding fire events. In addition to SEA, we used Pearson correlations to determine whether percent trees scarred and drought were related.

For wind-driven fires (i.e., downwind-burning fire movement), the flame heights, residence time and stem heating are increased on the leeward side of the tree bole (Gill 1974, Gutsell and Johnson 1996) and, therefore, could be an indicator of fire movement direction. For the three most severe fire years, we assumed wind-driven fire events and plotted the bearing (degrees) of the fire scars on the tree boles in order to characterize the direction of fire movement. Fire scars were assigned a bearing that represented the direction of the middle of the arc of killed cambium. In addition to fire directions, we used maps of tree locations to compare dates and locations of known prescribed burns and wildfires to events recorded by fire scars.

RESULTS

The tree-ring record spanned a period of 294 years (1712 to 2006) (Figure 4). One sample was excluded due to extensive rot and few numbers of tree rings. Post oak trees ranged in age from 100 years to 294 years. Based on pith dates, a period of post oak tree establishment occurred circa 1890 and, based on tree growth, many of the trees exhibited a growth release around 1904 (Figure 5).

We identified and dated 122 fire scars that occurred from 60 different fire events (20.4 percent of years had fire). Fire-scar events ranged in calendar years from 1722 to 2001 (Figure 4). Ninety-seven percent of fire scars occurred in the dormant-season ring position indicating that the fires burned, approximately, between September and March. For the entire period of record, the mean fire interval was 4.7 years. The MFI was 4.4 years for a pre-Euro-American settlement period (pre-1901) and

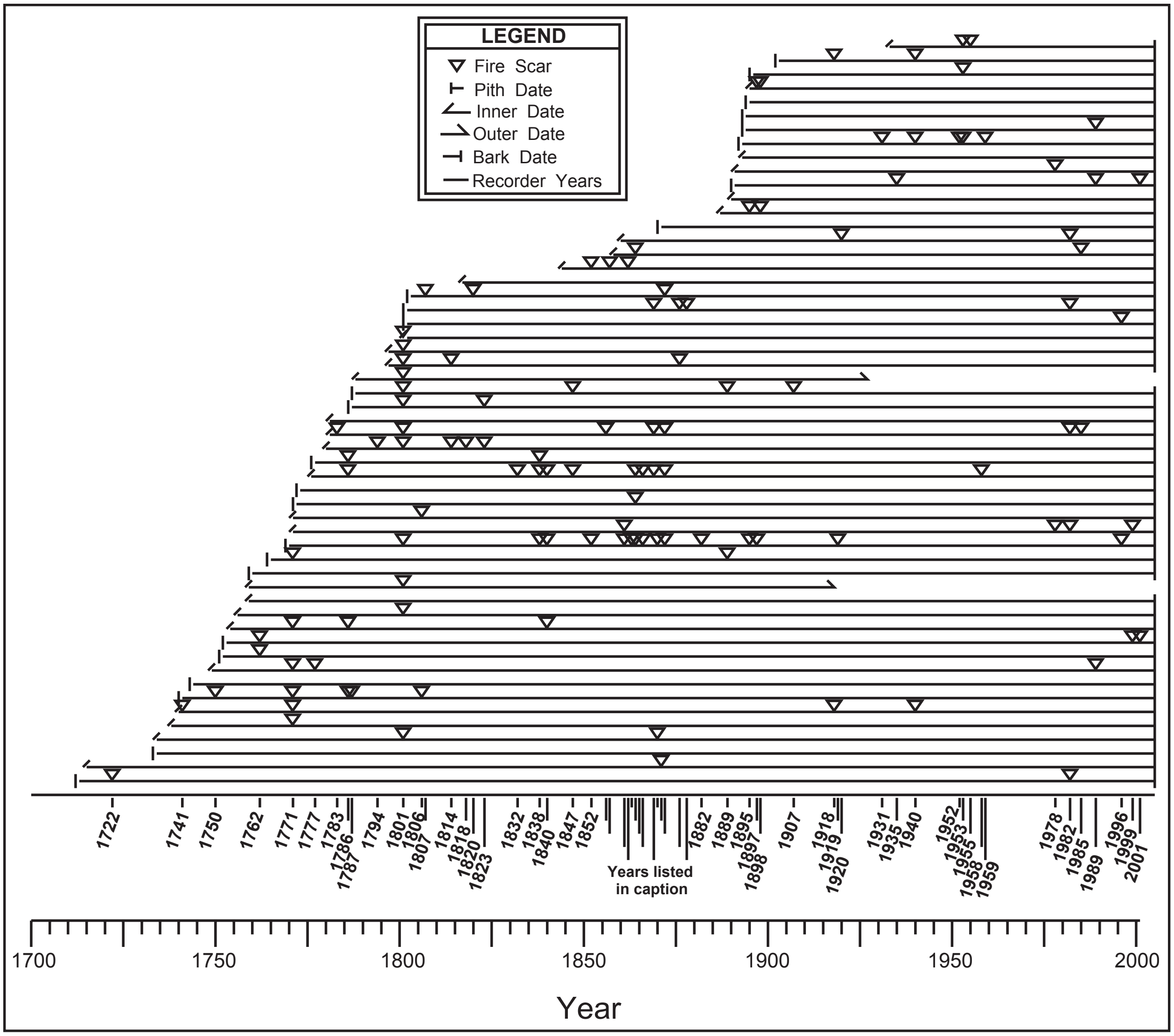

Figure 4. Fire scar history chart from north side of French Lake, Wichita Mountains National Wildlife Refuge, southwestern Oklahoma. Each horizontal line represents the length of the tree-ring record of a post oak sample tree. Inverted triangles represent the year of a fire scar. The composite fire scar chronology with all fire scar dates is shown at the bottom of the figure. Event years occurring between 1855 and 1880 are (left to right): 1856, 1857, 1861, 1862, 1863, 1864, 1865, 1866, 1869, 1870, 1871, 1872, 1876, and 1878.

lengthened to a MFI of 5.2 years post-1901. Based on the Kolmogorov-Smirnov test, a Weibull distribution was shown to better fit the distribution of fire intervals than the normal distribution. Weibull median intervals were 3.7 years for the entire period and 3.6 years for the pre-1901 period. The length of fire intervals for the entire period of record ranged from a minimum of 1 year to a maximum of 19 years, the latter occurring from 1959 to 1978. A period of increased fire frequency occurred from about 1855 to 1880 (MFI = 1.7 years). A greater relative abundance of non-fire injuries occurred after 1901 than before. Prior to 1901, non-fire injuries accounted for 20.2 % of all injuries, while after 1901 they accounted for 56.3 %. The abundance of these injuries increased the difficulty of interpreting the fire frequency and their role in influencing fire at the site. Causes of injuries other than fire were

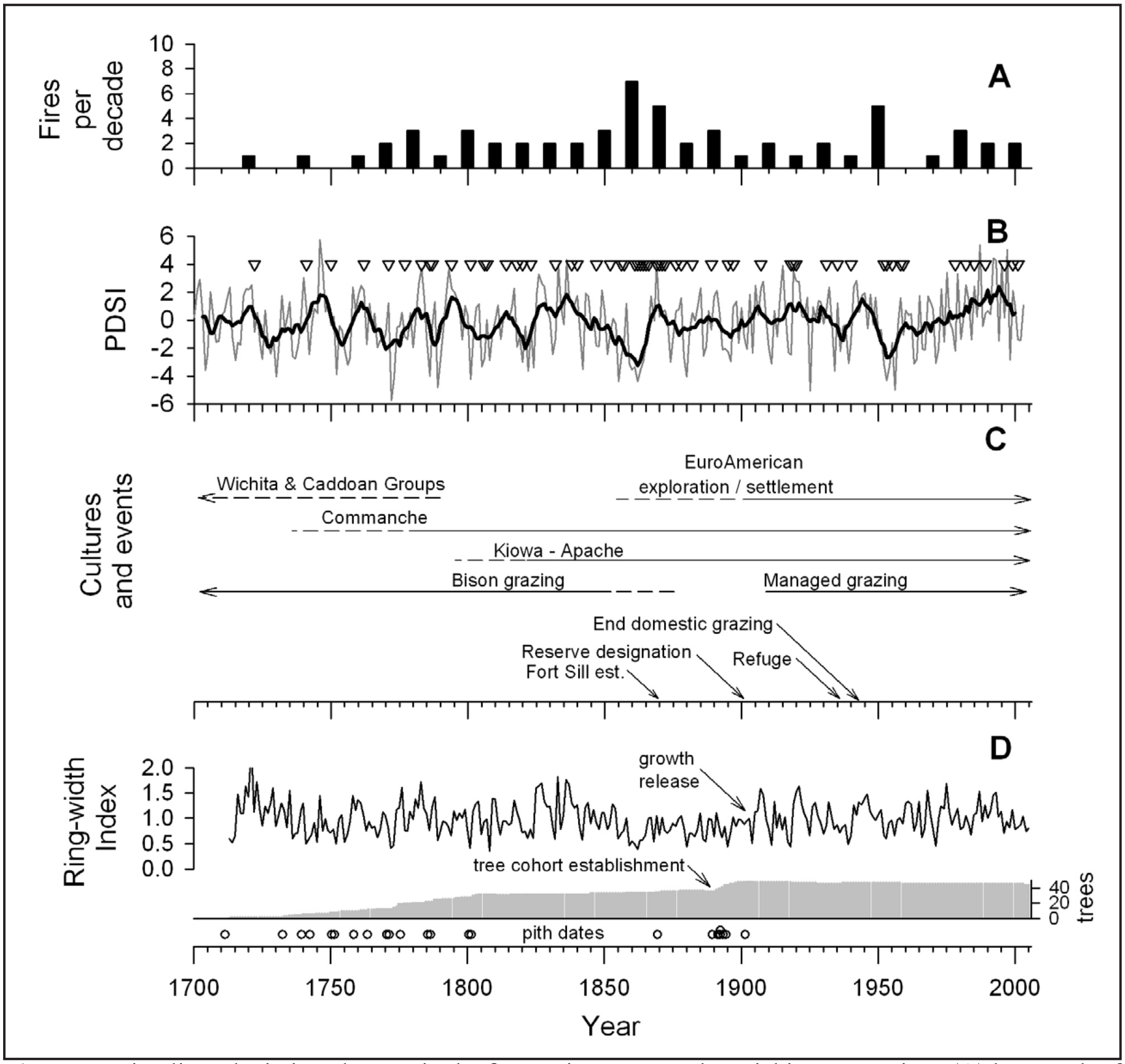

Figure 5. Timelines depicting changes in the fire environment at the Wichita Mountains. (A) bar graph of the number of fires per decade, (B) reconstructed Palmer Drought Severity Index (PDSI) (Cook *et al.* 2004) for southwestern Oklahoma (grey line) and a 7-point moving average (black line) emphasizing the lower frequency variability in drought. Triangles indicate fire event years at the study site, (C) timeline of changing cultures and events during the period of fire history, (D) standardized ring-width index chronology of post oak trees (black line), chronology sample depth (grey bars), and pith dates of solid trees (n = 24).

insects, spring frosts, and other unidentifiable causes possibly associated with land use activities (e.g., grazing).

Fire severity (percentage of trees scarred) was temporally variable, with the most severe fires (except for the 2006 fire that killed the sample trees) occurring prior to 1901 (i.e., Euro-American settlement). The three most severe fire years prior to 1901 occurred in a 30 year time span: 1771 (30% scarred), 1786 (15% scarred) and 1801 (36% scarred). With respect to drought, 1785 and 1801 were extreme (Palmer Drought Severity Index [PDSI] < -4.0) (Figure 5). For the three most severe fire years, the average bearings of fire scars (i.e., assumed fire movement direction) on the tree boles were 287° (1771, $n = 7$), 250° (1786, $n = 4$), and 357° (1801, $n = 11$), and suggest that all were west-to-north moving fires. After 1901, the most severe fire year was 1982 (10 % scarred), and fire events occurred during severe to extreme drought conditions (PDSI = <-2.99) in 1952 and 1953. Prolonged periods of drought corresponded with periods of annual to near-annual burning (e.g., 1856 to 1865 and the early 1950s). Percent of trees scarred was not significantly correlated with drought (PDSI), but more fire events occurred in drier conditions ($n = 16$) than wetter ($n = 11$). Although two of the three most severe fire years corresponded with severe droughts, the results of superposed epoch analysis suggested that no significant relationship between fire event years and drought conditions (including lagged conditions) existed when the full period of record was considered.

Comparisons between refuge fire records since 1975 and those recorded by tree rings showed good, but not perfect, agreement. The 1978 fire scar was unverifiable due to an alteration in the fire notes (i.e., fire records indicate an event occurred either in 1975, 1978, or both). The 1982 dormant-season fire scar corresponded to a February 1982 wildfire of unknown cause. The 1989 fire event corresponded to a January 1989 wildfire caused by vehicle sparks. A February 1993 prescribed fire event occurring throughout the study site was undetected through fire scars. The 1996 and 1999 fire scars were unverified by fire records. These scars were small, only represented by a partial scar on one sample, but we were unable to discount as fire events based on physical features and callus growth that mimicked those of fire scars. The 2001 dormant-season fire scar corresponded to a September 2000 wildfire.

DISCUSSION

An abundance of fire scars were found that extended fire event information into the early eighteenth century. In the Cross Timbers, only Clark *et al*. (2007) has used comparable methods to quantify the pre-Euro-American period fire regime, and they found a similarly frequent fire occurrence. The two studies are similar in their pre-settlement period mean fire intervals (3.4 years and 4.4 years), but differ with respect to changes in fire frequency during the twentieth century. Although Clark *et al*. (2007) found fire intervals to be significantly shortened; we found fire intervals to be relatively unchanged. Both studies found twentieth century fires to be less severe than those that occurred prior to Euro-American settlement. Clark *et al*. (2007) strongly implicated humans for the increased twentieth century burning. Burning of increased frequency, and sometimes annual burning, continues to be a common practice of ranchers managing grasslands. The fact that increased burning during the twentieth century did not occur at the Wichita Mountains site may be related to differences in land management and federal ownership.

Since 1901, the majority of the mountainous area has been under federal ownership; first as a forest reserve, then, in 1935, as part of the Wichita Mountains Wildlife Refuge, which currently encompasses 23 884 ha. During the early twentieth century, refuge managers used severe grazing of grasslands to remove fuel in order to prevent wildfires (F. Rush, Wichita Mountains Wildlife Refuge, unpublished report). Surveys from the early 1900s show that much of the area of the Wichita Mountains Wildlife Refuge was heavily grazed (F. Rose, Wichita Mountains Wildlife Refuge, unpublished report; Bruner 1931). In addition to bison and Rocky Mountain elk (*Cervus elaphus*), domestic cattle and horse grazing occurred at the preserve until 1937 (McCoy 1985). Currently, major herbivores include American bison, Texas longhorns (*Bos taurus*), white-tailed deer (*Odocoileus virginianus*), and Rocky Mountain elk. In addition, a limited area in the central valley of the refuge consists of black-tailed prairie dog (*Cyno-*

mys ludovicianus) towns with relatively sparse vegetation. In light of historic association of humans with fire, particularly in the midwestern USA (Guyette *et al.* 2002), it is highly likely that the fire regime experienced anthropogenic influences well before the establishment of the refuge.

Humans have occupied the Wichita Mountains for thousands of years (Wittry 1961). From 1550 to 1869, the area of the Wichita Mountains was inhabited first by Wichita and other Caddoan groups, eventually displaced by occupation of plains tribes such as Comanche, Kiowa, and Kiowa-Apache (Wittry 1961). By the 1830s the Kiowa had arrived in the region from the Black Hills and, with their Comanche allies, controlled a large portion of the southern plains (Schnell 2000). Beginning in 1836, the region was designated as Indian Territory by the US government, and Euro-American settlement was forbidden, although conflicts persisted throughout the nineteenth century. In 1869, Fort Sill was established in the southeastern portion of the Wichita Mountains, while Kiowa, Comanche, and Plains Apache allotments were located throughout the mountain range. The area was one of the last of the Indian Territory to be opened to American settlement in 1901 (Schnell 2000).

Because of a lack of detailed human population information for the area, it is difficult to determine how humans and other related factors such as climate may have differentially influenced the fire regime. An example of this is the 1856-to-1865 period of increased fire frequency that corresponds to the Civil War drought and arrival of military parties that led to the eventual establishment of Fort Sill in 1869. The 1856-to-1865 Civil War drought affected much of the Great Plains and was one of the longest and most extreme droughts in at least the past 300 years, rivaling the Dust Bowl (Fye *et al*. 2003). The Civil War drought was associated with persistently colder than normal tropical Pacific Ocean sea surface temperatures (la Niña conditions), suggesting that long-term variability in fire frequency was, at least in part, related to oceanic temperatures. Increased human population density and conflicts with occupying Native Americans also likely contributed to the increased frequency of fire events during this period—a feature of fire histories throughout the US. Though the Wichita Mountains area was not officially opened to non-Native Americans until 1901, much conflict occurred throughout the nineteenth century as pressure mounted for the military to subdue Native Americans (Francaviglia 2000). Native Americans burned the prairie to drive away unwelcome parties and eliminate forage needed for their animals to graze (Courtwright 2007). The human contribution to more frequent fire during this period is further supported by the continuation of frequent fire events well after the Civil War drought ended.

Interestingly, tree growth was significantly decreased beginning with the Civil War drought, but the reduced growth rates persisted until about 1904. Many trees show a growth release circa 1904, which could be related to the establishment of the forest reserve (that later became the Wichita Mountains Wildlife Refuge) (Figure 5). Based on the pith dates of sample trees, a period of post oak tree recruitment appears to have occurred around 1890 to 1895. This cohort established following approximately 20 years of frequent burning, and during a grazing transition from native herbivore to domestic animals. From a broad temporal perspective, the period of tree establishment represents a transition to less frequent fires compared to the previous century, plausibly with intervals long enough to allow trees to attain fire-resistant sizes. In the Great Plains, forest communities commonly relate to a gradient of species fire tolerance and forest density, whereby areas with more frequent fire are more likely to be dominated by fire tolerant species and open forest structure (Anderson 1990, Batek *et al*. 1999). The establishment and occurrence of post oak suggests a range of fire frequencies that may be relatively frequent (e.g., 4 yr to 20 yr) over a long period. Similarly, the establishment, encroachment rate, and extent of eastern redcedar is also a general clue to an even further decreased frequency or severity of fires as the species is very fire intolerant.

Fire Management

Although the specific role of humans in the historic fire regime may never be fully understood, the importance of humans to the future fire regime is certain. The fire history at Wichita Mountains demonstrates that relatively frequent fires have had a long-term presence. Maintaining historic fire frequencies will necessitate a continued and active human role. The information from this study provides many clues about the historic fire regime that can be used to guide future fire management. The long-term presence of post oak at the study site suggests that no stand replacement fires have occurred in the vicinity over the last three centuries. This is not to say that stand replacement fires did not occur on more exposed sites during severe fire years. Very severe fires did historically occur as indicated by high percentages of trees scarred; however, these events appear to be limited in representation to the pre-Euro-American settlement period. In general, fires at the study site were typically lower in severity with only minor injuries to trees. In fact, monitoring the extent of tree stem damage from prescribed fires is one method for comparing current fire severities to the historic. Fire severity is governed by many variables of the fire environment and its effects can be the result of infinite combinations of fire environment conditions. For example, a very fast moving wildfire through grassy fuels may be less severe in terms of scarring compared to a slower moving and longer duration fire burning leaf-litter and woody fuels.

Some historic fire regime characteristics may not be attainable through prescribed burning. For example, historic severe fires commonly occurred during extreme drought conditions. Burning during extreme drought conditions is not within most fire prescriptions; therefore, attaining the severity and effects of these fires on vegetation may not be feasible. Historic fires in extreme drought years were likely broad in their geographic extent. Additional fire history studies would be useful for understanding historic fire sizes and the rotation intervals for the refuge. In addition, replicated sites would put these findings in better context and aid in understanding the ranges of historic fire frequency for the Cross Timbers region.

It is possible that all fires were not recorded by the sample trees. Certainly, trees may not be perfect recorders of all fires, particularly fires of low intensity and patchy burn coverage. The ability of a tree to record a fire depends on many tree and fire characteristics. Tree characteristics include physical characteristics (bark thickness), time of year (moisture content), time since last scar, tree size, age, growth rate (Guyette and Stambaugh 2004), and landscape position. Fire characteristics include fuel type, load and condition, fire intensity, time of year, and the fire pattern. Despite many factors being important for scarring of post oak trees, they likely still have the potential to very accurately record true fire frequencies. When many trees are used, they can even document extended periods of annual burning (Guyette and Stambaugh 2005, Shirakura 2006).

The 2006 prescribed fire was a severe event, killing a high proportion of mature trees in the study area. The event is an important example of the future of fire management in light of eastern redcedar encroachment. Due to years of fire suppression activities, and perhaps other less well-known conditions (e.g., altered moisture and grazing regime), redcedars had been steadily encroaching throughout the site during the twentieth century (F. Rose, unpublished report; Gray 1998, Donnelly and Kimball 2005). Additionally, in the last 20 years, it appears that the site has experienced several of the wettest years of the last three centuries (Figure 5), perhaps leading to even more extensive redcedar encroachment. Prior to the 2006 fire event, mechanical operations were undertaken to kill redcedars, which, when, burned resulted in a high intensity and high severity fire event that resulted in effects likely unprecedented at the site. In the future, fire managers are likely to be faced with similar challenges that ultimately necessitate a phase of restoration followed by a phase of fire maintenance that uses fire history to mimic historic fire regimes.

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