HISTORY OF FIRE IN A SOUTHERN OHIO SECOND-GROWTH MIXED-OAK FOREST

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Abstract: The role of fire in shaping the composition and structure of *Quercus* (oak)-dominated communities in the deciduous forests of eastern North America is becoming clearer but fire regimes are less well known. I analyzed the fire-scar patterns in 14 oak cross sections from a mixed-oak stand in Vinton County, southeastern Ohio, to determine the frequency and seasonality of fire. This oak stand was even-aged and originated in the mid-1850s, so the fire history is representative of the period after Euro-American settlement. The tree rings were crossdated, calendar year of the fire scars was assigned, and season of burning noted. The fire-scar dates are Weibull-distributed, and the median probability interval is 3.6 years. The 95% and 5% Weibull probability exceedance intervals were 0.4 and 12.1. Spatially extensive (major) fires occurred every 7.5 years, and the 95% and 5% exceedance intervals for these fires were 0.9 and 24.3. The fires probably were ignited by people. Fire scars indicated that most fires (69%) occurred during the dormant season or in the spring (25%) and were rare (6%) during the summer (May 1 to July 30). These patterns are not significantly different from dates of observed wildfires in Vinton County. Seasonal climate has no apparent relationship to fire occurrence.

INTRODUCTION

Fire has played an undeniable role in the development of past and existing oak (*Quercus*) forests in eastern North America (Abrams 1992, Olson 1996). Lorimer (1985) characterized fire-related features of oak: oaks resist damage and mortality from fire because they have thick bark and rapidly compartmentalize cambium damaged by fire. Fire creates seedbeds for acorn germination, and seedlings and young trees sprout readily after being topkilled. Thus, in a regime of periodic fire, oaks are favored over shade-tolerant trees, especially *Acer* (maple) species, that are susceptible to fire (Abrams 1992). Since about 1930, effective fire protection has been applied broadly to the eastern deciduous forest (Pyne 1984). Abrams (1992) summarized widespread evidence that in the absence of fire, oaks are likely to be replaced by shade-tolerant species.

While recurring fire clearly was associated with the development of present-day oak forests, the fire regimes of oak forests are ill defined. Gill (1975) described the elements of fire regimes as frequency, intensity, spatial extent, seasonality, and type of fire (e.g., ground, surface, or crown fire). In coniferous forests of the western United States, fire regimes have been characterized by examining fire scars in the annual rings of centuries-old trees, and developing chronologies of fire (e.g., Baisan and Swetnam 1990, Brown and Seig 1996, Dieterich and Swetnam 1984). There are few fire histories of eastern oak forests (e.g., Abrams 1985, Cutter and Guyette 1994, Guyette and Cutter 1991, Guyette and McGinnes 1982) primarily because little of the presettlement forest remains after extensive deforestation following Euro-American settlement (Williams 1989). However, fire was an important process in the development of existing second-growth oak forests (Abrams 1992), and any information gained about the fire regimes that resulted in present forest composition and structure would be valuable in managing oak forests.

The history of Ohio's oak-dominated forests is typical of that of many Midwestern forests. Ninety-five percent forested at the time of Euro-American settlement (circa 1800), Ohio's forested area was reduced to about 15% of land cover by 1900, but has regrown to 30% since 1940. Currently, 65% of the unglaciated Allegheny plateau in southeastern Ohio is forested, and oak species dominate the overstory (Griffith and others 1993). The objectives of this study were to develop a fire history from a second-growth oak site in southeastern Ohio, and to make inferences about the past fire regime that resulted in that oak forest.

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PHYSIOGRAPHIC AND HISTORICAL SETTING

The area studied was within the unglaciated Allegheny Plateau physiographic region of southeastern Ohio, referred to as the Hill Country (Braun 1950). The topography was complex and dominated by highly dissected ridge and valley complexes with relative relief of 90 to 150 m. The climate was cool, temperate, and continental. October was the driest month; otherwise, rainfall was distributed relatively evenly through the year (King 1979).

Of the forest types in the Hill Country, 70% are mixed oak (*Quercus alba* L. (white oak), *Q. velutina* Lam. (black oak), and *Q. rubra* L. (northern red oak) (Type 52, Eyre 1980)). These upland forests lie in a geographical transition between the open woodlands of the Midwest and the more mesophytic forests of the Appalachians (Braun 1950).

Settlement of Vinton County in Ohio's Hill Country by Euro-Americans began in 1802, and an agricultural economy developed, primarily in bottomlands, where people cleared for field crops and pastures by tree-girdling and burning (Beatley 1959). Many more people migrated into the area in the 1850's with the development of the charcoal pig iron industry (Willard 1916). The demand for this high-quality iron caused rapid deforestation of the area around the smelters. Vinton County was 75% forested in 1853 when the furnaces were built, 59% forested by 1870, and only 18% forested by 1883 (Beatley 1959). Pig iron production peaked in the 1880's, and then declined with the loss of the timber resource for charcoal. Most of the smelters were closed by the turn of the century. The communities that surrounded the smelters were abandoned and the forests regrew (Stout 1933).

The site described in this study, Oreton, (latitude 39°09' longitude 82°24') was a 8-ha compartment on the Raccoon Ecological Management Area owned by Mead Paper Corporation in southern Vinton County, Ohio. The site was north-facing, with slopes of 0 to 25%. The site was purchased by Mead in 1965 from Sentry Royalty Company, a mining concern. Timber maps from that time show this was an uncut stand of second-growth upland oaks and other hardwood tree species.[2] The stand was second-growth, and the overstory was dominated by even-aged oak species about 150 years old, primarily black oak, white oak, and chestnut oak (*Q. prinus* L.).

METHODS

Analysis of fire scars initiated by low-intensity fire events is the most appropriate way to reconstruct fire history in surface fire regimes (Swetnam and Baisan 1996). The approach here was to collect samples opportunistically during harvesting activities with cooperating timber operators. Samples were collected for the fire-scar analysis during a selection cut conducted by Mead in September 1995. By prior arrangement, trees were cut 10 to 15 cm above the ground and the logs examined to determine whether cross sections would be cut from them. Trees were selected for fire-scar sampling if the logs were relatively free from center decay but showed some evidence of scarring; this is usually visible even on a rough, chain-sawed surface. Sampled trees were scattered throughout the 8-ha compartment. Twenty-eight intact crossections were identified and transported to the laboratory where they were allowed to dry for a month. After drying, the sections were examined, and 14 that showed promise for analysis (intact, and with multiple fire scars) were surfaced using a power hand planer and belt sander. (The remaining 14 sections had large rot pockets or other physical defects that made them unsuitable for further analysis.) Each section was crossdated (Fritts 1976, Swetnam and others 1985) using two lines drawn from the pith to the bark as close to 180° apart as possible, but at least 90° to 180° apart. The lines were skeleton plotted (Stokes and Smiley 1968) and these plots compared to master chronologies from the same area (WNF chronology in LeBlanc and Foster 1992, Sutherland, unpublished). Calendar-year dates were then assigned to each annual ring.

After the crossdating of all sections was verified, calendar-year dates were assigned to each fire scar. The position of each scar within or between annual rings (Baisan and Swetnam 1990, Dieterich and Swetnam 1984) was recorded when possible to estimate season of fires—dormant, earlywood (spring), or latewood (summer). The two dominant wildfire seasons on the Wayne National Forest in Ohio both occur during the dormant period (Haines and

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[2]Personal communication 6/20/96, Steve Mathey, Mead Paper Corp., Fine Paper Division, Chillecothe, Ohio.

others 1975): March-April and October-November (61 and 32% of all fires, respectively). Because the majority of wildfires occur in the spring, for simplicity, all dormant-season scars were assigned to the later calendar year. For example, a dormant-season scar between the tree rings that grew in 1870 and 1871 was assigned to the year 1871.

The distribution of dormant-season, spring, and summer fire scars were compared to dates of wildfires from state and federal agencies in the Vinton County area using a X^2 analysis (Sokal and Rohlf 1981). From dendrograph data taken in 1958 in central Illinois, Fritts (1960) found that virtually all of the earlywood of white oak trees and two-thirds of the earlywood of northern red oak trees formed before leafout (April 11 to May 5). For simplicity, I designated the earlywood (spring) growth period to have been April 15 to 30, the latewood (late spring/summer) period to have been May 1 to July 31, and the dormant season to have been August 1 to April 14.

Fire frequency or fire-return interval is a measure of central tendency derived from fire history data that indicates how often fire tends to occur at a site. However, central tendency may be poorly estimated by statistics such as the (arithmetic) mean fire interval (MFI) because fire-interval data are rarely distributed symmetrically; that is, there is no upper bound for the maximum fire interval but the shortest possible fire interval is 1 year (Swetnam and Baisan in press). Because fire history data often are positively skewed (Baker 1992), more flexible distributions such as the Weibull provide a better fit to the data and more robust measures of central tendency than the MFI (Baker 1992, Clark 1989, Johnson 1992). The Weibull distribution can be used to estimate both central tendency and range of fire history data, expressed as exceedance probabilities (Grissino-Mayer 1995). The central tendencies of Weibull distributions are expressed as the 0.5 exceedance probability (the 50^{th} percentile of the estimated distribution). This is called the Weibull Median Probability Interval WMPI. Range is expressed as the 0.95 and 0.05 exceedance probabilities, which can be interpreted as significantly short and long fire intervals (Grissino-Mayer 1995). The FHX2 program described by Grissino-Mayer (1995) compares the goodness-of-fit between the fire interval data and the normal and Weibull distributions with the one-sample Kolmogorov-Smirnov (K-S) test, and calculates the MFI, WMPI, and short and long exceedance probability. These values were calculated for all fires occurring at the site, and for major fires. Major fires were defined as years during which 25% or more of all samples or at least two samples were scarred. Fires probably were more spatially extensive and intense during major fire years than in years when only one tree was scarred (Guyette and Cutter 1991, Guyette and McGinnes 1982).

To compare the relationship between fire and climate, mean March and April precipitation was plotted for the period 1895 to 1995, and fire years were labeled according to the estimated season of the fire and the extent (major or minor) of the fire.

RESULTS

The sampled stand, essentially even-aged, originated around 1856; no trees have a pith date later than 1864, so the fire history is representative of the post-settlement period only. Twelve of the fourteen trees analyzed are black oaks; one white oak and one chestnut oak complete the sample.

Here, fire scars are defined as wounds occurring low on the tree bole, identified by the presence of callus tissue and a growth response to the death of a section of cambium (Guyette and Cutter 1991). Occasionally, false rings were observed near the scar, apparently a response to wounding. Although Abrams (1985) used the presence of charcoal in the scar as a criteria for attributing fire as the cause for scarring, I am not. Presence of charcoal is a highly conservative criteria for denoting fire scars because heating to 60°C kills cambium (Kayll 1968) and causes wounding. Actual combustion of the cambium is not necessary to cause wounding, and in the low-intensity fires typical in oak woodlands, combustion is probably rare. Occasionally, scars occurred that did not show callus and growth response that I attribute to fire-wounding response; such scars were not included in the fire-scar record. Although scars can be caused by a number of sources, including small mammals, fungus, and insect attacks (Arno and Sneck 1977, Mitchell and others 1983), there was no evidence of physical abrasion or insect galleries associated with the (fire) scarring events. Nor are the scars likely the result of fungus attack. Examination of a cross section from this site revealed that the broad "single year" nature of the wounds are not consistent with attack by a perthotrophic fungus as those in the genus *Armillaria* [3].

Many trees had more than one scar; the number of fire events causing scars ranged from one to seven per tree. Unlike conifers that typically develop a single scarred area or face with a number of scars and healing ridges (Baisan and Swetnam 1990, Dieterich and Swetnam 1984), scars were seldom visible from the outside. The area of damaged cambium generally was small (< 2 cm in length) and was compartmentalized rapidly and embedded in the stem within 3 to 5 years after the scarring event. Scars on oaks sampled at the Oreton site were not segregated in one area on the cross section, nor were scars usually near each other.

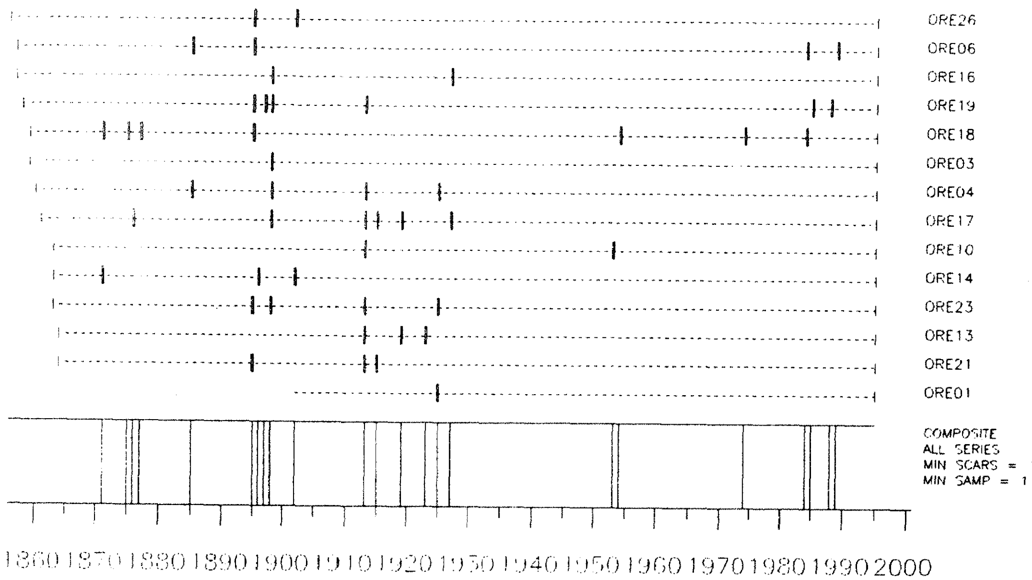

Figure 1. Fire chronology at the Oreton site, Vinton County, Ohio for the period 1856 to 1995. Each horizontal line represents the fire-scar chronology for an individual tree; each vertical bar represents a scar during a year.

Twenty-two fire events were recorded at the Oreton site (Figure 1, Table 1). The K-S d-statistic (0.573) was significant (Prob > d = 0.0001), so the data could not be modeled with a normal distribution. Alternatively, the Weibull distribution did model the fire-interval data adequately (K-S d-statistic = 0.222, Prob. > d = 0.2270). The observed fire intervals and calculated Weibull function for all fires and only major fires are shown in Figure 2. The median and the short and long probable interval values (Table 2) indicate that fire was likely to return to the Oreton site every 3 to 4 years, and that annual fires were unusual, as was an interval of more than 12 years between fires. Major fires (Table 2) occurred about half the time (every 7 to 8 years). It was unusual to have major fires in successive years, or for more than 24 years to pass between major fires.

[3]Personal communication, 11/12/96, Kevin Smith, Research Plant Physiologist, Northeastern Forest Experiment Station, Louis C. Wyman Forest Sciences Laboratory, PO Box 640, Durham, NH 03824-0640.

Table 1. Fire years, number of scars, fire interval, and season of fire of individual fires at the Oreton site, Vinton County, Ohio, 1856 to 1995. Fires occurred in 22 separate years. Major fires were designated where 25% of all samples or at least two cross sections had a fire scar during a given year. Seasons were designated as D = dormant, E = early spring (probably mid to late April), S = late spring/summer (probably May to mid July). (The * denotes significantly long ($p < 0.05$) intervals.)

Year	Number of trees scarred	Fire interval (years)	Major fire interval (years)	Season
1871	2	.	.	D
1875	1	4	.	D
1876	1	1	.	D
1877	1	1	.	D
1885	2	8	14	D
1895	6	10	10	E
1896	1	1	.	D
1897	1	1	.	D
1898	6	1	3	E
1902	2	4	4	S
1913	7	11	11	E
1915	2	2	2	E
1919	2	4	4	D
1923	1	4	.	D
1925	3	2	6	D
1927	2	2	2	E
1953	1	26*	.	E
1954	1	1	.	D
1974	1	20*	.	S
1984	2	10	57*	D
1985	1	1	.	S
1988	1	3	.	D
1989	1	1	.	D

Most fires burned during the dormant season (69%; 33 scars) and during spring when the earlywood was forming (25.0%; 12 scars); only 6% (3 scars) burned during the summer when latewood was forming. The X^2 distribution of the scars during the dormant, spring, and late spring/summer seasons was not different ($X^2 = 1.82$, 2 d.f.) from wildfire occurrences in the Vinton County area (Figure 3). Thus, my estimates of the periods during which scars formed probably are accurate.

Figure 4 illustrates the relationship between fire and climate from 1895 to 1995. If climate conditions affect fire occurrence, then more fire events should occur on the bottom half of the graph (drier than normal conditions). There are nine fire events above the mean and nine below. Dormant-season fires usually occur in spring but can occur in autumn. Thus in Figure 4, autumn dormant-season fires would not be expected to show a relationship to spring climate and would only add error to climate/fire relationships in this graph. However earlywood fires do occur in the spring. Figure 4 shows that five earlywood fires happened when precipitation was average or above average but that only three occurred below the average level. Thus, there was no obvious relationship between precipitation and the occurrence of spring fire. This observation is consistent with that of Haines and others (1975), who counterintuitively found more spring fires in nondrought than in drought years on the Wayne National Forest. Conversely, they found more autumn fires during drought years than in nondrought years. The data available here cannot illustrate such relationships.

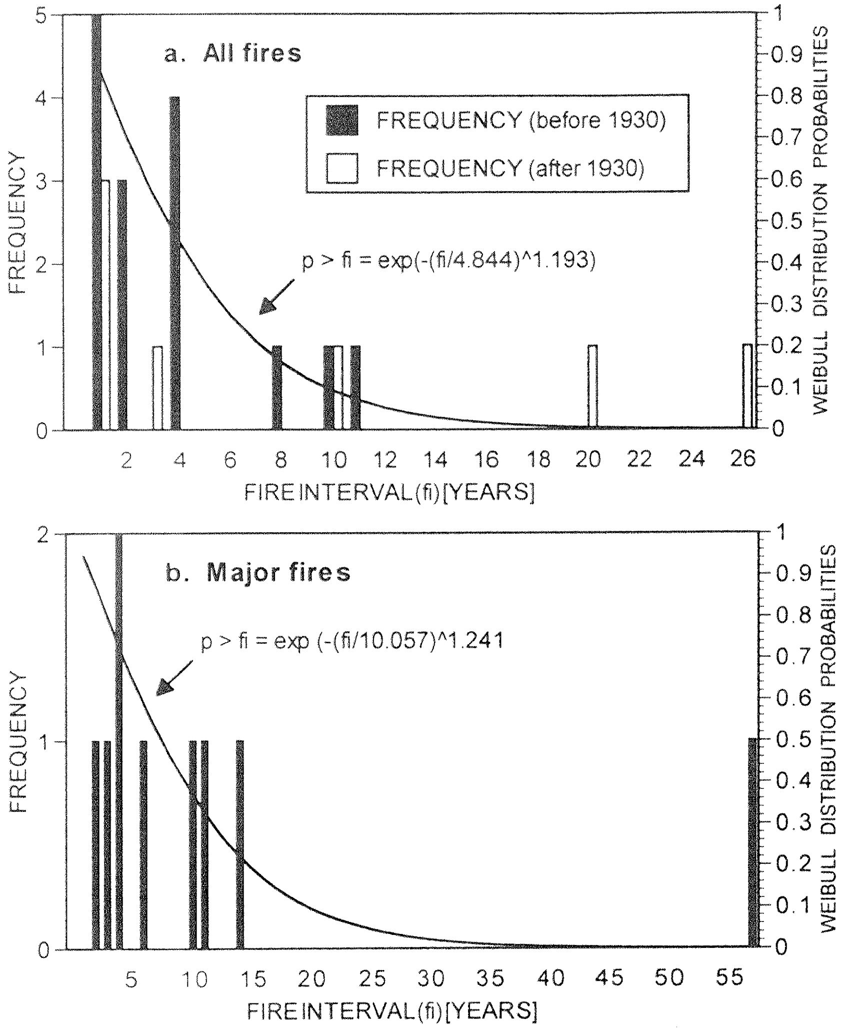

Figure 2. Distribution of fire frequencies, with accompanying Weibull probability distributions. Scale and shape parameters are shown in the equations, where p > fi = exp(-(fi/b)^c), b = scale parameter, c = shape parameter; (a) frequencies for all fires, before and after the fire suppression era (1930); (b) frequencies for major fires (25% of samples are scarred, or at least two samples). The only major fire after the fire suppression era is the longest interval (57 years).

Table 2. Fire intervals (years) at Oreton, Vinton County, Ohio 1856 to 1995. Data are Weibull, not normally distributed. The Weibull intervals indicate significantly ($p < 0.05$) short or long intervals between fires. Major fires are defined as when $\geq$ 25% of all samples scarred or at least two samples scarred in a given year.

	All fires	Major fires
Weibull median interval	3.6	7.5
Weibull short interval	0.4	0.9
Weibull long interval	12.2	24.3
Mean fire interval (MFI)	5.4	11.3

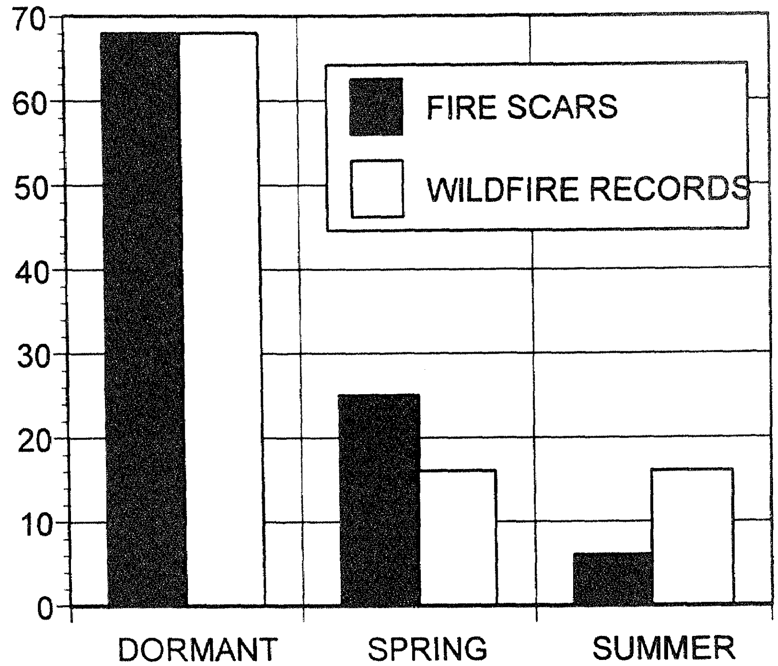

Figure 3. Distribution of fire frequencies by season, comparing fire scar records to local wildfire records.

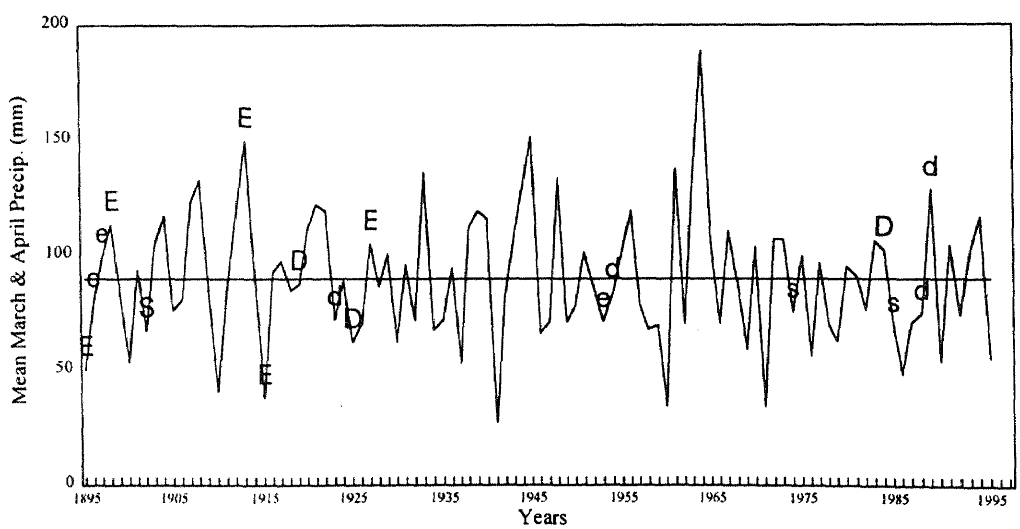

Figure 4. Climate and fire relationships Oreton, Vinton County, Ohio, 1895 to 1995. Mean March and April precipitation (mm) is plotted each year, and fire occurrences are labeled. Precipitation data are for the Southeast Ohio division (National Climatic Data Center, 1996). The horizontal line indicates mean regional March and April precipitation. The labels indicate season when the fire burned (D = dormant season, from August to mid-April but probably late March to mid-April; E = early spring, from mid- to late-April; and S =summer, early May to late July.) Uppercase letters indicate a major fire; lowercase letters indicate a minor fire.

DISCUSSION

This even-aged stand was about 140 years old, an age that is consistent with known land use patterns in the Hill Country, where the forests used for charcoal production, agriculture, and pasturage were abandoned and then naturally reforested in the mid to late 19th century.

Fire Regime

Type of fire. The eastern deciduous forest has predominantly low-intensity surface fires carried by hardwood leaf litter (Fuel Model 9, Anderson 1982). The overstory at Oreton is even-aged, which in other situations might be evidence of a severe, stand-initiating event such as catastrophic fire. However, given the area's land-use history, regrowth after intensive cutting is more likely than replacement after catastrophic fire.

Seasonality. Most fires occurred when the tree cambium was dormant, from about August 1 to April 14. Thus, the season of dormant fires is broadly defined, though wildfire records indicate that spring is the most important fire season, and most dormant scars probably occurred during early March to mid-April: a third of the fires might have happened during autumn. Haines and others (1975) found that the week of April 1 was the peak of the Wayne National Forest spring fire season. The timing of fires during earlywood formation probably can be narrowed to a short season in the spring, and fires during latewood formation probably occurred in late spring or early summer. Summer fires were rare because in these closed-canopy forests, leafy canopies reduce solar radiation at the forest floor while fuel moisture remains high (Haines and others 1975).

Frequency. Virtually all (99%) of fires in the Ohio River Valley are caused by people (arson or accidental ignition); few are caused by lightning (Haines and others 1975, Yaussy and Sutherland 1994). In vegetation types where people are the most important source of ignition, fire frequency reflects occupancy and culture (Whelan 1995). The more people there are, the more ignitions occur (Whelan 1995). In the last century, human populations in the Midwest have increased but fire suppression has been applied aggressively. For example, in the Ozark region of Missouri Guyette and Cutter (1991) developed a fire history using *Q. stellata* (post oak) trees. They reported reduced fire frequency after abandonment of the area by Native Americans, increased frequency after initial colonization by Euro-Americans, and decreased fire frequency during the 20th century era of fire suppression.

Between 1871 and 1989, fire occurred repeatedly at the Oreton site. Small or low-intensity fires that scarred few trees were likely (Weibull median probability interval) every 3 to 4 years, and widespread fires that scarred at least 25% of the sampled trees were likely every 7 to 8 years. In fact, there are only three decades (1930's, 1940's, and 1960's) without fire. There are several notably long intervals between fires in the Oreton record. In Figure 2a, both long intervals occur in the fire-suppression era (i.e., after 1930). Similarly, in the major fire distribution, the longest interval is after 1930. These intervals are outliers from the predicted Weibull probability distributions, where short-interval fires are most probable. Thus, long intervals between fires in this mixed-oak forest are unusual and probably an artifact of fire-suppression policy.

The mean fire intervals at the Oreton site for all fire events (5.4 years) and for major fires (11.3 years) are similar to those observed from other oak-dominated forests in the Midwest. (Note that other studies in similar forest types used the empirical descriptor of frequency, the MFI, and not the Weibull median probability interval; presumably, the MPI's would have been shorter. In a post oak forest in southern Missouri, Guyette and Cutter (1991) noted an MFI (1810 to 1989) of 6.4 years for all events and 11 years for severe events (defined as three or more trees scarred). Similarly, in an oak-hickory/glade transition area in the Ozarks of Missouri, Guyette and McGinnes (1982) noted MFI's of 3.2 years for all events, 8.75 years for two or more trees scarred, and 20 years for three or more trees scarred (1730 to 1870) from scars on *Juniperus virginiana* (eastern redcedar) trees. Alternatively, Cutter and Guyette (1994) noted in post oak stands in south-central Missouri, fire frequency decreased to 24 years during the postsettlement period (circa 1850 to present) from an MFI of 2.8 years before settlement (1740 to 1850). Henderson (1982) calculated fire frequencies of 5.2 years (1933-1981) and 11.1 years (1929-1981) in two neighboring black oak stands in northwestern Indiana. Abrams (1985) found MFI's ranging from 11.2 to 19.7 years in three oak gallery forests in tallgrass prairie in Kansas. Because Abrams used the presence of charcoal in the wound as a criterion for denoting a scar as fire-caused and because of his reported experimental evidence that not all fires caused scars, the actual fire interval probably is shorter than the estimated interval.

More fire events probably occurred at Oreton than were recorded by scars, and the estimated frequencies likely are conservative for several reasons. First, not all trees at the site were sampled, so some scarring events might have been missed. Second, not all fires cause scars (Abrams 1985). The higher the fire intensity, the higher the probability of scarring, so low-intensity fires are less likely to cause scarring (Guyette and Cutter 1991). Third, most of the trees sampled here had small fire-caused wounds that healed rapidly, so there were no consistent fire-susceptible faces. For example, on open scar faces on *Q. douglassii* H. & A. (blue oak) in California, Mc Claran (1988) found that fire scars were more frequent than in embedded scars in intact trees. Fourth, as the trees grew larger, the bark thickened. With thickening bark and without a fire-susceptible face, trees probably became less susceptible to scarring with time, and fires in later years might have been less likely to cause a scar than earlier fires. Conversely, it is possible that some scars were not caused by fire; as mentioned previously, other factors can cause scarring (Arno and Sneck 1977, Mitchell and others 1983). Scars caused by other sources would lead to overestimates of fire frequency.

<u>Spatial extent and intensity</u>. Some fires scarred many trees, such as the 1913 fire that scarred seven trees, but other fires like the 1923 fire scarred only one tree (Figure 1, Table 1). There are four potential reasons for these differences in number of trees scarred, including variation in (1) fire intensity, (2) fuel quantity and continuity, and (3) spatial extent of fires (due to fire suppression efforts) and 4) decreasing susceptibility to scarring over time (same-aged trees growing increasingly thicker bark). The lower the intensity of fires, the fewer trees are likely to be scarred. It also is likely that the reverse is true.

Fire behavior and hence intensity is a function of slope, fuel, and weather (Rothermel 1980). Within this site, fuel and weather varied in time. Results from this study did not show a relationship between seasonal climatic variables and major or minor fire events. If fire intensity is not driven by climate, fuel loading might explain spatial extent and fire intensity patterns; the longer the interval between fires, the greater the buildup of fuel (to the point where the rate of decay is equal to the rate of buildup). Before the era of fire suppression, fires likely burned freely until they were extinguished by precipitation or encountered a barrier. Additionally, long fire intervals probably ended in relatively intense fires that scarred more trees. But during the fire suppression era, fires were suppressed promptly, minimizing fire size and resulting in little or no scarring. Longer intervals also might reflect increasing resistance to fire-scarring in the increasingly older, thick-barked trees.

CONCLUSIONS

Many low-intensity fires, both large and small, occurred at this site in southern Ohio at frequencies similar to those for other Midwestern oak forests. The first fire was recorded in the 1870's, and despite fire-suppression efforts after 1930, fire has occurred in 10 of the 13 decades since the first fire. Most fires occurred during the dormant season, probably in the early spring (March-April). There is little indication that climate patterns are driving fire events at this site. Since nearly all ignitions are human-caused, frequency probably is a function of human population density and cultural factors (fire suppression), and the period of time required to develop a continuous layer of leaf litter, the fine fuel that carries fire in deciduous forests.

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