FINAL PERFORMANCE REPORT

FEDERAL AID GRANT NO. T-46-P-1

USING TREE RING ANALYSIS TO DETERMINE FIRE HISTORY IN THE OKLAHOMA OZARKS

OKLAHOMA DEPARTMENT OF WILDLIFE CONSERVATION

December 31, 2006 through December 30, 2011

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Grant Name: Using Tree Ring Analysis to Determine Fire History in the Oklahoma Ozarks

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A. ABSTRACT:

The role of humans in past ecosystem fires has had little quantitative attention. Here, we address this inadequacy by developing fire histories in northeastern Oklahoma at the Nature Conservancy's Nickel Preserve from 324 dated fire scars on shortleaf pine (*Pinus echinata*) remnants and trees. The purpose of this study was to provide an understanding of the role of humans, fuels, and climate in the historic fire regime. Variability in the historic fire regime was associated with human population, time since last fire, and drought. The population density of the Cherokee Nation and other Native American groups was significantly correlated ($r = 0.84$) with the number of fires per decade between 1680 and 1880. At the Tully Hollow site the mean fire interval (MFI) was 7.5 years from 1633 to 1731 and 2.8 years from 1732 to 1840. Before 1810, during low population densities of Osage and Caddo, the mean fire interval was 4.2 years. Coincident with the removal of the Cherokee and other native peoples from the eastern United States into northeast Oklahoma, the mean fire interval reached 1.8 years in length between 1840 and 1890 in this part of the Cherokee Nation. After 1925 a decrease in fire frequency (MFI = 16 years) occurred until the introduction of prescribed fire by the present owners (The Nature Conservancy). Previously documented widespread (340 km east-west) fires that occurred during drought years (1657, 1780, 1786 and 1808) in Missouri and Arkansas also occurred in the Oklahoma Ozarks. Over all, the occurrence of fires at the study site was weakly associated with drought years. During decadal length dry periods between 1680 and 1880 fire was less frequent. Fire severity (as measured by the percent of trees scarred) appeared to be lessened in cases when fire events were preceded by fires in the previous three years.

B. OBJECTIVE:

To determine the fire history of an oak-pine forest, woodland, and savanna mosaic in the Oklahoma Ozarks, and to examine the key factors that historically influenced fire regimes in the region.

C. INTRODUCTION:

Throughout North America the quantitative association of historic fire regimes with anthropogenic factors is often limited by the quality of data on Native American populations and to a lesser extent their many cultures (Delcourt and Delcourt 1997). Rarely are human population and culture data linked at the same location with long-term fire regime data. The Nature

Conservancy's Nickel Preserve in northeast Oklahoma was part of the Cherokee Nation in 1828 and it has a fire history that is strongly linked to human population, culture, and ownership for over three centuries. Fire history information provides both perspective and baseline data that are relevant to fire ecology, forest restoration, fuels management, human and ecological history, and species distributions (Lafon 2005, Rudis and Skinner 1991).

The fire history of Oklahoma's diverse vegetation, landscapes, and people is beginning to be described by studies conducted with fire-scarred oaks. Case studies using fire scar dates in oak trees from east central (Clark et al. 2007, DeSantis et al. 2010) and southwestern Oklahoma (Stambaugh et al. 2009) have begun to described the Cross Timbers region. These studies offer managers with historic fire frequency information but are not often comparable because of site differences. High spatial and temporal site variability has been found in fire frequency due to topography, geographic location, and historic human occupancy. No previous-documented fire histories are known to exist in the western Ozark Highlands region of Oklahoma. The nearest Ozark fire histories are about 200 km east in higher, cooler, and wetter mountain environments in northern Arkansas (Guyette et al. 2006). This study describes the historic fire regime in what is now The Nature Conservancy's (TNC) Nickel Preserve in Cherokee County, Oklahoma by using fire locations and dates as identified on fire-scarred remnants and trees.

D. APPROACH AND METHODS:

Study location

Study sites are located at what is presently the J.T. Nickel Family Nature and Wildlife Preserve, which occurs on the lands that were occupied by Native American tribes, and were assigned by treaty to the Cherokee Nation in the decades before 1887 (Figure 1). The 6,880 ha preserve, owned and managed by TNC since 2000, lies in the Cookson Hills of northeastern Oklahoma and is bordered by the Illinois River to the west. The region lies on the western edge of the Ozark Highlands with the lands further west occurring in the Cross Timbers physiographic region (Clark et al. 2005). The climate is humid continental, with mean maximum temperatures of 22 ^{o}C and mean annual precipitation of 122 cm. The topography is rugged and dissected, with steep cherty slopes, ridges, and narrow valleys. Twenty to fifty percent of the region has slopes over 14 percent (Rafferty 1980). Plant community associations include mixed oak-hickory (*Quercus* sp.-*Carya* sp.) forests, mixed oak-pine (*Quercus* sp.-*Pinus echinata* Mill.) woodlands and savannas, and small prairies.

Human history

The study site region has been continually occupied by humans throughout the period of the fire scar record. During the early period (~1630-1830) of the fire scar record, the region was likely occupied by the Osage and Caddo Native American groups (Vogt 1974). As early as 1541, the study site was within the boundaries of the expanding Osage territory (Burns 2004) and other Native American groups had left the region by the latter half of the 18th century (Vogt 1974; Bailey 2010). Osage villages were concentrated primarily in the Missouri and Arkansas Ozarks, but they utilized the western plains portion of their territory for annual game and bison hunts. The Illinois River trail was one of two significant trails utilized by the Osage for travelling from Arkansas to Oklahoma hunting grounds (Burns 2004) that bordered the study site.

The Cherokees began migration and cultural change early (before 1775) in the east (Goodwin 1977). By 1817, the "Western Cherokees" that had been settling in Arkansas since the 1790s were venturing into northeastern Oklahoma, encountering resistance from the Osage. Conflicts continued between the two tribes through 1825 (Goins and Goble 2006). In 1828, a treaty led to the exchange of Cherokee lands in Arkansas for land in Indian Territory encompassing the study site after which the region was occupied primarily by Cherokee for more than 6 decades. Between 1829 and 1838, the Western Cherokees were occupied with building cabins, clearing land for cultivation, raising livestock and hunting bison (Jones and Faulk 1984). In 1838, most of the remaining Eastern Cherokees were forced to relocate to northeastern Oklahoma on what came to be known as the Trail of Tears. Approximately 5,000 Cherokee were already living in lands west of the Mississippi when about 14,000 surviving emigrants from the East arrived (McLoughlin 1993; Goins and Goble 2006).

Many emigrants arrived in the new territory destitute, and struggled to survive in an unfamiliar climate and environment (McLoughlin 1993). The decades following the arrival of the Eastern Cherokees were marked by much turmoil as the reunited tribe struggled to establish social, economic and political stability (McLoughlin 1993; Goins and Goble 2006). Conflicts with other Plains tribes were common and the Civil War was particularly devastating for the Cherokee (Rafferty 1980). The arrival of railroads in the 1870s and 1880s ushered in a new era of trials for the Cherokee, ultimately leading to unconstrained white settlement of the Cherokee territory and the end of Cherokee sovereignty in 1898 (McLoughlin 1993).

Site selection
We surveyed much of the Nickel Preserve property and targeted study areas that had preserved and abundant remnants of shortleaf pine (*Pinus echinata*). Study site locations also were found by consulting the managers of the Nickel Preserve for known areas with fire-scarred pine stumps, snags, and trees. The study sites include one fire history site that had many samples available and four fire history site clusters where only a few samples were available. The best site, based on the number of samples and the abundance of fire scars, was located in Tully Hollow (Figure 1) in an area of approximately 1.2 km^2. At all sites, we exhaustively collected all available pine remnants. Four site clusters (Figure 2), areas with concentrated stumps or trees with fire scars, were used in combination with the Tully Hollow fire history site to determine the historic extent of fires. The study sites were limited in area as much as possible in order to estimate mean fire intervals that are unaffected by both scarring rates and site area (Baker and Ehle 2001).

Sample collection and processing
Shortleaf pine was selectively preferred to other tree species because of the potential for long fire scar records, the presence of charcoal associated with basal scars, and the sensitivity of the species to scarring. Samples were selected based on age, wood preservation, and the presence of scars on live trees. Location (GPS coordinates), slope, and aspect were recorded for each tree sampled. Cross-sections from live shortleaf pine trees, cut stumps, and natural remnants were surfaced, measured, and cross-dated. Surfaces of cross-sections were sanded with successively finer sandpaper (120 to 600 grit). Ring-width series from each sample were plotted and used for visual cross-dating and signature year identification (Stokes and Smiley 1968). A master dating chronology was constructed from the tree-ring measurements. The samples and dating chronology were cross-dated and verified using shortleaf pine chronologies from the Missouri and Arkansas Ozarks (Guyette 1996; Stambaugh and Guyette 2004). The computer program

COFECHA (Holmes et al. 1986; Grissino-Mayer et al. 1996) was used to ensure the accuracy of cross-dated tree-ring series.

Fire scars and chronologies

Fire scars were identified by cambial injury, callus tissue, traumatic resin canals, and charcoal. Fire scars were dated to the year and season of cambial injury. We used the computer program FHX2 (Grissino-Mayer et al. 1996) to plot composite fire scar chronologies and graphs. We used SAS/STAT (2002) software for the statistical summaries, analysis of means, and regression and correlation analyses. Fire intervals have been described in several ways. Mean fire intervals (MFIs) are the most often used and are simply the mean of the periods between fire scars (i.e., fire events) in years (Dietrich 1980). We averaged the number of fires per decade and created a time series which was used in correlation analyses with human population density.

Reconstructed drought data

Fire event data were compared to proxy climate data reconstructed from robust regional tree ring series. The proxy climate data used were reconstructed Palmer Drought Severity Indices (PDSI) (Cook et al. 2004) averaged for the Ozark region (grid points: 192, 193). All climate data are available from the Paleoclimate Program of the National Oceanic and Atmospheric Administration. In the time-series analysis of fire frequency, drought data were smoothed using a 10-yr moving average so as to correspond to fires per decade.

Human population density

Human population density is often difficult to estimate in longer term analyses because of rapidly changing population, area of occupancy, season of residence, and unknown population sizes. However, this study region has an exceptional record of Native American population because of its location in Native America, early records of 'land allotments' by treaties (1700-1900), and descriptions of different tribal groups. During the early period (~1630 to 1780) of this study's fire scar record the region was occupied by the Osage and others. The Osage claimed their original territory in what is now northeast Oklahoma, southwest Missouri, northeast Arkansas and southeast Kansas (Vogt 1974). The Nickel Preserve fire history study sites were a small area of a large region occupied by the Osage at low population density (Guyette et al. 2002).

Cherokee migration and population are particularly important to this study because Cherokee lived in and near the study area for nearly two centuries (Rafferty 1980). Associations of Cherokee migration and population with fire history data have been documented in several studies (Guyette and Stambaugh 2005; Guyette et al. 2002; Guyette et al. 2006a). Cherokee population estimates were derived from the regions of southeast Missouri, later in northwest Arkansas (Royce 1899; Gilbert 1996), and then in northeast Oklahoma (Morris et al. 1986). During the winter of 1811-1812 many Cherokee moved from Missouri to Arkansas and their population in northwest Arkansas (and probably northeast Oklahoma) increased to about 4,500 (Stevens 1991). In 1828, the Cherokee moved further west into the region of northeastern Oklahoma. Later, in 1838, approximately 13,000 Cherokees were forcefully removed from their homelands in the eastern United States along the Trail of Tears to northeast Oklahoma that included the fire history study sites. Using many of these data sources we derived annual estimates of Cherokee population from decadal historic population estimates. We used decadal and sub decadal linear interpolation to derive annual population densities of Native America at the study sites. Interpolations were based on 13 historic estimates of Cherokee and Osage populations from several data sources (Gilbert 1996, Guyette et al. 2002, Morris et al. 1986, Rafferty 1980, Royce 1899; Vogt1974).

E. RESULTS:

The fire scar record

Over 324 fire scars on 49 shortleaf pine remnant stumps and trees were located, identified, and dated at the five sites (Figure 2). The majority of sample trees (34) were located at Tully Hollow and a fire history was developed for this site (Figure 3). At Tully Hollow the mean fire interval varied from 1.7 to 17 years between 1633 and 1925 (Table 1). Although the period after 1925 is only represented by two trees at Tully Hollow, there were thousands of unscarred and uncollected trees at that location that had no recent fire scars. Thus, the long (30 years or less) intervals during this period are more representative of fire frequency than might be expected from judging the data based on sample size alone (Figure 2). The percentage of trees scarred in a single year ranged from 5 to 48. Nearly all (98 percent) fires occurred in the dormant season.

Table 1. Periods of the historic fire regime based on written history and fire frequency. Mean fire intervals (MFIs given in years) were calculated for the entire Nickel Preserve (NP) and for the smaller extent of Tully Hollow (TLY). MFIs for the entire Nickel Preserve are based on the combined composite fire interval for the five different study sites. Because of low sample sizes at four of the sites and few sites overall, the mean fire interval statistics for the entire Nickel Preserve are conservative estimates and likely do not represent all fires within the area. Drought is the reconstructed PDSI (Cook et al. 2004).

Cultural eras	Period, calendar years	MFI (NP)	MFI (TLY) (range)	Weibull median interval (TLY)	Mean % trees scarred, (# fires)	Mean # fires per decade	Ethnic Groups	Correlation coefficients (drought x % trees scarred)
Native American	1650-1780	na	5.0 (1-17)	4.45	13.4[1] (15)	2.0	Osage, Wichita, Caddo	-0.21[1]
Native American migration I	1780-1830	2.2	2.5 (1-4)	2.5	9.5 (21)	4.0	Osage, others	-0.30*
Native American migration II	1830-1889	1.3	1.7 (1-4)	1.6	11.0 (35)	6.3	Cherokee	-0.06
Euro American settlement	1890-1925	1.7	2.2 (1-4)	2.0	19.2 (17)	4.6	Cherokee, Euro American	-0.01
Fire suppression	1925-1992	5.0	17 (8-30)	16	na	0.5	Euro American	0.02

[1]Dates for this analysis were 1731-1780 because of limited sample numbers before 1731. * = $p < 0.05$. Study area sizes are: Tully Hollow (TLY) approximately 121 ha, Nickel Preserve (NP) approximately 6880 ha.

Fire and drought

Three climate-fire associations were found at the study site: 1) fire years were slightly more common in dry years (Figure 4), 2) years with fires of large extent were synchronous with regional droughts, and 3) effects of human ignitions and fuels were more important than annual climate differences with respect to determining the frequency of most fires between 1680 and 1880. During this period twenty four fire years (34 percent) occurred during wetter than normal conditions (PDSI > 0), while 47 fire years (66 %) occurred during drier than normal conditions (PDSI < 0). Widespread fires occurred at the study sites in 1753, 1772, 1780, 1786, 1801 and 1808 during drought years with regional PSDI values that averaged -2.2. Annual reconstructed drought explained about 10 percent or less of the variance in fire frequency compared to over 80 percent that was explained by fuels and human population density (Equation 1, 2, 3).

Temporal effects of prior fire on the percent of trees scarred

The number of years since the last fires was an important factor influencing the percent of trees scarred annually during fire years (Table 2). This change in the percent of trees scarred implies that some increased degree of fire intensity was caused by a temporal reduction of fuel accumulation. Our data support this hypothesis and indicate that fuel accumulation for up to three years before a fire was the most important fuel reduction proxy. Here we used the number of fire years and the percent of trees scarred during those years as a proxy for fuel removal by fire. We found a weighted mean of the percent of trees scarred for the three years before a fire event to be the most significant predictor of the percent of trees scarred. Weights used in averaging were 1.0 for one year prior, 0.6 for two years prior, and 0.3 for three years prior to the fire event. Longer time lags were not significant and the weighted averaged follows an expected exponential decline in fuel accumulation in the region (Stambaugh et al. 2006). Reconstruction PDSI was tested as a predictor variable in this model but was not significant. The prior fuel reduction by fire model is described by the regression model (Figure 5):

$$\%TSCAR = 11.9e\,(-0.112x3ps), \qquad \text{Equation 1}$$

where:

%TSCAR = percent of trees scarred at Tully Hollow,
3ps = weighted (1.0, 0.6, 0.3) mean of percent trees scarred in previous 3 years,
$r^2 = 0.13$, $p < 0.01$,
Period of record: 1680 to 1880,

Table 2. Correlation coefficients among fires per decade and the percent of trees scarred with anthropogenic and environmental variables (1680-1880). The Previous Fire Index is a proxy estimate of unburned fuels based on a scaled mean of percent trees scarred in previous 3 years. Ln is the natural log of population. Statistically significant ($p<0.05$) tests have an *. [a]Significance levels for population density and fire variable correlation coefficients are not given because of the high autocorrelation in population time series. Knowledge of human-fire-cultural associations at low population levels gives a priori qualitative and quantitative significance to these correlations (Guyette et al. 2002, 2006a). [b] is for the natural log of percent trees scarred during fire years.

Population and climate variables	Fires per decade	Percent trees scarred
Population density (Osage+Cherokee)	0.74[a]	0.16[a]
Ln (population density) (Osage+Cherokee)	0.80[a]	0.17[a]
Drought (reconstructed)	- 0.06	- 0.14*
Drought (reconstructed, % scarred fire years)	- 0.02	- 0.33*[b]
Previous Fire Index	0.34*	0.20*

Fire frequency and human population

The importance of anthropogenic influences on the fire regime was evident in the large differences in correlations of climate and human variables with fire variables (Tables 1 and 2). Associations among fire variables (Previous Fire Index, fires per decade) and human population variables were stronger than with local drought reconstructions (Table 2). By far the most important variable affecting the early (before 1880) historic record of the fire regime was the population of Native Americans. Fire frequency (fires per decade) was positively correlated with population density (Table 2). A regression equation was developed that described the number of fires per decade from Native American population density (Figure 6):

$$\text{Fires per decade} = 7.7 + 1.14(\text{popdensity}) \qquad \text{Equation 2}$$

where:

Fires per decade = the number of fires per 10 year period at Tully Hollow,
popdensity = natural log of the sum of Osage and Cherokee population per 28,000 km^2,
$r^2 = 0.75$, $p < 0.001$,
period of record: 1680 to 1880,

Although it is difficult to address the statistical significance of these autocorrelated series because of the dependence of these observations (i.e., moving averages and annual population interpolation), the strength of the correlation between fires per decade and Cherokee population was robust ($r = 0.81$) and consistent with similar analyses (Guyette et al. 2002, Guyette et al. 2006a).

Fire frequency human-climate model

Fire frequency at decadal temporal scales can be affected by anthropogenic ignitions and decadal climate variability. Drought can enhance the probability of burning by decreasing fuel moisture and increasing the effectiveness of ignitions and fire spread. Drought can also decrease the probability of burning by reducing fuel production and ignition effectiveness, especially after burning has reduced fuels. In ignition-saturated environments, fuel production becomes the limiting factor controlling the frequency of fire (Guyette et al. 2002). There is some support for these hypotheses in this studies regression modeling results. We predicted fire frequency using the population density of Native Americans as an ignition proxy and reconstructed drought (PDSI, Cook et al. 2004) as a fuel production proxy. The resulting equation is:

$$\text{Fires per decade} = 8.08 + 1.42(\text{popdensity}) + 0.47(\text{PDSI}) \qquad \text{Equation 3}$$

where:

Fires per decade = the number of fires per 10 year period at Tully Hollow,
Popdensity = natural log of the sum of Osage and Cherokee population per 28,000 km^2,
PDSI is the 7 year average of the reconstructed Palmer Drought Severity Index,
$r^2 = 0.78$, $p < 0.00$, partial r^2 are is 0.75 for population and 0.03 for drought,
intercept and variables are significant ($p > 0.01$),
period of record: 1680 to 1880.

The interesting aspect of Equation 3 is that when the effects of ignitions (population density) are taken out in the multiple regression procedure what is left are drought periods that have less frequent fire (+ sign in front of the PDSI coefficient). A small (~ 3 percent) but significant component of the predicted fires per decade is found to decrease with drought and increase with wetness (Figure 7).

F. DISCUSSION:

The fire scar record

The fire scar record in the Oklahoma Ozarks had similarities to those in the eastern Ozarks of Arkansas and Missouri. Widespread fires occurred across the Ozarks of Missouri, Arkansas, and Oklahoma (study area) in 1657, 1753, 1772, 1780, 1786, 1801, 1808. These fires likely encompassed very large areas, and were likely high intensity, high severity fires that may have resulted in forest canopy removal. Fires during these years probably resulted from the interactions of drought, Native American migrations, human conflict, and human attempts to culture or condition the landscape for subsistence as well as increased accidental fires resulting from greater human population density.

The pre-Euro-American settlement mean fire interval at the Tully Hollow site was similar to that of other fire history sites at similar latitudes in North America within oak and pine woodland and forest ecosystems (Table 3). Although we report mean fire intervals with two significant figures, it is doubtful, given the limited precision of fire scar history reconstructions, that any of the MFIs in Table 3 are significantly different. Thus, the Tully Hollow MFI is consistent with other regional fire history site MFIs with open forest structure during the period of pre-Euro-American influence.

Fires were least frequent between about 1925 and 2000 at the Oklahoma Ozark study sites (Figures 2, 3). Mean fire intervals at the study site during this period are in contrast to other fire history studies in the adjacent Cross Timbers physiographic region of Oklahoma which were not reduced in frequency (Clark et al. 2007, DeSantis et al. 2010, and Stambaugh et al. 2009). This difference in fire frequency could be the result of climate, topography, human population, vegetation, or burning culture. The drier climate of the Cross Timbers is a major factor in the decrease in forest cover and the increase in more pyrogenic grasslands. More rapid fire spread in the less rugged landscapes with more abundant areas of grassland fuels could be a major contributing factor. Additionally, the culture of burning was changed more in forested regions of the U.S. by education and propaganda on the results of burning for industrial forestry. In contrast, a culture of burning persists today in many grassland regions with an agricultural focus on grazing.

Table 3. A comparison of the pre Euro American MFI of the Tully Hollow fire regime with those of forest, woodland, and savanna fire regimes between 34°N and 37°N latitude.

Site name	Tully Hollow	Caney Mountain	Granny Gap	Saltwell Hollow	Land Between the Lakes	Wichita Mountains
State	East OK	South MO	North AR	Mid TN	West KY	West OK
Period	1650-1830	1702-1821	1680-1820	1700-1810	1700-1810	1720-1820
Vegetation	Mixed oak-pine forest, woodland, savanna	Mixed oak forest, woodland, savanna	Mixed oak-pine forest woodland	Mixed oak forest, woodland	Mixed oak forest, woodland	Oak-cedar woodlands prairie
Mean fire interval	5.0 years	5.2 years	4.6 years	6.0 years	6.6 years	6.6 years
Data source	This study	Guyette & Cutter 1991	Guyette & Spetich 2003	Guyette & Stambaugh 2005	Guyette et al. 2008	Stambaugh et al., 2009

Fire and climate

Many of the years when fires occurred at the five study sites were the same years that fire occurred at other fire history sites throughout the Ozark region of Arkansas and Missouri (Guyette et al. 2006a). The Oklahoma, Arkansas, and Missouri Ozarks fire history data indicate that there was extensive burning in a 50 year period (1753, 1772, 1780, 1786, 1801, and 1808) associated with annual drought and anthropogenic ignitions as eastern Native American began migrating west (Table 4). We estimate that fires between 1748 and 1810 in the Ozarks of Arkansas, Missouri and Oklahoma could have burned over a total area (as estimated by the number of sites with fire scars) equal to three times the size of the Ozarks during this 62 year period (Guyette et al. 2006a). Thus, an area the size of the Ozarks in Arkansas, Missouri, and Oklahoma (~12,950,000 ha) burned about every 21 years. Since these fires were large and occurred during known drought years they were probably mixed-severity fires and included some stand replacement fires. The occurrence of these large mixed-severity fires as well as more frequent maintenance fires at the study sites probably lead to more open forest canopies in woodlands.

Major Ozark fire years were associated with widespread drought (Table 4). Low correlations between mild drought and fire are to be expected because of the timing differences between tree growth based summer climate reconstructions, and the fire season (fall, winter, early spring) as documented by dormant season fire injuries. This dormant season regime is expected because of burning conditions between October and mid- to late-April and when micro-canopy climate conditions favor burning (lower humidity, higher surface winds, more solar exposure of tree litter fuels, and dry litter fall).

Table 4. Percent of study sites burned at other Ozark locations during major fire years at the Nickel Preserve. Rank is by the mean percentage of all sites in the Ozark region (right hand column). Drought is reconstructed Palmer Drought Severity Index (PDSI) for the Ozark region (Cook et al. 1999; Cook et al. 2004). More negative PDSI values indicate increasing drought severity.

Fire Year	Oklahoma Ozarks	Lower Boston Mtns. (AR)	Interior Boston Mtns. (AR)	Missouri Ozarks	Drought (PDSI)	Rank	Ozark region
1780	40 %	100 %	33 %	50 %	incipient dry, -0.99	1	56 %
1808	40 %	66 %	66 %	26 %	near normal, -0.46	2	49 %
1786	20 %	66 %	66 %	23 %	mild drought, -1.14	3	44 %
1772	25 %	100 %	0 %	27 %	extreme drought, -4.45	4	38 %
1801	40 %	0 %	66 %	31 %	extreme drought, -4.33	5	34 %
1753	25 %	0 %	66 %	39 %	mild drought, -1.78	6	32 %

Fire frequency and human population

Threshold values for the effects of human population density on fire frequency represent the population density at the time when more humans (and ignitions) fail to increase the frequency of fire (Guyette et al. 2006b). At this point the landscape is saturated with ignitions and fuel availability becomes the limiting variable affecting fire frequency. The fire regime at the study site transitioned from an Ignition-dependent stage to a Fuel-limited stage circa 1850 at a human population density of 0.49 humans per km^2 (Guyette et al. 2002). This compares with a threshold value of 0.64 humans per km^2 that was reached in the Missouri Ozarks at the same time by early Euro-American subsistence settlers. A threshold value of 0.26 (humans per km^2) in the interior Boston Mountains of Arkansas was reached earlier (1820) with increases in Cherokee population density. Estimates of human populations and their landscape density are coarse and small differences in threshold values of population density may not be significant. Although differences in population and topography are known to play a role in fire frequency (Guyette et al. 2006a, Stambaugh and Guyette 2008) the role of vegetation and climate are unknown for the study site.

Conclusions and management implications

This study and others indicate that humans have been an important cause in shaping ecosystem for centuries if not millennia (Delcourt and Delcourt 1997). Humans now and in the past have used fire to culture this ecosystem for many reasons. The study area is located between two physiographic provinces (the Ozarks and Cross Timbers), along a major river system, next to a transportation corridor, and in a fertile stream valley. These characteristics have made the location attractive to human cultures for centuries if not millennia. Arguably, the continued use of prescribed fire matches the historical fire regime of this ecosystem.

In the Oklahoma Ozarks, large and probably severe fires that may have altered the forest canopy occurred about every 21years. Although fire prescriptions to maintain canopy openings are often effective, severe fire effects are difficult to mimic through fire alone because of the potentially dangerous fire weather and fuel conditions required. Canopy openings that mimic severe fires may be duplicated by firing techniques that create locally hot conditions or by silvicultural treatments. Our results suggest that historically, fuel accumulation for at least three years resulted in increased fire severity. If management goals are to remove small woody stems while maintaining open canopies then fire intervals of three years in length may be most effective.

In summary, there were at least five significant findings from this study that may have management implications.

1. Human population density and culture were the most important factors affecting the frequency of fire during the three centuries of record. Frequent burning to enhance ground level vegetation by overstory canopy removal was repeatedly associated with the occupancy of the site by Native Americans (Osage, Cherokee, and others) and by the present owners (The Nature Conservancy). Less frequent burning occurred between 1925 and 2000 that may be associated with cultural changes and industrial forestry.
2. The duration of fuel accumulation was shown to have an effect on fire severity and tree scarring. Fire severity was increased when there had been no fires (reduced fuel accumulation) for at least 3 years.
3. Climate appeared to influence the range of variability in the frequency of fire at the study site owing to two processes: 1) reduced fuel production and fire by decadal droughts, and 2) large scale droughts allowing wide spread severe fires. Annual reconstructed drought conditions were poor predictors of individual fire years.
4. Prior to 1830, fire frequency in the Oklahoma Ozarks was similar to that found at woodland-savanna ecosystems populated by Native Americans between 34°N and 37°N latitude in mid-continental North America.
5. Fires were most frequent between 1830 and 1889 during the highest levels of Cherokee population and ownership.

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G. SIGNIFICANT DEVIATIONS: none

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Figure 1. Map showing the topography of The Nature Conservancy's Nickel Preserve and the locations of fire history sites. One fire history site consisting of 34 trees was collected at Tully Hollow (TUL) whose area is depicted by the dashed line. Other outlying fire history site clusters were located in Pumpkin Hollow (PMK), Dog Hollow (DOG), Cedar Hollow (CDH), and Tell Hollow (TEL).

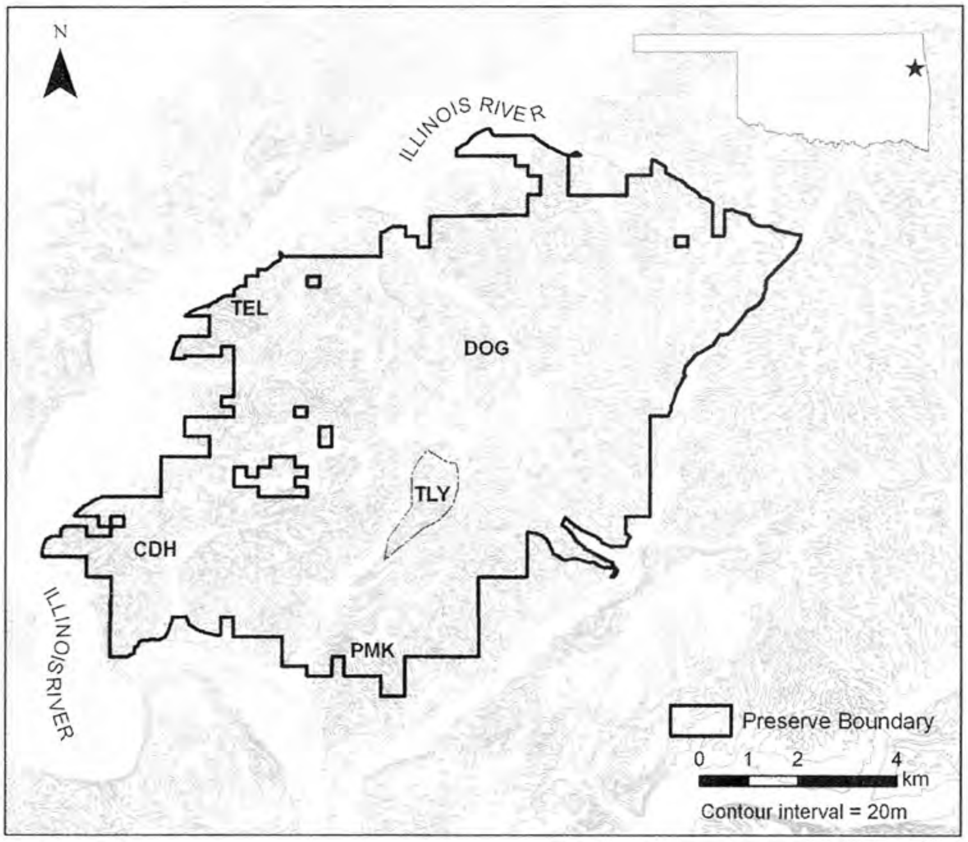

Figure 2. Composite fire scar history diagram of all five Nickel Preserve sites. Each horizontal line represents the length of the fire scar record at the collection site. Bold vertical marks represent fire scars. The preserve-wide composite fire scar chronology (bottom axis) indicates the presence of a fire at one or more of the study sites.

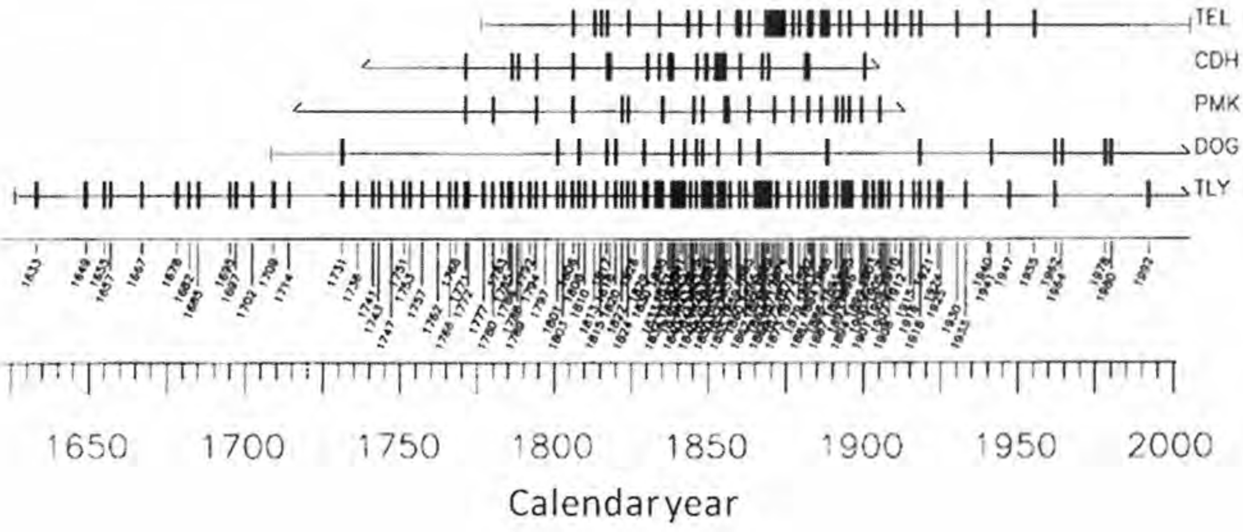

Figure 3. Tully Hollow fire history showing fire scar dates of 34 individual trees and a fire scar composite chronology for the site. Each horizontal line represents the length of the fire scar record of a live shortleaf pine tree or remnant. Each bold vertical mark represents a fire scar on trees. The composite fire scar chronology with all fire scar dates is shown at the bottom of the figure.

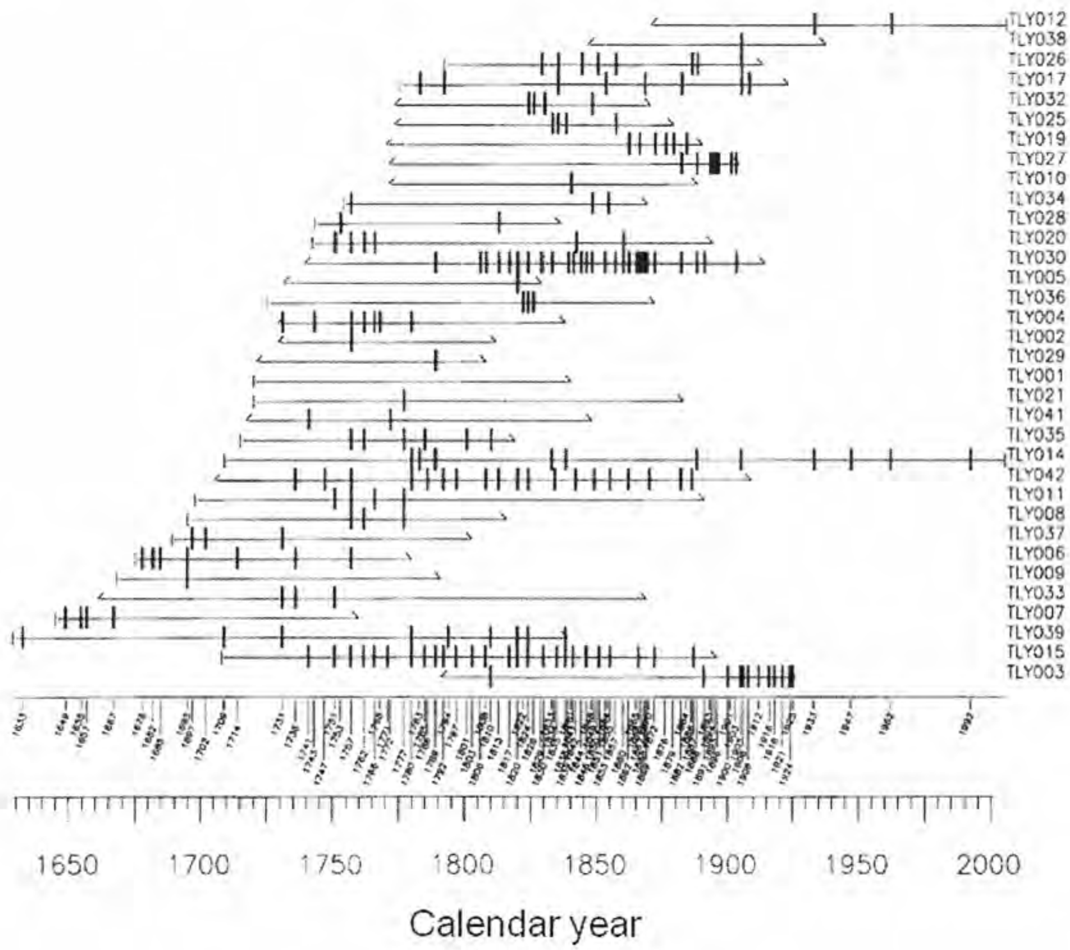

Figure 4. Scatter plot of the percent trees scarred and drought (Palmer Drought Severity Index). The association of drought on the occurrence of fire and percentage of trees scarred is illustrated for dry years (negative PDSI values, left side of graph) and wet years (positive PDSI values, right side of graph). There were 33 fires during wet years (right side of graph) and 42 fires during dry years. The percent of trees scarred during wet and dry years was not significantly different.

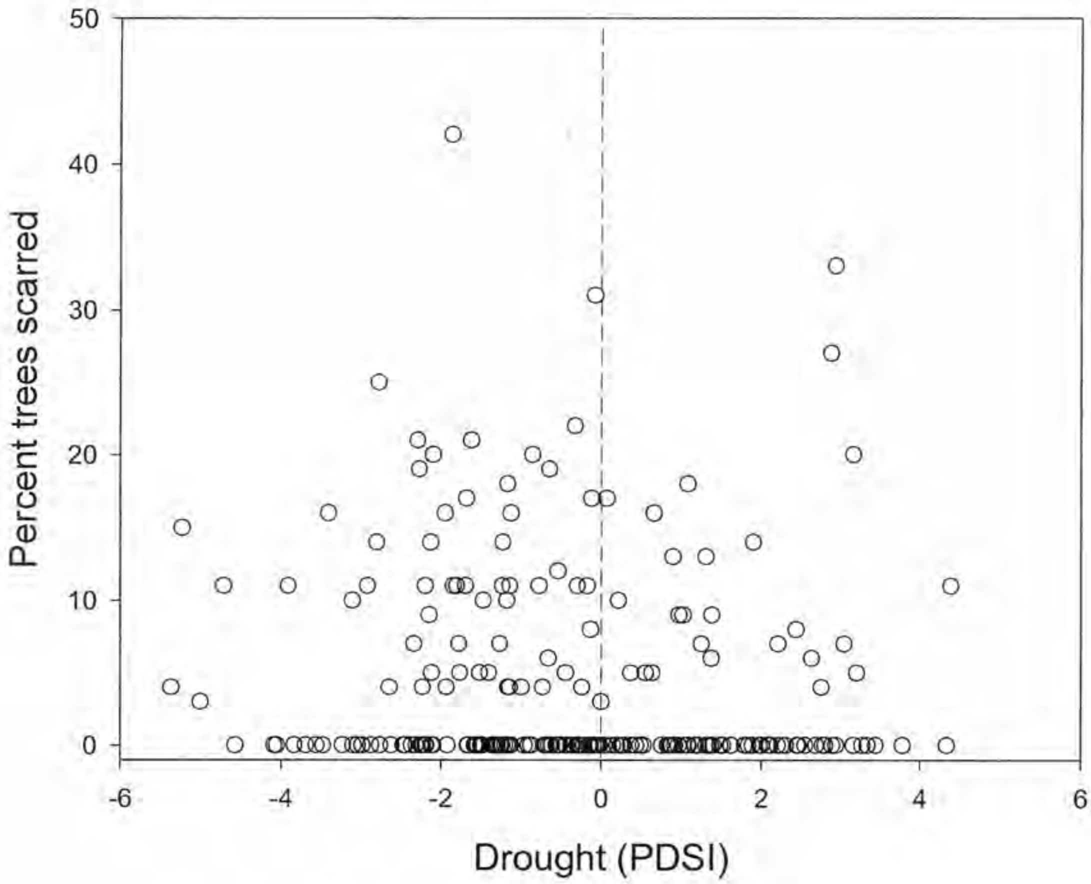

Figure 5. Scatter plot and non linear regression line (Equation 1) relating percent trees scarred to the previous three year weighted mean of the percent tree scarred. The annual percent of trees scarred serves as a proxy for fire extent and severity (y-axis) while the prior three-year mean of the percent of tree scarred serves as a proxy for fuel reduction by fire (x-axis).

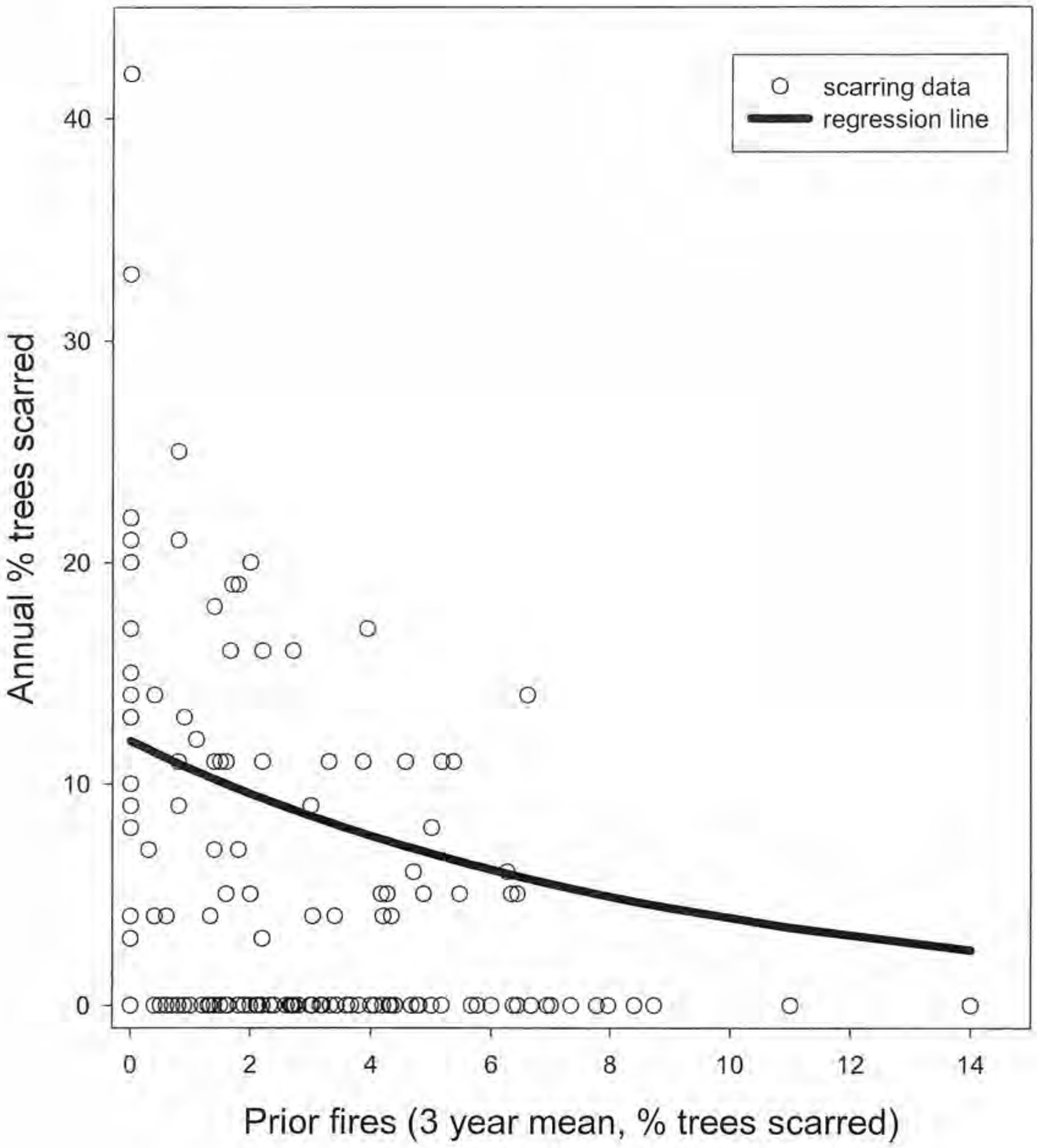

Figure 6. Scatter plot and regression (gray line and text) illustrating the association between natural log of Native American population density and the number of fires per decade (FPD) between 1680 and 1860. The top axis gives the non logarithmic population densities per 100 km^2.

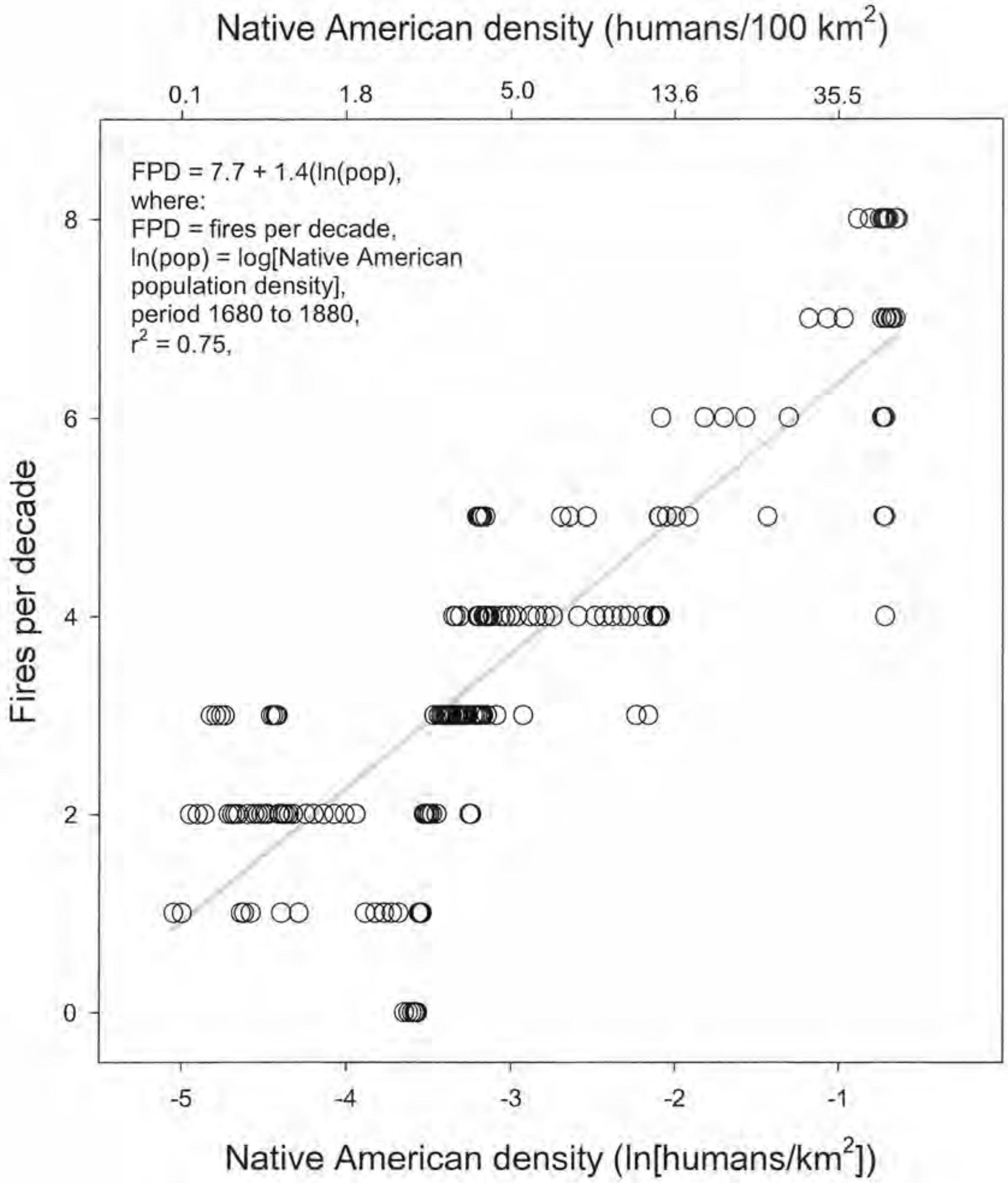

Figure 7. Time series plots of the number of fires per decade and the fires per decade predicted by population density and drought model (Equation 3).