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FIRE HISTORY AT THE EASTERN GREAT PLAINS MARGIN, MISSOURI RIVER LOESS HILLS

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ABSTRACT—The purpose of this paper is to provide quantitative fire history information for a geographically unique region, the Loess Hills of northwest Missouri. We sampled 33 bur oak (*Quercus macrocarpa* Michx.), chinkapin oak (*Q. muehlenbergii* Engelm.), and black oak (*Q. velutina* Lam.) trees from the Brickyard Hill Conservation Area in northwest Missouri. The period of tree-ring record ranged in calendar years from 1671 to 2004 and fire-scar dates (n = 97) ranged from 1672 to 1980. Fire intervals for individual trees ranged from 1 to 87 years. The mean fire interval was 6.6 years for the pre-Euro-American settlement period (1672-1820), and 5.2 years for the entire record (1672-1980). A period of more frequent fire (mean fire interval = 1.6 for 1825 to 1850) coincided with Euro-American settlement of the area. The average percentage of trees scarred at the site was 16.8%, or about 1 in 7 trees sampled per fire. No significant relationship between fire years and drought conditions was found; however, events prior to 1820 may have been associated with wet to dry mode transitions.

Key Words: bur oak, fire history, Great Plains, Loess Hills, *Quercus*

INTRODUCTION

The Loess Hills are a geologically and ecologically unique region located along the border of the Great Plains and eastern deciduous forest, a transition zone with a historically dynamic boundary that is "climatically capable of supporting either woodlands or prairie" (Novacek et al. 1985). During the Holocene, changes in dominant vegetation within this transition zone were largely due to variations in climate and fire frequency (Delcourt and Delcourt 1981; Schroeder 1982; Anderson 1990; Whitney 1994; Licht 1997; Clark et al. 2001). From plains to forest, fire frequency likely decreased due to increased topographic roughness and differences in the fuel matrix (Rodgers and Anderson 1979; Anderson 1990). Within the transition zone, interactions among fire, climate, and topography created a continuum of prairie and forested communities such as oak-hickory savannas and woodlands (Braun 1950; Dey 2002; Nelson 2005).

A lack of reliable historical records limits our understanding of the pre-Euro-American settlement fire regime of the Loess Hills and the larger Great Plains. Due to the scarcity of trees available for fire history research, most of our current understanding of the Great Plains fire history is derived from early written descriptions and charcoal records from kettle lakes. Numerous early accounts describe large grassland fires, both lightning and human caused, occurring annually or near annually throughout the Great Plains (Pyne 1982; Higgins 1986; Anderson 1990), though several limitations must be considered when interpreting such accounts. Recent studies of charcoal records do not provide a precise measure of fire frequency but can provide other information about the historic fire regime of the Great Plains. For example, research into charcoal records and reconstructed climate suggests that wet periods were more commonly associated with fire events at the century scale (Brown et al. 2005), though fire events likely occurred during shorter periods of dry weather. In contrast, studies of annual fire-scar data in Missouri and Arkansas Ozark forests have shown a correlation between fire occurrence and annual reconstructed drought (Stambaugh and Guyette in press; Guyette et al. in press). In the Great Plains, years of higher than average annual precipitation may have facilitated the buildup of herbaceous vegetation, creating a large fuel load and subsequently more frequent and extensive fires (Clark et al. 2002). The location of the Loess Hills at the margin of the Great Plains provides a unique opportunity for the quantification of historic fire frequency using fire-scarred trees. Though the topographic roughness of the hills likely prohibited adjacent grassland fires from spreading through the entire area, fire history information from the Loess Hills can provide valuable additional information about the historic fire regime of the Great Plains.

Prior to fire suppression and extensive grazing, frequent grassland fires likely limited savanna and woodland development to the most protected areas within the hills and favored the dominance of prairie grasses and forbs in the understory (Mutel 1989). Fire exclusion and agricultural practices for at least the past 50 years, however, have altered the ecology of the Loess Hills, fostering the spread of woody vegetation into areas previously covered by prairie and oak savanna (Novacek et al. 1985; Mutel 1989; National Park Service 2000; Nelson 2004). Remnant patches of prairie persist on high, exposed slopes that are well drained to the point of aridity. Many drought-adapted plants typically found farther west exist here, and the eastern limits of several Great Plains species' ranges are reached at the Loess Hills (Iffrig 1983; Novacek et al. 1985). In sheltered ravines and hollows, plants typically found farther east thrive, and the western limits of several eastern forest species' ranges are also reached at the Loess Hills. Though some examples remain, these natural community types and associated plants are currently considered imperiled or threatened due to human activities (MNHP 2006). Many recent restoration and preservation efforts in the Loess Hills include the application of prescribed fire.

The objectives of this study were (1) to reconstruct fire events of a Loess Hills site from fire scars on trees, and (2) to characterize historic fires in terms of their frequency and severity in relation to changes in culture, human population, and climate.

METHODS

Study Site

The Loess Hills are a band of rugged bluffs approximately 320 km long (~280,000 ha) bordering the Missouri River alluvial plain through Nebraska, Iowa, and Missouri. Formed by repeated aeolian deposition of fine-grained quartz silt during the Illinoian and Wisconsin glacial periods and subsequent erosion throughout the Holocene, these deposits can reach thicknesses of over 75 m, with slopes ranging from 30° to greater than 75° (Iffrig 1983; Novacek et al. 1985). While loess deposits are a relatively common feature associated with major river systems, they are rarely thick enough to create new landforms, and the Loess Hills are one of only two such regions in the world (Mutel 1989).

Our study was conducted on loess hills at Brickyard Hill Conservation Area, a 915 ha site located in Atchison County in the northwest corner of Missouri (40°29'N, 95°35'W) (Fig. 1). The area is immediately adjacent to the Missouri River alluvial plain and is part of the Central Dissected Till Plains ecological section (Bailey 1995). Samples were collected from the first and second hills from the alluvial plain. Soils are deep, well-drained silt loams and silty clay loams overlying Pennsylvanian-age geologic formations (Nelson 2005). The study site is located at the southern tip of the Loess Hills, receiving more annual precipitation (average 86.4 cm) and warmer temperatures on average compared to the northern Loess Hills (Novacek et al. 1985). On the eastern edge of the alluvial plain (elev. 270-275 m), the Loess Hills increase abruptly in elevation up to 360 m (Iffrig 1983).

From the alluvial plain, the first west-facing slope is commonly a mosaic of prairie and oak forest, with the leeward side being dominated by bur oak (*Quercus macrocarpa* Michx.) and chinkapin oak (*Q. muehlenbergii* Engelm.) forest. The areas of prairie harbor xerophytic plants that are typically associated with the Great Plains but are rare in Missouri, such as soapweed (*Yucca glauca* Nutt. var. *glauca*), downy yellow painted cup (*Castilleja sessiliflora* Pursh), plains muhly grass [*Muhlenbergia cuspidata* (Torr. ex Hook.) Rydb.], and silverleaf scurf pea (*Psoralea argophylla* Pursh). Woody encroachment, particularly of rough-leaved dogwood (*Cornus drummondii* C.A. Mey), eastern redcedar (*Juniperus

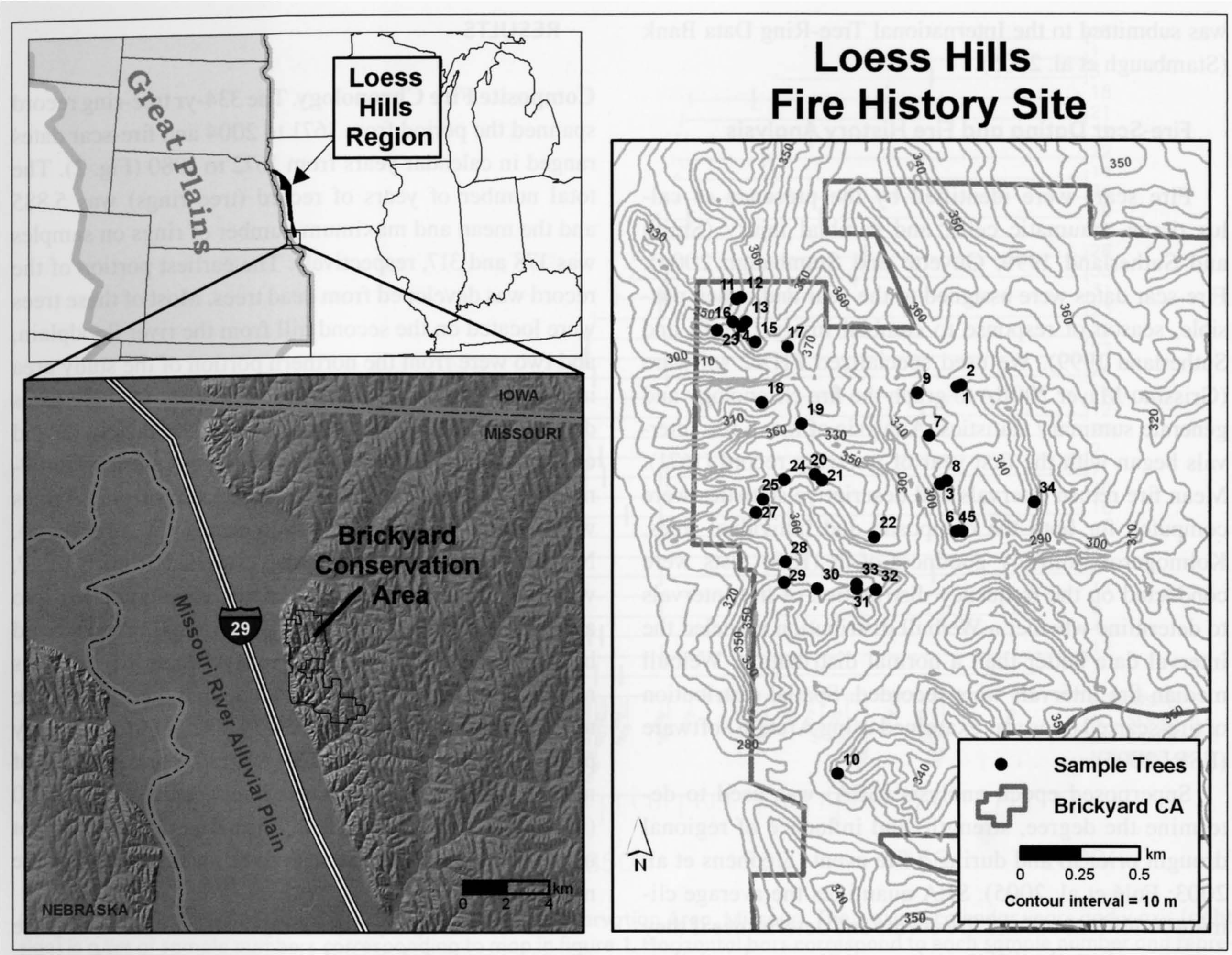

Figure 1. The Loess Hills study site is located within the Brickyard Hill Conservation Area in Atchison County, MO. This area represents the southernmost portion of the Loess Hills region, which extends north along the eastern edge of the Missouri River alluvial plain. Detailed map of study area shows locations of sample trees (refer to Fig. 2).

virginiana L.), and smooth sumac (*Rhus glabra* L.), is commonly observed in prairie patches.

Sample Collection and Preparation

An initial survey of forested areas within the Brickyard Hill Conservation Area confirmed the presence of fire-scarred trees appropriate for the study. In March 2005, samples were collected from a 150 ha area on the first and second hills from the edge of the Missouri River floodplain (Fig. 1). Trees were nonrandomly selected to ensure collection of samples that had fire scars. Trees commonly had no exterior evidence of fire scarring, and their quality was assessed both visually and by sounding the tree bole with a hammer. Thirty-three cross-sections of live (n = 22) and dead (n = 11) oak trees (25 bur oak, 7 chinkapin oak, 1 black oak [*Q. velutina* Lam.]) were collected using a chainsaw for the purpose of reconstructing the fire history. Cross-sections 10-30 cm thick were cut from the base of trees. Sample locations were recorded using a GPS, and slope degree and direction were recorded. After drying for 2-4 weeks, cross-sections were surfaced with an electric hand planer, and the cellular detail of annual rings and fire-scar injuries were revealed by sanding with progressively finer sandpaper (80 to 600 grit). All tree-rings were measured to 0.01 mm precision using a binocular microscope and a moving stage fixed to an electronic transducer. Tree-ring series were cross-dated using standard dendrochronological techniques (Stokes and Smiley 1968) and a master chronology was developed from the live tree samples with known ring dates. The computer program COFECHA (Grissino-Mayer 2001a) was used to ensure accurate dating of samples and facilitated fire-scar dating. A bur oak master tree-ring chronology was submitted to the International Tree-Ring Data Bank (Stambaugh et al. 2005).

Fire-Scar Dating and Fire History Analysis

Fire scars were identified by the presence of callus tissue, traumatic cells, and cambial injury (Smith and Sutherland 1999, Guyette and Stambaugh 2004). Fire-scar dates were assigned to the year and, when possible, season of response to cambial injury (Smith and Sutherland 1999). We used specialized FHX2 software (Grissino-Mayer 2001b) to graph the fire chronology and generate summary statistics. Analysis of mean fire intervals began with the first year of tree-ring record (1671). Mean fire return intervals and descriptive statistics were computed for both the composite and individual trees. Kolmogorov-Smirnov goodness-of-fit (K-S) tests were conducted on the frequency distribution of fire intervals to determine whether a Weibull distribution modeled the interval data better than a normal distribution. Weibull median fire intervals were recorded. Spatial distribution of fire-scarred trees was examined using ArcGIS software (ESRI 2005).

Superposed epoch analysis (SEA) was used to determine the degree, strength, and influence of regional drought prior to and during a fire event (Stephens et al. 2003; Fulé et al. 2005). SEA quantifies the average climate conditions around fire events and determines if they were significantly different (e.g., wetter or drier) than that of all years. The data were bootstrapped for 1,000 simulated events in order to derive confidence limits. Fire event data were compared to reconstructed drought data (Palmer Drought Severity Index, Grid 191, Cook et al. 2004) to determine if climate was significantly different from average during the six years preceding and four years succeeding fire events ($n = 60$). We conducted SEA separately for three time periods (1670-1820, 1821-1880, and 1881-1980) that generally corresponded with pre-Euro-American settlement, Euro-American settlement, and a modern multi-use period. We also described relatively severe fire years in terms of drought and used correlation analysis to relate drought to percentage of trees scarred during fire event years. The correlation analysis was conducted for the three time periods above, excluding the earliest portion of the record (1670-1765) due to small sample size. In addition, we explored possible relationships between pre-Euro-American settlement fire occurrence and indices of El Niño and the Atlantic Multidecadal Oscillation (AMO) using graphical methods and correlation analysis.

RESULTS

Composite Fire Chronology. The 334-yr tree-ring record spanned the period from 1671 to 2004 and fire-scar dates ranged in calendar years from 1672 to 1980 (Fig. 2). The total number of years of record (tree rings) was 5,885 and the mean and maximum number of rings on samples was 178 and 317, respectively. The earliest portion of the record was developed from dead trees. Most of these trees were located on the second hill from the river floodplain, and two were from the northern portion of the study area in a north-facing cove position. The ages of these trees demonstrate that these hills were not completely devoid of trees around the period of early Euro-American settlement (~1810-1830). Ninety-seven fire scars from 33 trees were dated, yielding 59 fire intervals (60 fire years). Number of fire scars per sample ranged from 0 to 17, with a mean of 2.9. Fire-scar dates were compiled into a composite fire chronology, which was characterized by high variability in fire frequency. Mean fire intervals ranged in length from 1 to 22 years, and the MFI for the total record was 5.2 years (Table 1). The MFI for the early portion of the record (pre-1820) was 6.6 years. A period of more frequent burning occurred between 1825 and 1850 (MFI = 2.0), coinciding with Euro-American settlement of the area. Only one fire scar (1980) was found after the mid-1950s.

Three of 97 (3%) fire scars, or three of 60 (5%) fire events, occurred during the growing season. These fire scars appeared as latewood injuries (Panshin and de Zeeuw 1980) and occurred in 1682, 1714, and 1826. All other fire scars and fire events occurred during the dormant season (approximately September to March). Years with relatively high percentages of trees scarred were 1782 (44% trees scarred), 1818 (45%), and 1869 (33%). In each of these years, the spatial distribution of fire-scarred trees demonstrates that a single fire likely burned the entire study area (Fig. 3). Average percentage of trees scarred was lower in the 20th century (average 4% of trees scarred per fire event) compared to the period 1765-1899 (average 14% of trees scarred per fire event).

Individual Tree Fire History. Seventy individual fire intervals resulted from the 33 sample trees. The mean and modal fire intervals were 21.6 and 2 years, respectively. Individual fire intervals ranged from 1 to 107 years. K-S tests revealed that the actual data were not normally distributed. Weibull distributions did not adequately fit the composite fire interval data ($p = 0.035$) and were not used for the analysis of individual fire

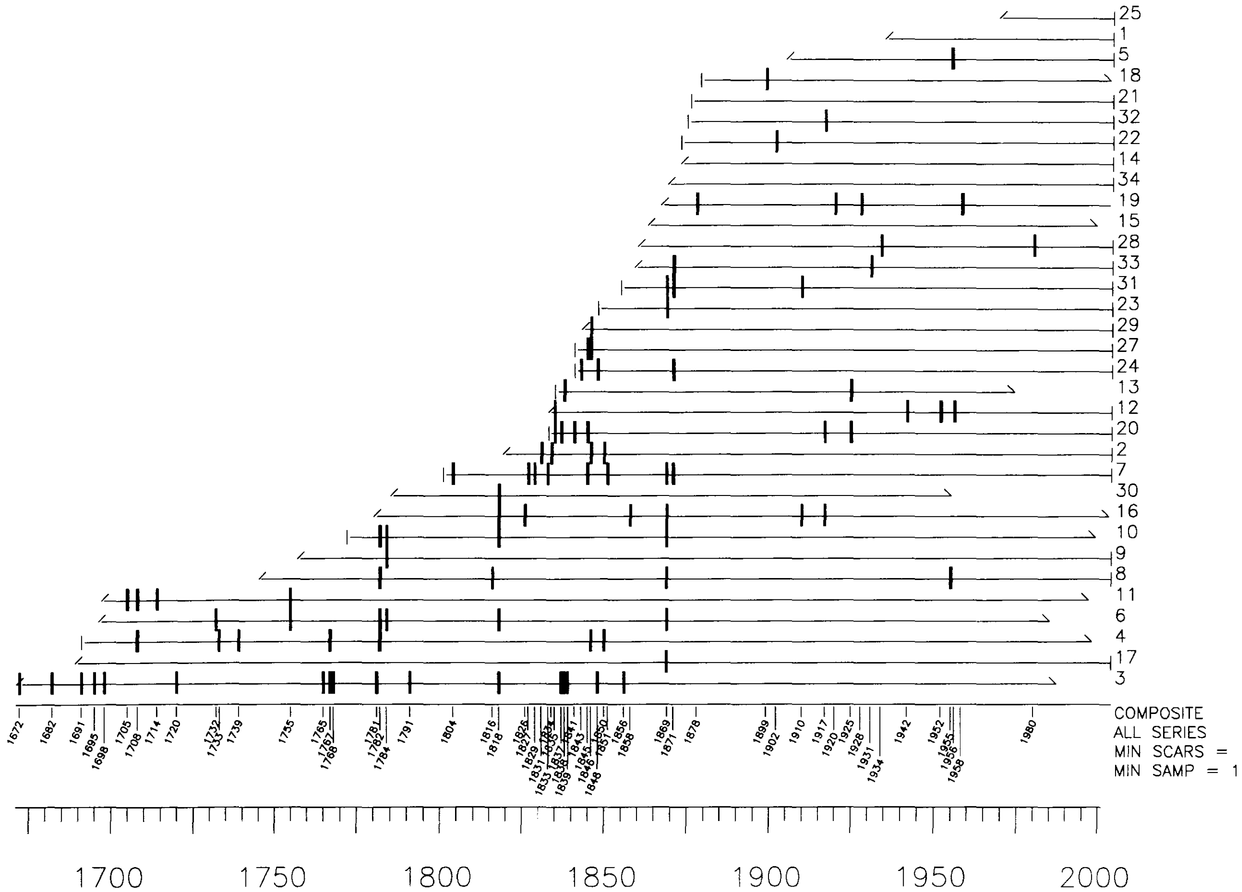

Figure 2. A composite fire chronology of Brickyard Hill Conservation Area, Missouri. The x-axis is calendar years and y-axis (right side) is a list of sample numbers corresponding to map in figure 1. Horizontal bars correspond to each sample number and represent the period of record for that tree. Bold vertical bars indicate the year of fire injury. Pith dates (center of tree) are represented by short, thin vertical lines at the left end of horizontal bars, while inside ring dates (pith absent, hollow center) are represented by short, thin diagonal lines. Bark years (outside of tree) are represented by short, thin vertical lines at the right end of horizontal bars while outside ring dates (bark missing, partially decomposed) are represented by short, thin diagonal lines. A composite fire-scar chronology with all fire years is given at the bottom of the plot.

intervals. The spatial distribution of fire-scarred trees prior to 1900 encompassed both the first and second hills from the alluvial plain. After 1900, all fire-scarred trees except one were located on the first hill from the alluvial plain.

Drought and Fire. The superposed epoch analysis revealed that regional annual reconstructed drought conditions were not associated with fire events in the Loess Hills of Missouri (Fig. 4). Fire events were not consistently correlated with drought years for the entire length of the record (1670-1980). In fact, many of the extreme drought years (PDSI < -3) had no recorded fire events. For the pre-Euro-American settlement analysis period (1670-1820), climate conditions were generally wet for several years prior to fire events and dry following fire events. These effects may be indicative of a lower-frequency climate oscillation that was undetected by SEA (e.g., ENSO, Atlantic Multidecadal Oscillation), though no significant correlations or relationships were found between pre-Euro-American settlement fire occurrence and either the reconstructed El Niño or AMO indices. The period of increased burning during Euro-American settlement (1825-1850) was a wet period on average (PDSI = 0.35). The three years with the highest percentage of trees scarred—1782, 1818, and 1869—had reconstructed PDSI values of 3.9, -1.6, and 1.9, respectively. Correlation analysis revealed no significant correlations between percentage of trees scarred and reconstructed PDSI in any portion of the fire record (Table 2).

TABLE 1
SUMMARY OF FIRE HISTORY ANALYSIS, INCLUDING MEAN FIRE INTERVALS (MFI) FOR THE ENTIRE RECORD AND FOR THREE PERIODS OF CULTURAL INFLUENCE

Number of samples	33
First and last year	1671-2004
Length of record (yr)	334
Total number of tree rings	5,885
Number fire scars	97
Number fire years	60
MFI all years (1671-2004)	5.22
MFI (1671-1820)	6.64
MFI (1821-1880)	2.48
MFI (1881-1980)	5.79

Note: Cultural periods are Pre-Euro-American Settlement (1671-1820), Euro-American Settlement (1821-1880), and Modern (1881-1890).

DISCUSSION

Compared to many other ecosystems, the Loess Hills were largely unaltered by humans prior to Euro-American settlement, with the exception of anthropogenic fire. Early inhabitants were nomadic and semi-nomadic groups, and despite evidence of a few permanent settlements along the floodplain, the Loess Hills were only sporadically occupied as late as the early 1800s (Mutel 1989). In addition, discoveries of bluff-top Native American burial sites suggest that the hills were viewed as sacred sites by at least some prehistoric inhabitants. Euro-American settlement instigated rapid and dramatic changes to the natural communities of the hills, however, through such activities as grazing, timber exploitation, and fire suppression (Mutel 1989).

The adjacency of the Loess Hills to the vast expanses of the Great Plains means that the large and frequent grassland fires of prehistoric times also shaped the natural communities of the hills. Additional evidence of pre-Euro-American settlement fire in the Loess Hills is provided by early written descriptions, artistic depictions and land surveys, current plant community characteristics, and cultural studies of Native American groups that inhabited the region (Moore 1972; Pyne 1982; Mutel 1989). The Lewis

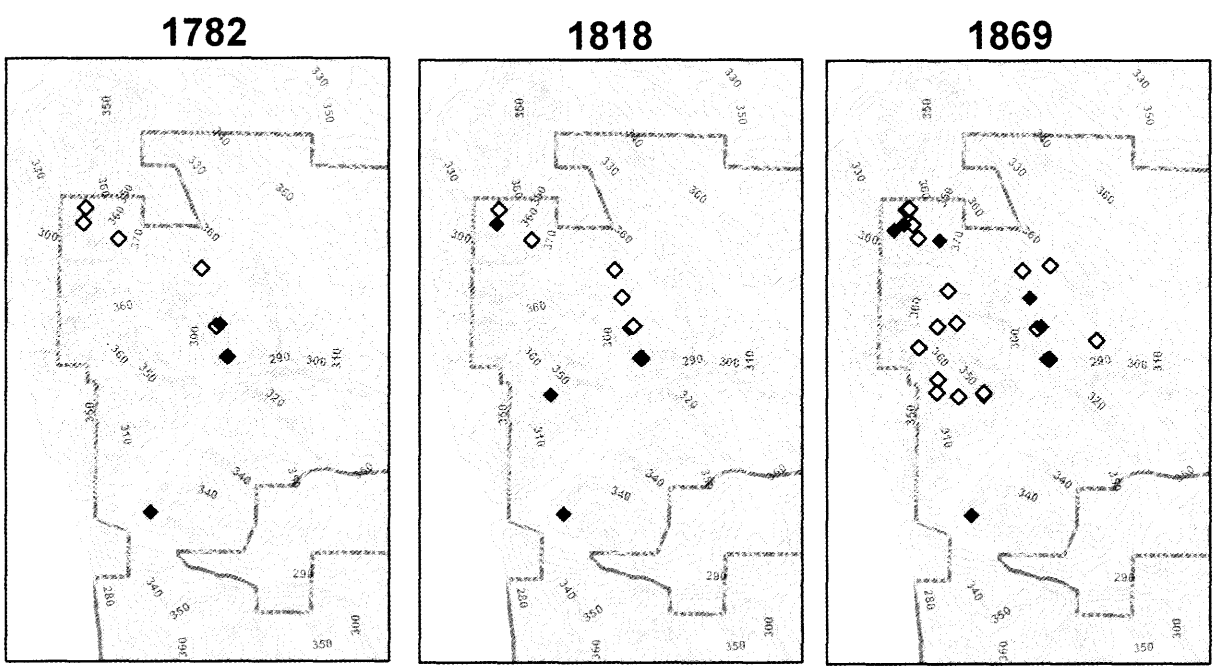

Figure 3. Spatial distribution of fire-scarred trees for the three years having the highest percentage of trees scarred. Open diamonds represent trees present but not scarred by the fire event, while closed diamonds represent fire-scarred trees. Contour interval = 10 m.

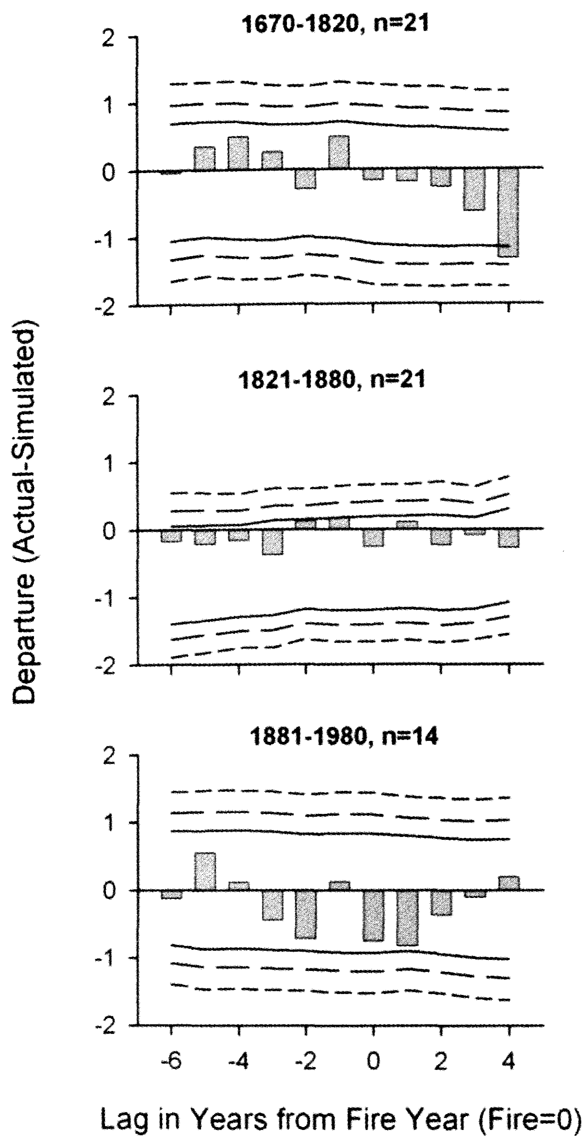

Figure 4. Results of superposed epoch analysis for three distinct stages of the Loess Hills fire chronology. Bars represent deviation from normal conditions based on 1,000 simulations. Confidence limits are 90% (solid line), 95% (long dash), and 99% (short dash).

and Clark expedition made note of "ball [bald]-pated prairie" and "bald hills" when passing the current location of the Brickyard Hill Conservation Area (Harlan and Denny 2003). Members of the expedition also observed evidence of frequent Great Plains fire in present-day Cass County, NE, approximately 40 miles north of the study site: "The Soil of Those Praries appears rich but much Parched with the frequent fires [July 20, 1804]" (Moulton 2003). Interestingly, an 1804 fire scar was identified at the study site, corresponding to the passage of the Lewis and Clark expedition. Late-19th-century descriptions by Bush (1895) describe the Missouri Loess Hills as "bald-headed mounds," with north- and east-facing upper slopes having a mosaic of short, shrubby growth and savannas. The artist George Catlin made many paintings and illustrations of the landscape during his journey up the Missouri River in 1832, including "Prairie Bluffs Burning," which depicts a fire creeping over bluffs, though no fire scars were identified for 1832 at the study site. In addition to such eyewitness accounts of fire prior to Euro-American settlement, many of the older oak trees at the study site exhibit "retro-crown" branch and bole architecture (Fig. 5), suggesting that they developed without competitive pressures in a more open canopy structure than what currently exists (Oliver and Larson 1996). Occurring most frequently on upslope positions, particularly on the first ridge from the river bottom, these trees provide further evidence that these landscape positions within the hills were historically fire-maintained open savanna, with grass-dominated understories.

TABLE 2
CORRELATIONS BETWEEN PERCENTAGE OF TREES SCARRED AND RECONSTRUCTED PALMER DROUGHT SEVERITY INDEX FOR THREE TIME PERIODS OF CULTURAL INFLUENCE AND ALL FIRE YEARS

Period of record	Pearson Correlation Coefficient	p-value
1765-1820 (n = 10)	0.128	0.725
1821-1880 (n = 22)	0.106	0.637
1881-1980 (n = 15)	0.064	0.821
1765-1980 all years (n = 47)	0.127	0.395

There is little evidence that historic fire events at the study site corresponded to regional droughts. Fire history studies at other Missouri sites have found weak but significant correlations between reconstructed drought and fire occurrence, usually strongest in the years before Euro-American settlement (Stambaugh and Guyette in press). Anthropogenic activities (e.g., ignitions) often mask the influence of drought on fire frequency. In the Loess Hills, however, no relationship between drought and fire was evident for any portion of the record. This could be a result of seasonal differences between drought reconstructions (growing season) and fire occurrence (dormant season),

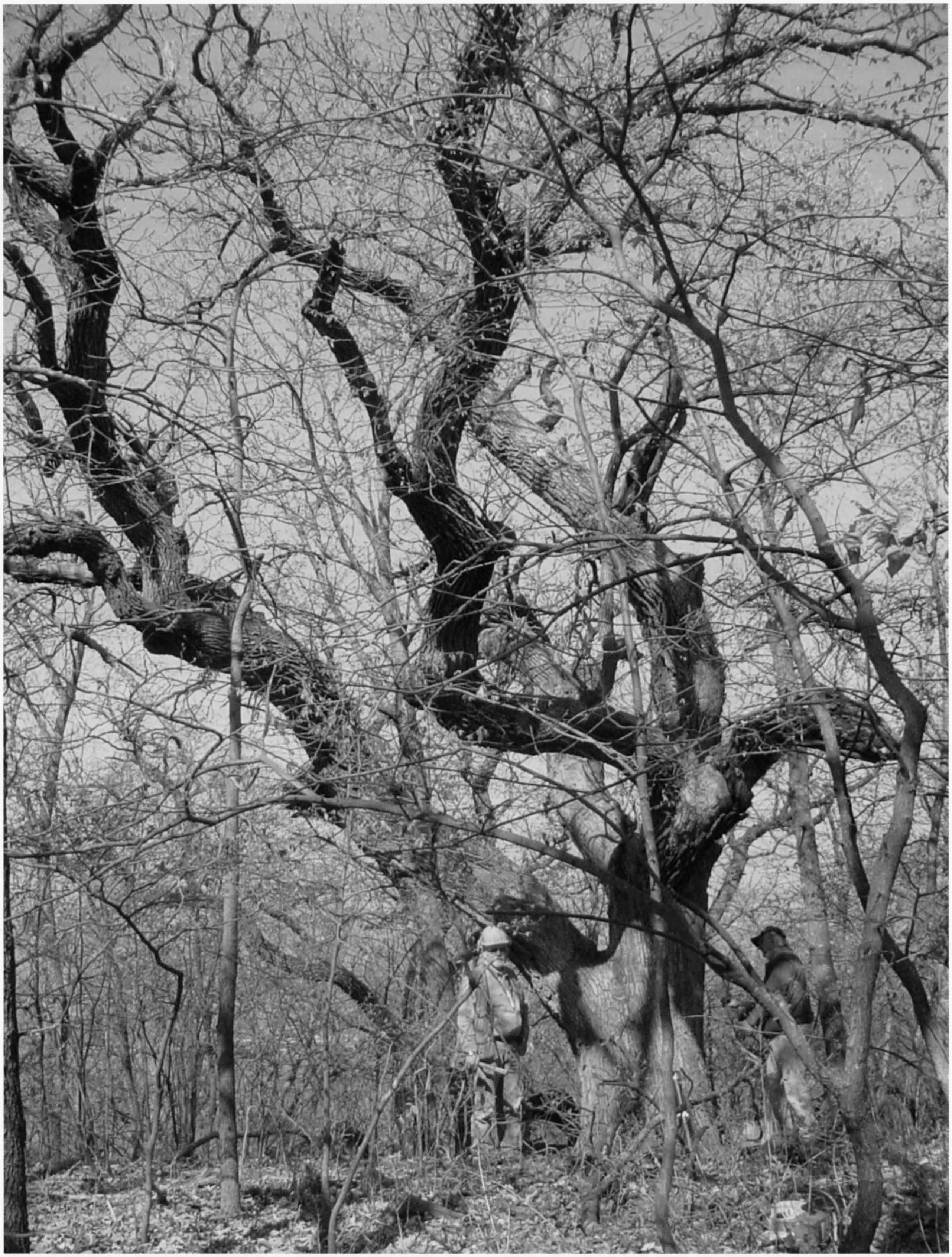

Figure 5. A bur oak at the study site demonstrating "retro-crown" branch and bole architecture, an indicator of historically frequent fire. Facing the camera is George Hartman; coring the tree is Richard Guyette. Photo by Michael Stambaugh.

or indicative of historic fire events being controlled primarily by other factors, such as short periods of dry weather and human ignitions. One possibility is that the Loess Hills are a landform more affected by local climate and topoedaphic conditions than by regional climate. In other words, the well-drained hills are droughty and susceptible to fire regardless of annual regional precipitation. Another possibility is that fire occurrence, especially in the adjacent grasslands, was historically a function of fuel buildup during wet periods as opposed to fuel drying during drought periods (Clark et al. 2002). A third and most likely possibility is that fire occurrence was controlled primarily by human ignitions.

The period of most frequent burning (~1825-1850) corresponds to the period of most active Euro-American settlement of the area. The Platte Purchase in 1838 opened northwest Missouri to settlement, and by 1860 the frontier of settlement had passed through Missouri and into Kansas (Gerlach 1986). Location on the Missouri River corridor and Lewis and Clark's reports of the Loess Hills landscape attracted settlers to the region. The advent of steamboats on the Missouri River also facilitated a rapid increase in settlement. Steamboat numbers on the Missouri River increased steadily through the 1850s, and traffic was most heavily concentrated in the reaches south of Omaha (Schneiders 1999). Steamboats were the primary vector of trade and settlement in northwest Missouri until railroads reached the river valley in 1859. Situated near the Loess Hills, both Fort Leavenworth and the city of Independence were major centers of military, trader, Indian, and settler activity during mid-19th-century westward expansion (Partin 1983). In addition to the influx of Euro-American settlers, displaced Potawatomi Indians and Mormons traveled through the southern Loess Hills during the 1830-1860 period. The fires of the mid-19th century may have resulted from both accidental fires and purposeful burning, possibly by settlers attempting to clear the land for grazing and agriculture.

The higher percentage of trees scarred in the pre-1900 period may represent a shift in fuel types and characteristics due to the advent of livestock grazing in the Loess Hills with the arrival of Euro-American settlers. Grazing has been common throughout the Loess Hills for over 100 years (Mutel 1989), and former cattle paths were readily apparent at the study site. Grazing removes the fuels that carry periodic low-intensity surface fires, and has been shown to modify fire behavior and reduce fire frequency in ecosystems with similar historic fire frequency (e.g., Savage and Swetnam 1990; Touchan et al. 1995; Belsky and Blumenthal 1997).

Another difference between the 19th- and 20th-century portions of the chronology involves the spatial extent of fires. Although many fires occurred in the 1900s, the majority of fire-scarred trees occurred on the first ridge from the Missouri River floodplain. While the inherent variability in fire scarring of trees does not preclude that fire occurred on the second set of hills more frequently, it is possible that settlement patterns influenced the spatial occurrence of fire. Homesteads in the area were generally located at the floodplain edge, at slope bases, and along wooded creek bottoms (Mutel 1989). The dissected topography of the hills in conjunction with reduction of fuels by grazing likely limited the spread of fires ignited by settlers at these landscape positions, leading to smaller, more isolated fires.

The location at the border of the Great Plains, distinctive ecological characteristics, and the rich history of the Missouri Loess Hills make the area one of the most interesting sites for the study of fire, climate, and cultural interactions. The unique natural communities and the extreme vulnerability of the Loess Hills to anthropogenic influences, evidenced by the rapid changes that occurred after Euro-American settlement, also make them a frequent target for ecological restoration activities, including the application of prescribed fire to the landscape. The fire chronology at Brickyard Hill Conservation Area suggests that fire occurrence has historically been less controlled by regional drought than other factors, with small fires occurring every five to six years and more extensive fires occurring less regularly. The presence of old fire-scarred trees in protected landscape positions suggests that the Loess Hills likely harbor large acreages of old oak trees (200-400 years), a valuable resource for future research.

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