Tree-Ring Analysis of Fire History of a Post Oak Savanna in The Missouri Ozarks[1]

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ABSTRACT: Fire scars from 43 trees were dated by dendrochronological methods to reconstruct the extent and frequency of fire in an area of post oak savannas in southern Missouri. Post oak (*Quercus stellata* Wang.), shortleaf pine (*Pinus echinata* Mill.), and eastern red cedar (*Juniperus virginiana* L.) trees from the Caney Mountain Wildlife Refuge were used to construct two fire-scar chronologies. Fire frequency and extent was found to be greatest between 1700 and 1810 on post oak savannas. The mean fire-free interval during the pre-1810 period was 4.3 years for an area of post oak savanna of approximately 2.5 km^2. Evidence for several fires at least 6 km^2 in extent was found from trees scarred in the years 1785, 1796, and 1806. A decrease in fire frequency on post oak savannas began in 1820, the time when native Americans began moving westward out of this area. In oak-pine woods, fire frequency was found to increase after 1850 with the settlement of the area in the 1860s by European-Americans.

INTRODUCTION

Fire has influenced the wildlife, woodlands, and prairies of the Ozarks for centuries. Historic anthropogenic changes in fire regime have had a profound effect on the present state of southern Missouri's vegetation and wildlife. Post oak (*Quercus stellata* Wang.) savannas have been, and still are, a major vegetation type in much of southern Missouri (Nelson 1985) as well as much of the south-central United States. These savannas are characterized by open-grown trees, the absence of a shrub layer, and grassy and herbaceous groundcover. In the past, low-intensity surface fires perpetuated these savannas. Recent changes in land use, however, have resulted in woody plant encroachment in these savannas (Schroeder 1982).

The climate in this area is classified as humid and continental. Precipitation averages about 115 cm annually. Spring is the wettest season, followed by fall, summer, and winter. During the fall and spring of nearly every year, dry vegetation and the proper climatic conditions for the occurrence of low-intensity surface fire exist. These conditions combined with the rarity of natural ignition factors make wildfire in the Ozarks a function of human culture and land use.

We determined the changes in fire frequency and extent during the last 300 years using tree-ring analyses of fire scars from post oak trees growing in the savannas of the Caney Mountain Wildlife Refuge (CMWR), located in south-central Missouri. Tree-ring analysis has been used successfully to establish fire histories (Guyette and McGinnes 1982, Stokes and Dieterich 1980).

METHODS

Study Area

The Caney Mountain Wildlife Refuge is owned by the Missouri Department of Conservation. It is located in part or all of Sections 4, 5, 6, 7, 8, 9, 16, 17, 18, and 19, T 23 N, R 13 W and Sections 1, 2, 12, 13, and 24, T 23 N, R 14 W, 5th P.M. This is in Ozark County, Missouri, in the southern part of the Missouri Ozarks. Steep topography, resulting from the deep dissection of an old elevated plateau by stream erosion, and shallow soils have made the land unsuitable for commercial agriculture. Thus this area was one of the last places to be settled in Missouri. In 1850, the population was less than two persons per square mile. The present population density is not much different — between 0 and 10 persons per square mile (Rafferty 1982). The area was considered "open range" for grazing until 1940, when it was acquired as a turkey refuge by the Missouri Department of Conservation.

The CMWR contains several thousand hectares of virgin post oak savanna where old post oaks are common. While there is some evidence of logging for shortleaf pine (*Pinus echinata* Mill.), white oak (*Quercus alba* L.), and eastern red cedar (*Juniperus virginiana* L.) in the refuge,

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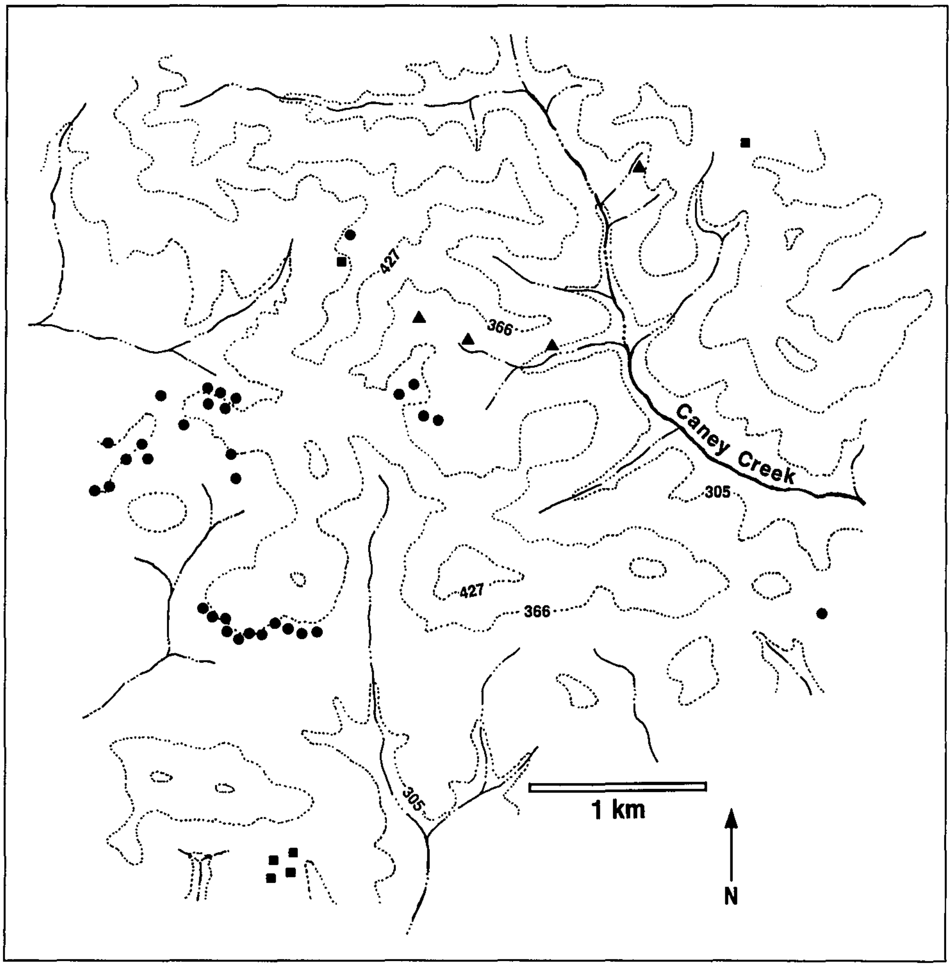

FIGURE 1. Map of sample trees in the study area. Circles represent post oaks; squares, shortleaf pine; and triangles, red cedar. Contour intervals are in meters.

most of the savanna areas remain uncut and there is an abundance of post oak trees greater than 200 years old.

Field Sampling

Fire wounds from three tree species — post oak, red cedar, and shortleaf pine — were used to reconstruct the fire history of the post oak savannas. We sampled red cedar and shortleaf pine to obtain a complementary data base for use in interpreting fire extent and change in an area dominated by post oak savannas. Cross-sections were cut from 47 living and dead post oak trees growing in a 2.5-km^2 area of the refuge (Figure 1). Of these only 33 were used in the fire-scar data. The other 14 sections were not usable because heart rot obscured the growth rings, making dating of scars and injury impossible. All cross-sections were taken within 30 cm of ground level. Post oak trees were sampled in all size classes greater than 10 cm to minimize scarring bias due to tree size. Some of the savannas were overgrown with smaller trees, but all tree sites had some remnant grass and herbaceous cover. Estimated canopy closure varied from 0% for areas with isolated trees to near 90% for overgrown areas.

Six shortleaf pine specimens were dated and used in the fire histories. Four cross-sections were taken from old stumps. Wedges were cut from two living trees. These pines grew in stands mixed with oak on steep slopes.

Live eastern red cedar trees were not studied because there were few live, old trees present. The live, old trees observed did have multiple fire scars. Of the eight dead trees examined, only four of these were datable and used in the fire-scar chronology. Red cedar remnants (dead wood) were taken from along Caney Creek and its tributaries, near the forest-glade interfaces, and rocky, fire-protected dry washes. Red cedar is much more susceptible to fire kill than either shortleaf pine or post oak because of its short bole, thin bark, and highly combustible evergreen foliage, which extends to the ground, particularly in young, open-grown trees.

Dating

Dendrochronology utilizes tree-ring patterns caused by climate to date annual growth increments (Stokes and Smiley 1968). These patterns enable accurate dating to the year. This serves as a check on ring counts and scar dates and allows for the dating of wood of unknown age, such as the pine stumps and red cedar snags used in this study. The matching of ring patterns between trees is called cross-dating. Precision in tree-ring dating can only be assured by cross-dating. Errors in counting, false rings, and missing rings can only be detected by cross-dating. Serious errors in data and interpretation can result from not cross-dating annual rings. In serial data, such as tree-ring series, being incorrect by one year can result in a doubling of the number of fire years and a halving of the extent of fires.

Cross-dating and the subsequent identification of fire-scar years requires that the cellular detail of each ring be distinct and discernible. Cross-sections were surfaced first with an electric hand planer, second with a belt sander, and last with an orbital sander. Fine sand paper (220 grit) and steel wool were used for the final finish.

Shortleaf pine stumps in this study were dated using cores from live shortleaf pine growing in the study area. Post oak and red cedar were dated using chronologies from the nearby Ava Ranger District of the Mark Twain National Forest (Stahle et al. 1985, Guyette 1981). Ring-width patterns from post oak sections of live trees were cross-dated to ensure accuracy of dating. All fire dates are for the year of the growth response to the fire injury. Thus a fire scar for which the earliest callus tissue dates to 1714 may have been caused by a fire anytime in the previous dormant season — from approximately September 1713 to April 1714. This dating convention is of particular importance when correlating fire with annual climatic variables or ring width.

The callus tissue of some fire scars is initiated within an annual ring, but this situation is rare, probably because growing season fires are rare in the Ozarks, except in years of extreme drought. These scars often resulted in the partial formation of a ring, perhaps owing to crown scorch. Defoliation and the consequent flush of foliage of deciduous trees during the growing season can result in the partial formation of a ring (Christensen 1987). Two post oaks had scars that were initiated within an annual ring in the year 1748.

Scarring Biases

There are many factors that could have biased the data in the fire-scar chronologies. Variables that typically influence fire scarring are tree size, bark thickness, growth rate, tree hollows, initial wounds, litter type, moisture content of the wood, and the thermal conductivity of xylem tissue. Some of the factors are complex and difficult, if not impossible, to quantify. The analysis and presentation of the data was kept as straightforward and unadjusted as possible.

Tree size is related to scarring and can present a problem when evaluating changes in fire frequency through time. Small stems are more likely to die in a fire and leave no record. The cambium of trees with large boles is better protected from heat damage than that of trees with small boles because of the lower surface to mass ratio and thicker bark. Fuel loading, fire duration, and temperatures of each fire determine what size trees are scarred. Bole diameter potentially biases the fire-scar chronologies of post oak more than those of red cedar and shortleaf pine because of the typical concentric growth habit of the post oak bole. The initial (first) scarring of shortleaf pine is related to bole diameter and bark thickness, as in post oak. In shortleaf pine, once the cambium has been killed and the bark has fallen off, the cambium adjacent to the scar face can be scarred even by very low intensity fires. Scarring of red cedar is probably least affected by tree size because of that species' thin bark.

To compensate for the potential bias of size on the more recent fire-scar history, post oak trees with both small and large diameter boles were sampled. The number of sample trees and their susceptibility to scarring had to be taken into consideration. The number of trees in the record was adjusted by tree size, a factor in scarring susceptibility. Because growth rates did not vary widely among trees, the number of rings was used to estimate size. Thus only trees that had 140 rings or fewer were counted. At the top of Figure 2 is an index of the change in scarring frequency through time. The index value is calculated by dividing the number of fire scars per 20-year period by the number of trees during the period with less than 140 rings. This number yields a relative estimate of the change in influence of fire on an ecosystem through time. This adjustment was made only for post oak samples because size is much less of a factor in scarring in red cedar and shortleaf pine.

Post oak is probably the most fire resistent species in the Ozarks, with the possible exception of shortleaf pine. Because post oak is so resistent to scarring, determination of fire frequency is difficult. Paulsell (1957) noted that only 10% of the post oaks were scarred in annual burning plots, whereas 23% of the post oaks were scarred on periodic burn plots. This difference in scarring could relate to differences in litter buildup, but more influential is the fact that the species is very scar resistent—so much so that a tree may sustain only one scar for every four fires. To compensate for this bias, we attempted to sample several trees in an area, hoping that at least one would be scarred with each fire.

Hollow trees are the dendrochronologist's nightmare. At least 80% of the old trees cored in CMWR were hollow. Because only more or less solid trees and stumps were studied, the data set includes only those trees that were not scarred as often and extensively as is necessary to result in a hollow tree. This implies a bias in sampling and a possible underestimation of fire frequency.

RESULTS AND DISCUSSION

Fire Scar Location and Appearance

Fire scars in post oak were basal injuries that resulted in cambial death, exhibited a localized cambial growth response, and contained callus tissue. Fire scars also were associated with abnormal tyloses formation, general growth responses (from release or crown damage), and false rings. Fire scars in young (<60 years) trees were often associated with an abrupt reduction in ring width. This probably resulted from leaf scorch and cambial damage in the crown by fire.

Fire scars were identifiable by location on the bole. Over 90% of fire scars are on the uphill side of the bole in post oak trees (Paulsell 1957). Although some fire scars extended a meter or more above the ground, most occurred within 30 cm of ground level. Often there was no external evidence indicating which post oak trees had multiple fire-scar records. Charcoal was only rarely associated with fire scars in post oak, although it occurred often on large, open, and undatable scars.

Fire scars in shortleaf pine occurred most frequently on the growing edge of an old fire wound. Flammable resin is exuded at the edge of wounds on shortleaf pine. Ignition of this resin near the thin-barked callus tissue results in scarring from even very low intensity fires. Because of this, shortleaf pine stumps often have many scars. One pine stump from CMWR had 30 fire scars dating from between 1714 and 1902. Charcoal was nearly always associated with fire scars on shortleaf pine. Traumatic resin canals (i.e., those formed as a result of wounding) were often found in the xylem and helped identify fire scars. Multiple scars in pine were usually on the uphill side of the tree.

Fire scars in red cedar were associated with false rings and included sapwood. Scar faces often took the form of multiple triangular wounds at the tree base, like those in shortleaf pine. Red cedar boles, because of their thin bark, were more likely than either oak or pine stems to be scarred in directions other than uphill. Charcoal was usually present on the exposed heartwood of red cedar trees but was rarely traceable to a particular fire year.

Many other types of scars occurred on the cross-sections sampled. In post oak, damage caused by pin worms and bark scarrers was common but distinctive and easily distinguished from fire scars. Lightning scars were identified by narrow, longitudinal callus tissue in sections well above the ground. Basal scarring in red cedar can result from flood and rockfall, although scarring from these causes usually can be identified.

Fire Frequency

Post oak trees provided the best record of fire history on the refuge because of their age and abundance. However, rotten wood and extremely narrow rings made cross-dating and ring counts difficult in some cases. Thirteen of the 93 fire scars found on the 33 samples were datable only to within plus or minus three years. These scars were given the date of the closest fire year. The remainder of the scars were datable to the year.

Figure 2 summarizes the data from the post oak trees in several ways. A fire-scar chronology constructed from all the fire scars from all the post oaks is shown at the bottom. The number of trees sampled per year of record is displayed above. At the top is a relative index value of the number of scars per 20-year period per tree for trees with fewer than 140 rings.

The greatest frequency of fires scarring multiple post oaks occurred during the period 1710 to 1810. During this 100-year period, nine fires scarred between 23% and 80% of the trees sampled. Thus the mean fire interval is 11 years for "severe fires" (fires that scarred three or more trees) during this "native American" period. Altogether, 23 fire-scar years occurred during this period. Thus a fire occurred somewhere in an area of approximately 2.5 km^2 every 4.3 years. This interval is similar to the mean fire-free interval of 3.2 years obtained in a study of a nearby cedar glade (Guyette and McGinnes 1982) of approximately the same area and is also in line with fire frequency cited by Chandler et al. (1983) for the southern reaches of the North American temperate forest. The greater resistance to scarring of the thicker barked post oak may account for the small difference between the oak and red cedar studies.

During the 179-year period after 1810, the fire-free interval is 6.4 years, despite an increase in sample size. More important, none of the fires during this later period scarred as many trees. In only one year, 1824, were more than two trees scarred in the same year, whereas nine such fire years occurred before 1810. This change in the frequency and extent of scarring probably relates to a change in the size and severity of fires and perhaps also to a lack of human sources of ignition during the "transition" period (see Figure 3)—from 1810 to 1850. Schoolcraft (1821) noted that Osage were leaving the area around 1815: "... several Indian camps, but all in a state of decay, and leaving the appearance of having been deserted three or four years. Several causes have induced the Indians to relinquish hunting in their quarter, and principly their wars

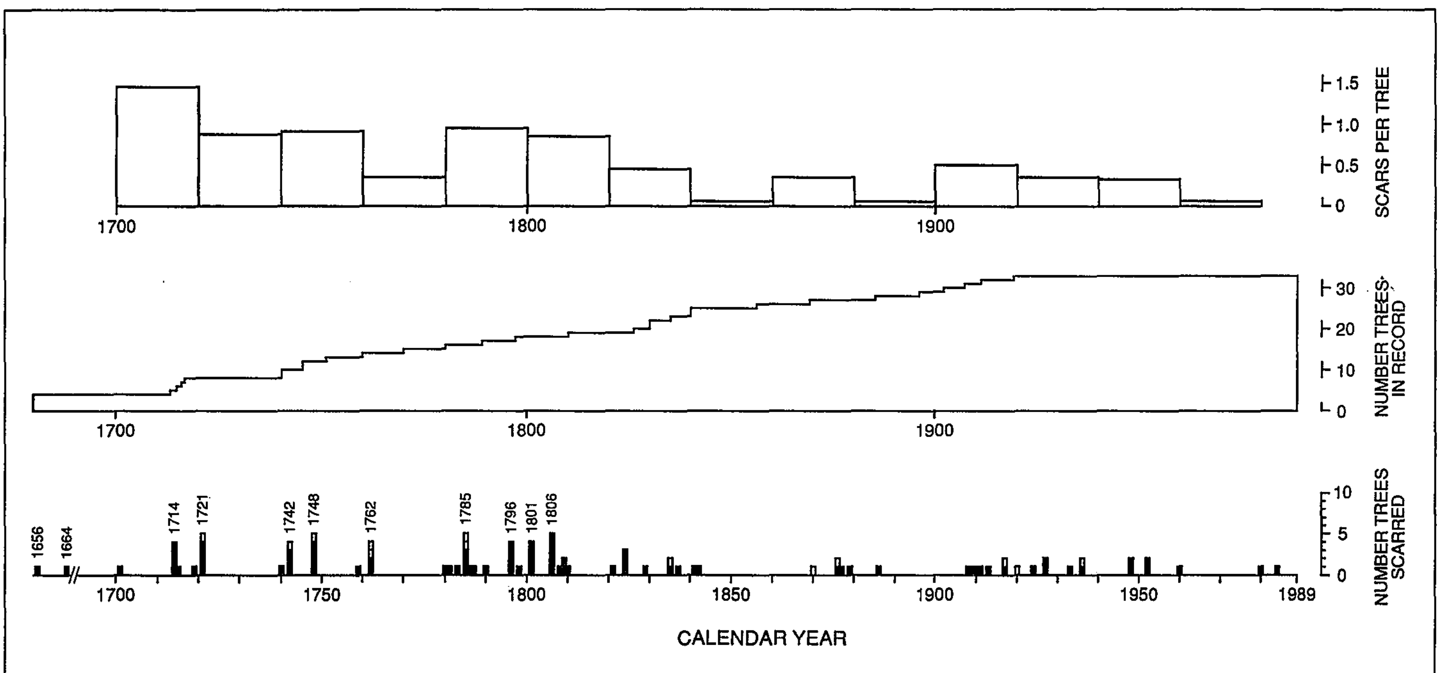

FIGURE 2. A post oak fire-scar chronology of the Caney Mountain Wildlife Refuge. Solid blocks represent dated fire years. Hollow blocks represent approximate fire years as described in the text. The top graph is the number of scars per year per 20-year period per tree, for trees with fewer than 140 rings.

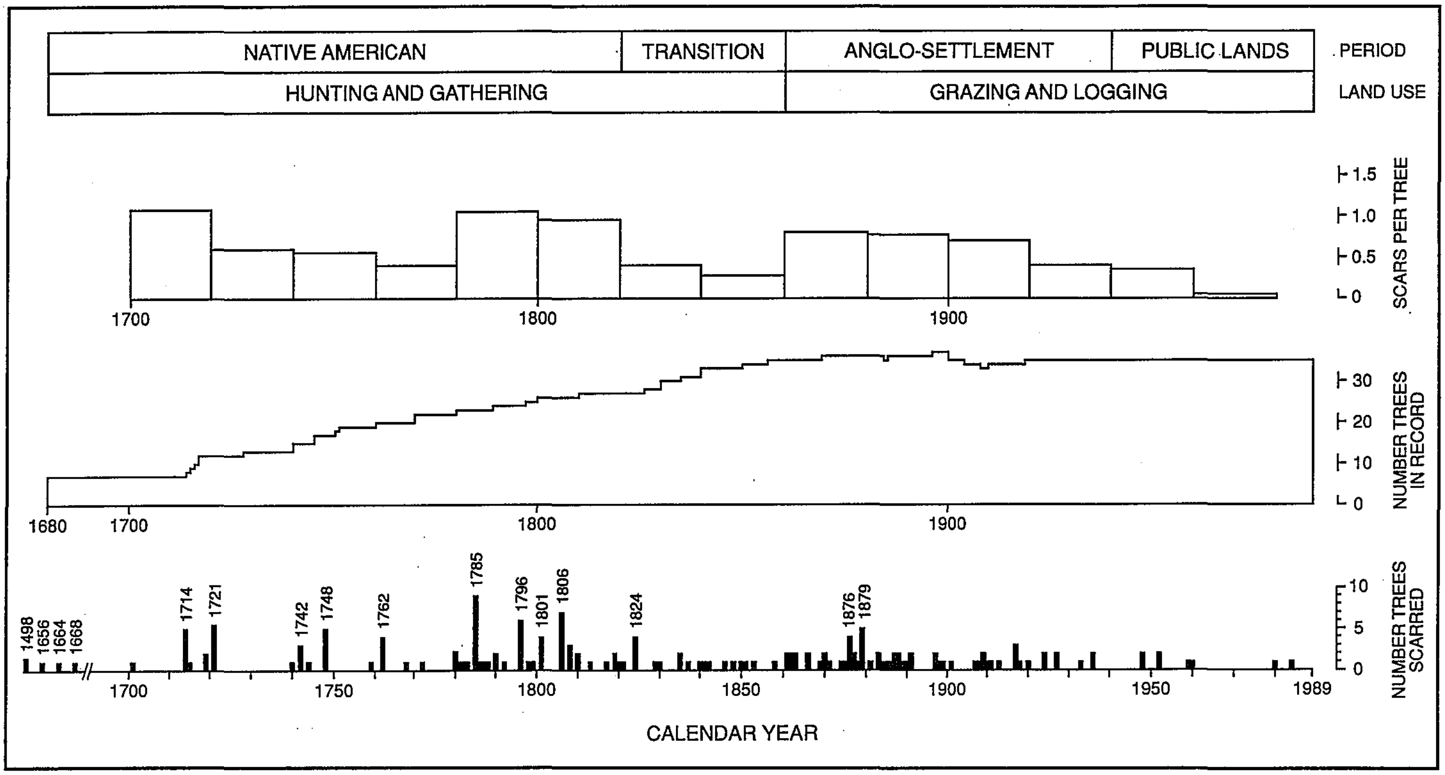

FIGURE 3. A composite fire-scar chronology of post oak, shortleaf pine, and red cedar.

among themselves . . . lately, the Indian title has been extinguished by the purchase by the United States." Schoolcraft also noted the villages of Cherokee, Delaware, and Shawnee. The presence of these tribes, their "wars," and occasional European-Americans may account for much of the frequency and extent of fire during the late 1700s and early 1800s.

An increase in oak stems of sapling size may have resulted from the low fire frequency between 1810 and 1850. The change in size class representation and development of an overstory with a partially closed canopy may account for some of the reduction in fire extent and frequency after 1810: a change from grass cover to young oak stands would have decreased the rate of fire spread. Somewhat later on, as settlement by European-Americans increased in the area, the effects of grazing on fuel loading and oak-sprout release would have decreased the rate of fire spread and the intensity of the surface fires. The accompanying reduced amount of fine fuels also would slow the rate of fire spread and decrease fire intensities.

The individual post oak with the most scars was a 316-year-old tree growing near a small wash. This tree measured 63 cm at 25 cm above the ground and had 11 fire scars. Ten of these fires occurred during the native American period, from 1714 to 1785, giving an average fire-free interval of 7.1 years.

Fire Extent

Figure 3 shows the combined 175 fire scars from 43 trees of the three species sampled. Ninety-three of these scars were from post oak trees, 62 were from shortleaf pine, and 20 were from red cedar. The important change in this species composite chronology as well as the post oak chronology (Figure 2) is in the extent of fires as measured by the spatial distribution of trees scarred in a year. The locations of the trees scarred in the years that the most extensive scarring occurred (1721, 1785, 1796, and 1806) were mapped (Figure 4). The tree scar maps show that fires may have been several square kilometers in extent and perhaps much larger (there is little additional evidence as to how much larger). Some fire years, such as 1796 and 1806, when several trees were scarred on the CMWR, were years of multiple tree scarring on a red cedar glade 27 km to the west (Guyette and McGinnes 1982). Given the size and extent of documented wildfires elsewhere in the United States, such as the Hinckley and Peshtigo fires (Pyne 1982), it is not unreasonable to speculate that fire in those years extended over a wide area.

The composite chronology in Figure 3 shows a relative increase in the number of fire scars between 1850 and 1900 compared to the post oak chronology in Figure 2. This is caused by an increase in the number of fire scars dated from shortleaf pine.

Climatic influences

Narrow rings in post oak are correlated with past drought conditions (Stahle and Hehr 1984). Many ring-width chronologies have been constructed for southern Missouri by DeWitt and Ames (1978), Guyette (1981), and Stahle et al. (1985). In the post oak fire-scar chronology, of the ten fire years with more than two trees scarred, seven were also extensive drought years

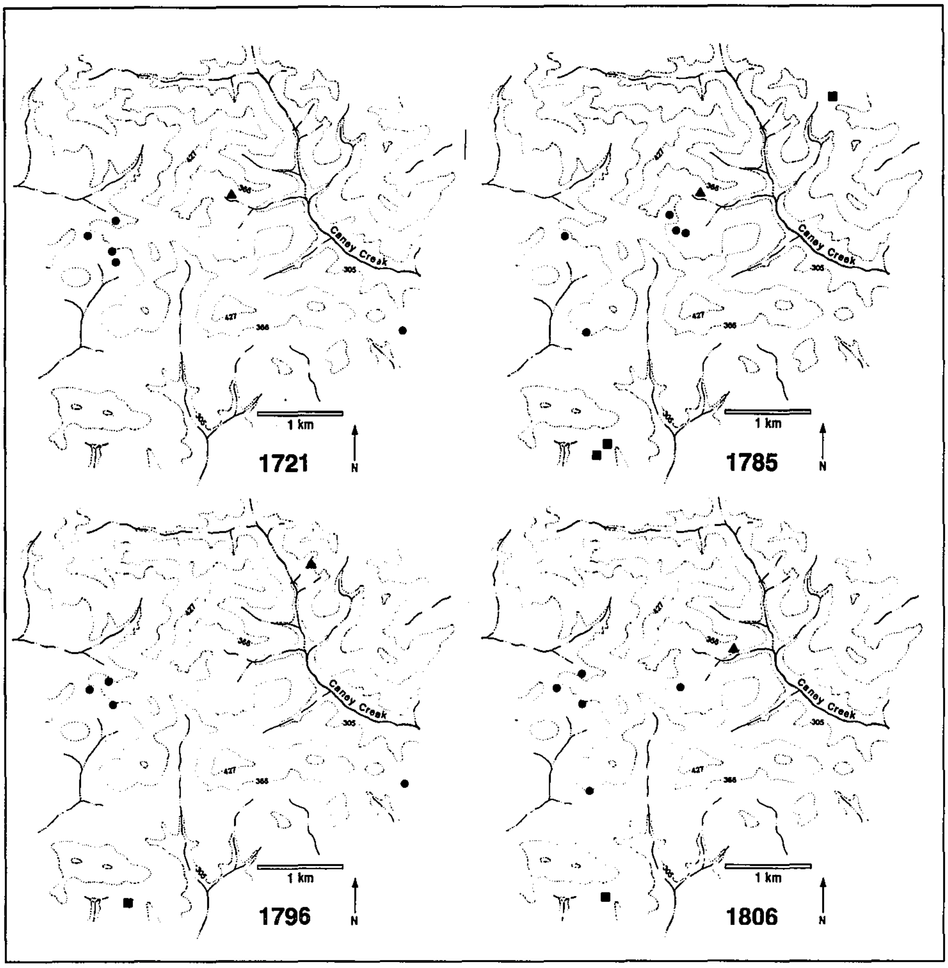

FIGURE 4. Maps of fire-scarred trees for the four years showing the greatest extent of fire damage. Circles represent post oaks; squares, shortleaf pine; and triangles, red cedar. Contour intervals are in meters.

(exhibiting narrow rings in many post oak chronologies outside the CMWR), two were years in which ring widths were locally narrow, and one year had above normal ring widths. Obviously, drought would be a contributing factor to the intensity and duration of fires.

Pith Dates

The center ring or pith of each ground-level cross-section can be used as an approximation of the life span of the stem. Because of dieback and sprouting of small oaks, the actual germination date of the plant may be much older. The pith dates of the post oak trees in the chronology present an interesting pattern. Of the 33 post oaks in the fire-scar chronology, no trees were sampled that had pith dates during the period of frequent and severe fires between 1750 and 1810. After this period, during a time of less frequent fires between 1810 and 1860, 11 trees had pith dates. However, no attempt was made to randomize the selection of trees cut, so it is possible that this pattern resulted from a priori selective sampling or limited sample size.

SUMMARY AND CONCLUSIONS

The chronology of fire regimes for the post oak savannas in Caney Mountain Wildlife Refuge based on tree-ring data from this study, is as follows. Between 1700 and 1810 the mean fire-free interval was 4.3 years on the post oak savannas. This interval may be a conservative estimate because low-intensity fires may not have scarred any of the sample trees and thus would be undetected. Nine severe fires (fire years with three or more trees scarred) that occurred during this period had an average interval of 11 years. These severe fires were more frequent during drought years. The period between 1785 and 1810, a time of movement into the area of eastern native American tribes and European-American exploration, shows the most extensive evidence of burning. This also was a period of frequent and extensive fire in a cedar glade 27 km to the west. Fire frequency dropped between 1810 and 1850, coincident with the exodus of native Americans and the delayed settlement of these lands. As a possible consequence, an invasion of woody vegetation may have begun, which could have contributed to a decrease in fire frequency and extent. After European-American settlement, approximately 1860, although ignition factors probably increased and oak-pine woods burned more often, post oak savannas burned less because of decreased amounts of fine fuels — a result of invasion by woody vegetation and grazing, as well as fire suppression after the 1940s.

One of the implicit purposes of research into the fire history of a particular area is to aid in wildland management. In this sense, fire management is goal dependent and may include such diverse ends as timber quality, wildlife habitat, seed production, recreation, and watershed management. Often the goals are multiple and conflicting. We confine our remarks to the potential use of low-intensity fire in areas such as CMWR to manage post oak savannas as natural areas.

Caution is in order when generalizing from this study to other situations. The goals of management may not be the same; limitations on burning are often imposed by political, geographic, and liability factors. Furthermore, each place has its own unique fire history. Even post oak savannas close to CMWR may differ in fire history, for reasons not immediately apparent.

Problems of definition arise for natural areas where humans have been the main source of ignition, either by accident or by design, for many years. A "natural" state of vegetation (without human intervention) may never have existed during the most recent climatic era. Since the last glaciation, a number of fire-dependent vegetation types may have existed at various times. If we choose to manage an area for a particular feature, such as post oak savanna and its associated wildlife, then vegetative succession must be held back. In the case of post oak savanna, we are trying to manage an area as a place in time as well as space, and prescribed fire must be used. However, prescribed fire as a management tool is fraught with hazards (Pyne 1982, 1984).

Knowledge of an area's fire history can contribute in two important ways to the management of that area. It can provide an estimate of the frequency and timing of past fires. Although these frequency estimates are crude, they far outweigh the alternative — no historic basis for frequency of burning.

One can also gain a fresh perspective on the present state of vegetation by knowing the area's fire history. Vegetation structure, age, and diversity are often fire dependent. For example, on parts of the CMWR, more than 800 young (<100 years old) blackjack oaks (*Quercus marilandica* Meunch.) per hectare are growing among more than 40 post oaks that are more than 150 years old. A reduction in fire frequency, especially during the last 50 years of suppression, may account for this change in species distribution.

Changes in vegetation caused by changes in fire frequency are not always easily reversed. In areas where fire has been suppressed for many years, the condition of vegetation and fuels may cause initial fires to be more destructive than those in the past, when fire was a more common occurrence. For example, woody undergrowth less than 100 years old is commonly found under 300-year-old post oak and red cedar trees. Often this young competition is highly combustible (e.g., young red cedar) and its ignition, even in low-intensity fires, may result in the death of old-growth savanna trees. In these cases, fire exclusion, cutting and removal of young stems, or experimentation with fire on small plots may be necessary aspects of management for the old-growth trees.

Although changes in vegetation structure and diversity are often the most obvious results of a fire management policy, the effects of fire on nutrient cycling and soil chemistry should not be overlooked. Fire suppression can increase the amount of nutrients sequestered in woody vegetation. In areas such as CMWR, where shallow soils provide limited nutrient input, a significant proportion of the total available nutrients can be tied up in woody vegetation. Burning releases nutrients tied up in slowly decaying litter and small fuels (Chandler et al. 1983). Land managers should not overlook the implications of fire for nutrient cycling.

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