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Fire History of a Ridge and Valley Oak Forest

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Abstract

We document the fire history of an oak stand located near Pike Knob, Pendleton County, WV using 17 northern red oak (*Quercus rubra* L.) basal cross sections. The FHX2® program was used to characterize fire intervals and to evaluate the goodness of fit between fire intervals and the normal and Weibull distributions. The composite fire chronology was compared to mean fall and spring Palmer Drought Severity Index (PDSI) from 1895 to 2002. A 156-year fire history chronology was developed from 1846 to 2002 and fire intervals ranged from 7 to 32 years for a single forest stand. The most recent fire occurred in 1962 based on the fire scar presence. The Weibull median fire interval was 14.76 years for one or more trees scarred during a single year, and 17.11 years when at least two trees were scarred during a single year. Mean fall PDSI was less for fire years than nonfire years ($p = 0.046$), but there was no evidence that mean spring PDSI differed between fire years and nonfire years ($p = 0.596$). Oak recruitment ceased after 1937, during an unusually long fire-free interval, offering indirect support of the important role of fire in perpetuating oak forests of the region.

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Introduction

There is increasing acceptance of the historical role of fire in shaping the composition and structure of oak forests in the eastern United States (Abrams 1992, Delcourt and Delcourt 1997, Ford and others 2002, Pyne 1982, Van Lear and Waldrop 1989, Whitney 1994). However, the role of fire has changed in conjunction with the changing role of humans in North America. Since plant associations stabilized approximately 4000 years ago (Delcourt and Delcourt 1987), there have been three profoundly different fire regimes in most Appalachian mixed-oak forests (Brose and others 2001). Fire regimes prior to European settlement have been characterized as periodic low-intensity fires set by Native Americans and occasional lightning strikes (Delcourt and Delcourt 1997, Van Lear and Waldrop 1989, Whitney 1994). During the early post-settlement period, fire use may not have changed significantly in many locations as early settlers adopted Native American practices of using fire to manage vegetation for subsistence needs. The subsequent industrial revolution and concomitant capital-intensive timber harvesting with steam-driven locomotives often created conditions and provided the ignition source that led to high-intensity fires. Such fires often led to dramatic losses of timber resources and soil productivity (Clarkson 1964). As a reaction to these often destructive, high-intensity fires, fire control became the dominant philosophy in the early 20th century and fire use became illegal in most states. Fire was viewed solely as a destructive force that threatened a growing nation's timber supply (Pyne 2001). Benefits in wood production and timber quality were realized, but the replacement of oaks in the eastern United States by other species is correlated with this period (Clark 1993). Such replacement may occur more commonly on mesic sites (Abrams 1992), but oak regeneration failures and concomitant replacement by other species also can occur on dry-mesic and xeric sites as well (Lorimer 1984, Pallardy and others 1988, Russell and Fowler 2002). Other factors also are commonly cited with oak decline. Perhaps most ubiquitous is the population increase of white-tailed deer (*Odocoileus virginianus* Zimm.) in the 20th century leading to significant impacts on vegetation dynamics (Russell and Fowler 2002, Horsley and others 2003). Today, while land management practices are heavily influenced by the fire control era and game management practices are debated by constituent groups, there are emerging efforts to use fire to manage forests for both commodity and ecological objectives (Brose and others 2001, Ford and others 2002).

A better understanding of how fire influences ecological processes can be partially achieved by reconstructing past fire regimes (intensity, frequency, spatial extent, and type of fire). In the eastern United States, past fire regimes for particular forest types are largely unknown. In part, to better understand historical fire regimes, researchers study fire scars in the annual rings of trees that were alive during periods of interest. In the eastern United States, opportunities are limited for such investigations because most forests were harvested one or more times in the last century, post-dating the era of most interest. Use of the few remaining tracts of old growth forest usually is not feasible because fire scar analysis requires numerous basal stem cross sections which would destroy old-growth trees. However, some studies have examined fire scars using trees of sufficient age to capture periods of interest. In a mixed-oak forest in southeastern Ohio, a study of 150-year-old trees revealed minor fires occurred about every 3.6 years and major fires occurred every 7.5 years, though fires were less frequent after the 1930s (Sutherland 1997). Fire intervals ranged from 5.2 to 11.1 years in two black oak forests in northwestern Indiana during the 1900s (Henderson and Long 1984). In a western Maryland mixed-oak forest during a period from 1616 to 1959, a fire return interval of 7.6 years was common and an exceptionally long interval without fire was 12.4 years (Shumway and others 2001). In the Missouri Ozarks, the fire return interval was 6.4 years in an oak savanna with tree ages dating back to the 1700s (Guyette and Cutter 1991). Fire frequency decreased following settlement on an oak-hickory ridgetop in Missouri, from about every 2 years prior to settlement to about every 24 years after (Cutter and Guyette 1994). These widely dispersed studies are based on forest types with significant climatic differences and land-use histories. Yet, the results illustrate that fires in oak forests were not uncommon throughout much of the eastern and central United States before the fire control era.

To better understand fire regimes in the Ridge and Valley Province, in this study we reconstruct the fire history of an oak stand located on North Fork Mountain in eastern West Virginia on property owned and managed by The Nature Conservancy. There are numerous references of fire use in the Ridge and Valley by both Native Americans and settlers (Brooks 1911, Van Lear and Waldrop 1989, Whitney 1994), but fire return intervals using tree-ring analysis for oak-dominated forests have not been studied previously. We also evaluate the relationship between fire occurrence and climate using historical weather observations.

Methods

Study Area

The study site (elev. 1224 m) is located on a southwest aspect near Pike Knob (elev. 1302 m), on the high elevation crest of North Fork Mountain, approximately 5 km east of Circleville, WV. This portion of the Ridge and Valley Province is known as one of the driest locations in West Virginia, as it is affected by the rainshadow of the higher ridges of the Allegheny Plateau to the West (Strausbaugh and Core 1978). Total annual precipitation in the area is approximately 86 cm and the mean annual temperature is about 10.9 ° C (National Oceanic and Atmospheric Administration 2003).

Soils are primarily of Tuscarora sandstone parent material, and are stony, acidic, and of low natural fertility. The moderate-rapid permeability and rapid runoff of this soil, in combination with low annual precipitation, maintains very dry growing conditions (Harmon 1981). The resultant plant communities have been further maintained through weathering, ice storms, high winds, and a historic occurrence of fire (Batcher and others 1997). Representative vegetation of this portion of the North Fork Mountain crest includes a mixture of oak-pine forest, northern hardwood forest, grass balds, and the southern-most stands of red pine (*Pinus resinosa* Ait.). The area sampled is situated within the transition of the oak-pine and grass bald communities, in an area of predominantly northern red oak (*Quercus rubra* L.), dwarfed by the elements and site conditions.

Field Data

Fire scar analysis requires complete tree cross-sections near the ground line. Core samples, often used for dendrochronology, are inadequate because past fire scars are often small (e.g., 2 cm) and occur at different locations around the perimeter of the stem. Because stem cross-sections cannot be collected without destructive sampling, there are limited opportunities for revealing past fire scars. In this study, sample collection was made feasible after 31 trees (> 5.0 cm diameter at stump height: d.s.h) within about a 0.06 ha area were illegally cut by unknown individuals during the spring of 2002. Basal area was 20.79 m^2 ha^{-1} for all trees and 13.28 m^2 ha^{-1} for stems > 28 cm d.s.h. prior to cutting. Upon discovery of this unplanned opening, cross-sections from the cut stumps were sawn about 10 to 15 cm above the ground during the fall of 2002. We obtained mostly solid cross-sections from 17 northern red oaks and 3 ironwoods (*Ostryea virginiana* (Mill.) K. Koch) from the disturbed area. All disks were prepared for analysis by sanding the surface with up to 600-grit sandpaper followed by polishing the wood with a felt pad on a high-speed rotary tool. Marker years or years with unusually narrow growth rings were used to help cross-date individual tree chronologies. Ironwood samples were difficult to cross-date due to partial rings and could not be used.

Fires scars were defined as wounds resulting from the death of a section of vascular cambium and subsequent development of callus tissue (Sutherland 1997, Shumway and others 2001), while others have used the presence of charcoal to designate a past fire (Abrams 1985). However, surface fires in the eastern United States often do not reach intensity to burn through the bark (Smith and Sutherland 1997). Even wounding caused by lethal temperatures of the vascular cambium (60^o C) (Kayll 1968) may underestimate fire frequency because wounds, when they do occur, may not be at the same height on the stem as the cross-section sample. Some wounds also may be caused by fungi, insects, small mammals, or abrasions (Arno and Sneck 1977, Mitchell and others 1983). However, it was not considered a fire scar if there was evidence of insect galleries or physical abrasion associated with the wound. Moreover, the single year trait of most fire wounds are not consistent with the wound characteristics caused by perthotropic fungi (Sutherland 1997).

Data Analysis

Past fires were evaluated graphically and statistically using the distribution of fire scar dates. Such distributions may not be described adequately by symmetrical measures of central tendency because there is no theoretical upper bound to periods free of disturbance but the lower bound can never be negative. Distributions of this nature are often positively skewed (Baker 1992) and more appropriately described by measures of central tendency, such as the two-parameter Weibull distribution (Grissino-Mayer 2001). Central tendencies of the Weibull are expressed as exceedance probabilities (*i.e.* the 0.5 exceedance probability is the 50^{th} percentile of the distribution). The FHX2® program was used to characterize fire interval data and to evaluate the goodness of fit between fire intervals and normal and Weibull distributions utilizing the one-sample Kolmogorov-Smirnov (K-S) test (Grissino-Mayer 2001). Two criteria (conservative and liberal) were used to estimate fire intervals. The conservative criterion is any year when two or more trees exhibited fire scars; the liberal criterion is any year when just one tree had a fire scar. We could not determine the season of the fire (i.e., spring, summer, or fall) due to extremely slow radial growth rates of most of the sample trees. Fire years were assigned to the last full growth ring before the wound

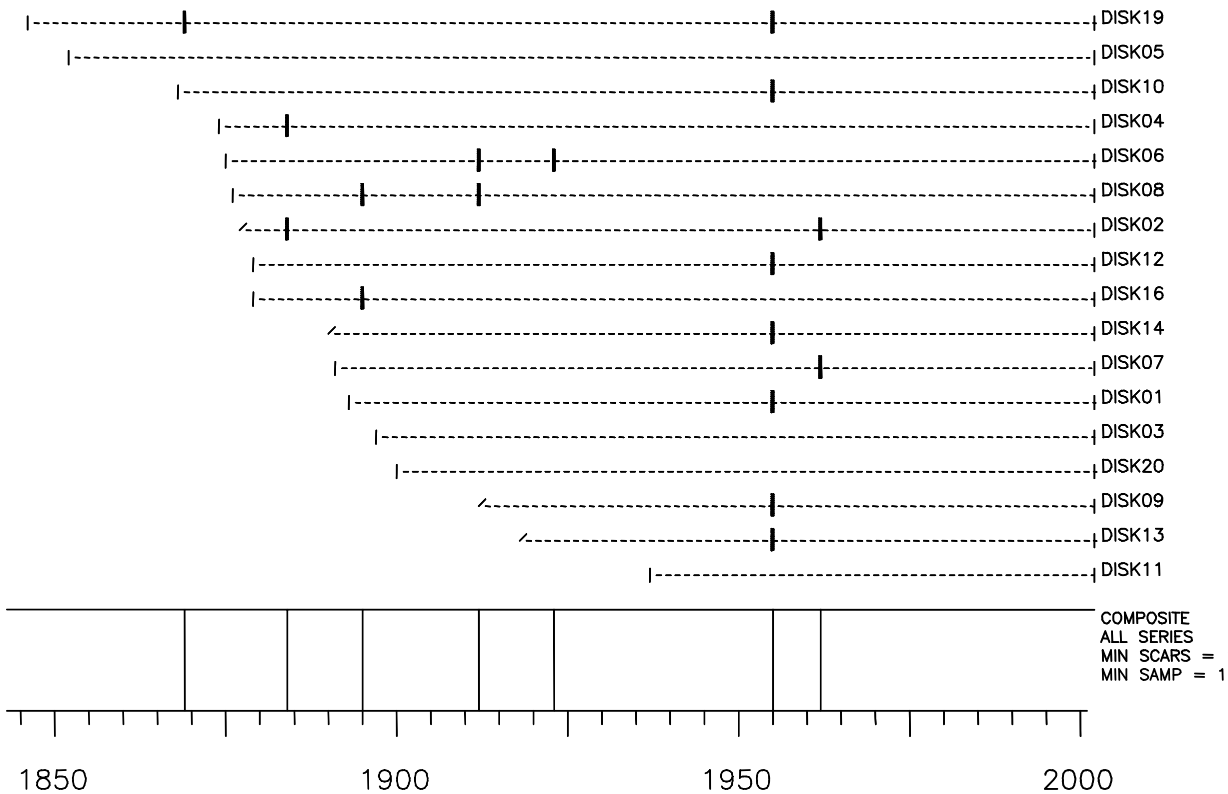

Figure 1.—Fire scar chronology from 17 northern red oak cross sections cut from the Pike Knob study area, Pendleton County, WV. Each horizontal line represents the annual rings of one cross section and bold vertical bars represent fire scars. Disks 02, 14, 09, and 13 did not have piths; annual rings closest to the pith are represented by a slash. The 1972 scar on disk 19 was determined to be from a physical abrasion and was not used in fire interval analysis.

occurred. As such, a fire date of 1955 may have occurred in either the fall of 1955 or the spring of 1956. The majority of fires in Pendelton County for the past 60 years have been in the spring.[1]

To assess the relationship between drought and fire occurrence, the composite fire chronology was compared to mean fall (September, October, and November) and spring (March, April, and May) Palmer Drought Severity Index (PDSI) values from 1895 to 2002. PDSI values were obtained from the National Climatic Data Center (National Oceanic and Atmospheric Administration 2003) for the Central Mountains Division (division code: 05) of Virginia (state code: 44). We chose this location because it is the closest designated climatic division to the study area wholly within the Ridge and Valley physiographic province. PDSI incorporates both temperature and precipitation and is an indicator of conditions that develop over a period of months. A PDSI of zero is a neutral value, -2 is moderate drought, -4 is extreme drought, and positive values indicate wetter than normal conditions. PDSI was –5.1 in March 1931, and was the most extreme drought for the observation period.

Since we could not determine the season of fire, we examined the PDSI values for both the spring and fall months associated with fires. PDSI values change slowly over a period of months and accordingly are correlative from month to month. Therefore, to simplify our analysis, we calculated mean spring and fall PDSI values for each year. We then compared spring and fall fire event PDSI values and non-fire event PDSI values for the period of record from 1895 to 2002 using a two-sample t-test with unequal variances. We intended to determine if fire years occurred during abnormal conditions (either drier or wetter). We recognize that our inability to determine the season of the fire limits inferences of this approach.

Results

A 156-year fire history chronology was developed from 1846 to 2002 using 17 fire scars (Fig. 1). Pith dates of the sample trees ranged from 1846 to 1937. Pith date

[1]M. Dillon, Assistant State Forester, West Virginia Division of Forestry, Charleston, WV. Personal communication.

could not be established on four stems due to heart rot. Years in which fires were detected by the presence of at least one fire scar were 1869, 1884, 1895, 1912, 1923, 1955, and 1962. An injury in 1977 was observed but was judged to result from an unknown physical abrasion and was not used in the fire interval calculations. Fire intervals ranged from 7 to 32 years (Table 1). The 40-year period between 1962 and 2002 was the longest period without fire and was not used in the calculations because fire intervals must be bracketed by fires at both the beginning and ending points.

Using one or more trees scarred as an indicator of a past fire, the K-S test indicated the intervals between fires could be adequately described using either a normal ($p = 0.6441$) or Weibull distribution ($p = 0.9133$). However, it should be noted that this test lacks robustness when the number of intervals being evaluated is small, therefore both empirical and Weibull summary statistics are reported (Table 2). Disturbance intervals less than about 7 years were unusual, as were intervals greater than about 25 years as indicated by Weibull exceedance probabilities of 0.875 and 0.125, respectively. The fire interval from 1923 to 1955 represents a significantly long interval based on the Weibull distribution. The current fire-free period extending from 1962 to the present is not characteristic of the period modeled between 1869 and 1962.

Using two or more trees scarred as an indicator of a past fire, the total number of intervals was reduced to four, eliminating 1869 and 1923 as years when fire occurred. Again, the K-S test indicated the intervals between fires could be adequately described using either a normal ($p = 0.6957$) or Weibull distribution ($p = 0.9596$) and both are reported (Table 2). Disturbance intervals less than about 6 years and greater than 35 were unusual based on Weibull exceedance probabilities of 0.875 and 0.125, respectively. The mean fire interval increased by 4 years and the Weibull median fire interval increased by about 2 years using this more conservative criteria. The fire interval between 1912 and 1955 was the longest fire-free interval. The 1955 fire also resulted in the greatest percentage of trees scarred (about 41.2 percent).

Table 1.—Fire summary information. Sample depth represents number of trees present in the sample for the fire year. Fire interval must be bounded by two fires and there was no evidence of fires between 1963 and 2002.

Year	Sample depth	Total scars	Fire interval
1869	3	1	
1884	9	2	15
1895	12	2	11
1912	15	2	17
1923	15	1	11
1955	17	7	32
1962	17	2	7

Table 2.—Fire interval analysis using the liberal (at least one tree wounded by fire) and conservative (more than one tree wounded by fire) definitions. The scale (b) and shape parameters (c) are used in the two-parameter Weibull distribution to predict probabilities (p) of fire intervals (fi) as follows: $p > fi = \exp(-(fi/b)^c)$. All units are in years except for number of intervals.

	Liberal criteria	Conservative criteria
Total intervals	6.0	4.0
Mean fire interval	15.5	19.5
Standard deviation	8.8	16.2
Median fire interval	13.0	14.0
Weibull modal interval	12.8	10.6
Weibull median interval	14.8	17.1
Weibull scale parameter	17.6	21.8
Weibull shape parameter	2.1	1.5
Minimum fire interval	7.0	7.0
Maximum fire interval	32.0	43.0

In our assessment of drought and fire occurrence, fall fire-year PDSI was less than mean fall PDSI for years without fire ($p = 0.046$). Mean fall fire year PDSI was –1.026 (SD = 0.639) and mean fall non-fire-year PDSI was –0.221 (SD = 1.864). However, there was no evidence that spring fire-year PDSI was different than spring PDSI for years without fire ($p = 0.596$). Mean spring fire-year PDSI was –0.316 (SD = 1.126) and mean spring non-fire-year PDSI was –0.017 (SD = 1.592). During periods of extreme drought (≈PDSI < -4.0), we found no evidence of fire in either the spring (Fig. 2) or the fall burning season (Fig. 3).

Discussion

The composite fire chronology we developed is partially corroborated by historical records and other research. For example, in 1891 and 1892, a widespread bark beetle outbreak in Pendleton County resulted in the death of about 75 percent of the mature pine timber. The subsequent increase in dead fuels was followed by

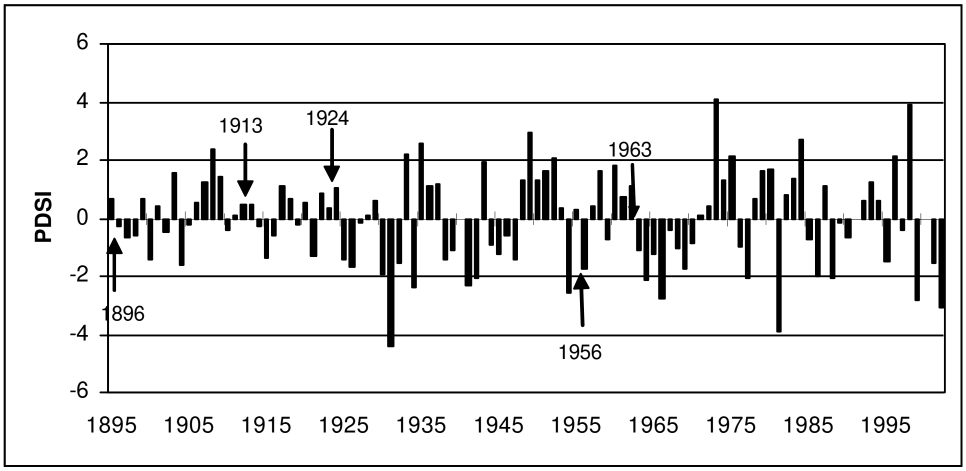

Figure 2.—Mean March, April and May Palmer Drought Severity Index (PDSI) for the Pike Knob study area, Pendleton County, WV. Highlighted years indicate when fires could have occurred if they were spring fires.

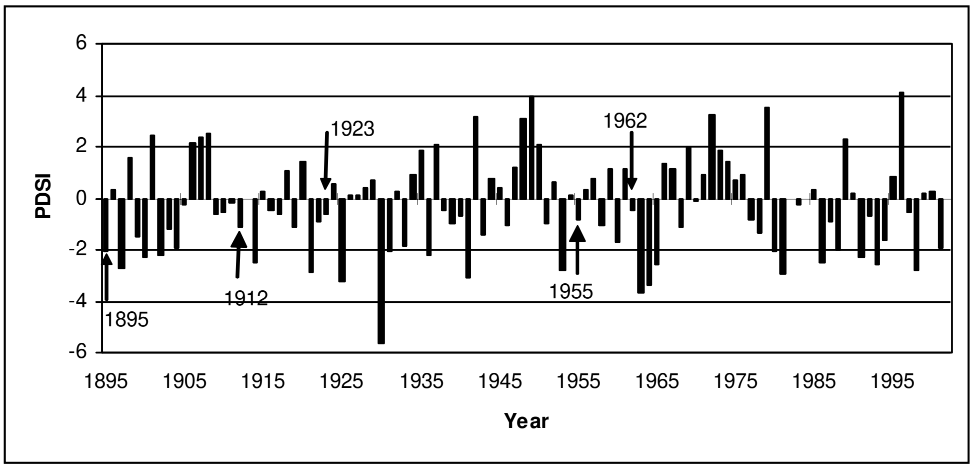

Figure 3.—Mean September, October, and November Palmer Drought Severity Index (PDSI) for the Pike Knob study area, Pendleton County, WV. Highlighted years indicate when fires could have occurred if they were fall fires.

intense and widespread fires in 1895 (Brooks 1911), corroborating one of the fire-years in our chronology. Stephenson and others (1986) studied a red pine stand near our study area and determined the even-aged stand reached breast height in 1914, two years after a fire in our chronology. Natural red pine stands are often dependent on wildfire for regeneration (Rudolf 1990, McRae and others 1994). After the 1920s, we found no evidence of fire until 1955, which statistically was an unusually long interval without fire. This period coincides with the establishment of fire wardens in West Virginia (Carvell and Maxey 1998) and a nationwide effort to stop all fires on both public and private land (Pyne 2001). The 1955 fire resulted in a high percentage of injured trees suggesting greater than usual fire intensity. An increase in fire intensity may have been the result of an increase in available fuels after an unusually long fire-free period or unusually dry conditions. The 1955 fire year included the spring of 1956, which was the driest of any of the spring fire years in our chronology. Other evidence also indicates the 1950s were a time of intense fires on North Fork Mountain. During this time, a large fire destroyed a fire lookout tower on nearby Bennet Knob.[2]

The period in our fire chronology was a time when settlement activities were well under way in Pendleton County. Fire regimes before settlement may have been different as has been shown elsewhere (Cutter and Guyette 1994). But since settlers adopted many of the native American burning practices, fire frequency may have remained relatively constant until the 1900s as illustrated by the 400-year fire history of a mixed-oak forest in western Maryland (Shumway and others 2001). When settlement activities reached Pendleton County in 1747 (Brooks 1911), valleys in the eastern portion of the county were cleared for cultivation or pasturage as

[2]R. Bartgis, State Director, The Nature Conservancy, Elkins, WV. Personal communication.

needed, often with fire. Timber harvesting along the mountainsides was generally limited to subsistence needs and wide-scale timber harvesting had not occurred by the early 20th century (Brooks 1911). However, these forests were not free of anthropogenic disturbances. In addition to the use of fire, grazing of forest understories by domestic livestock was prevalent (Whitney 1994). This often poorly recognized land-use pattern of many eastern forests, even in the absence of widespread timber harvesting, makes the interpretation of historic fire intervals somewhat problematic. Were frequent fires simply artifacts of land-use practices that had minimal influence on ecological processes or were they disturbances that perpetuated oak-dominated and mixed-oak forests?

In either case, fire history studies of oak forests from the eastern and central United States are notable in their findings of recurrent fire. Oaks either tolerated or were dependent on fire intervals ranging from one to two decades. In our study, fire return intervals were between 7 and 15 years prior to the fire control era and did not deviate significantly from previous research in Ohio, Maryland, and Missouri (Cutter and Guyette 1994, Guyette and Cutter 1991, Shumway and others 2001, Sutherland 1977). But there are differences worth noting. For example, Shumway and others (2001) reported a shorter fire return interval in the mesic western Maryland Allegheny Mountains than we found for the relatively xeric Ridge and Valley. This counter-intuitive difference may be related to methodology. The western Maryland study encompassed a larger area on aspects ranging from southeast to southwest and their results reflect fires that occurred in any part of the study area, whereas our results are from a smaller, single site with uniform conditions. Being smaller and more uniform, we believe any fire that burned through the area we sampled would encompass the entire area. This may not always be the case with studies using larger areas with different aspects. Thus, when considering fire history analysis, larger study areas with variable topographic features may represent forest-level fire return intervals, whereas smaller units represent stand-level fire return intervals. A larger sample area also may account for the shorter fire return interval reported by Sutherland (1997).

Mimicking past fire regimes may help sustain oak-dominated forests on North Fork Mountain and elsewhere, but the effects of fire occurrence today, after an historically unprecedented period without fire, may be dissimilar to the effects when fire was more frequent. One reason may be related to fire intensity. In the current fire control era, fire use is illegal in most circumstances, prescribed fires are rare, and most woodland fires in West Virginia are the result of arson or accidental ignitions when droughty conditions prevail.[3] In contrast, prior to the fire control era, some evidence suggests fires often were used when conditions would moderate fire activity. For example, in New York fires were used to manage blueberry (*Vacinnium* spp.) production only when organic soils were moist enough to avoid degrading soil properties (Batcher and others 1997). In southern Ohio, most spring fires occurred during nondrought years prior to the 1930s (Sutherland 1997, Haines and others 1975), suggesting that fire use coincided with conditions that resulted in less intense fire behavior. In our study, there was some evidence that fall fire years were drier than nonfire years but spring fire years were similar to spring conditions without fires. Moreover, there was no evidence of fires in either the fall or spring during extreme droughts. The collective results of fire history research in the eastern United States imply managers wishing to emulate the effects of past fire regimes should plan on repeating fires every decade or two during nondrought years to limit fire intensity and to continue suppressing accidental or arson ignitions during drought years.

The theoretical basis for fire as a critical ecological process in maintaining oak in mixed-oak forests is compelling (Abrams 1992). However, in current practice, fire has not always favored oak species (Wendel and Smith 1986, Collins and Carson, in press). Moreover, in our study, there was no evidence of oak recruitment that persisted following the fires of 1955 and 1962. One plausible explanation for the lack of oak recruitment following these most recent fires includes changes in herbivory patterns near the study area, which is adjacent to a ridgetop grass bald still used for domestic livestock grazing. It is not known how long grazing has occurred at the bald or when grazing was initiated. However, grazing and trampling of seedlings and acorns may have contributed to the lack of oak recruitment in the mid-20th century. High deer densities common in the late 20th century clearly have been shown to damage and reduce the density of tree seedlings in the understory (deCalesta 1997, Horsley and others 2003). However, deer densities during the mid-20th century in West Virginia were putatively much lower than current levels and may not be related to the lack of oak recruitment nearly a half-century ago.

The most promising use of fire to perpetuate oak in today's forests combines a 50 percent canopy reduction followed several years later by a prescribed fire to favor

[3]M. Dillon, Assistant State Forester, West Virginia Division of Forestry, Charleston, WV. Personal communication.

oak from competing woody vegetation (Brose and Van Lear 1998). Such a technique will eventually lead to an even-aged oak cohort that is released following final overstory removal. Northern red oak is generally regarded as unsuitable for uneven-aged management in mesic forests, however such forests were not always even-aged as demonstrated by gap-phase replacement of oaks until the early 20th century in old-growth forests in Ohio (Rentch 2001), Maryland (McCarthy and Bailey 1996), and West Virginia (Abrams and others 1995). Uneven-aged oak stands have been maintained using partial cutting practices in the relatively xeric Ozarks of Missouri (Lowenstein and others 2000), but uneven-aged management usually leads to replacement of oaks by other species in more mesic forests (Schuler and Gillespie 2000). In our study, we also document uneven-aged conditions in the past with oak recruitment occurring from 1846 to 1937. We speculate that the xeric conditions of North Fork Mountain combined with about a 15 year stand-level fire return interval may have kept stocking low enough to permit periodic recruitment of oak following significant mast years. In the absence of such a fire regime and in the presence of significant deer and/or livestock herbivory, overstory stocking is likely to increase and understory oak seedlings are not likely to persist. Accordingly, we agree with Batcher and others (1997) that the high-elevation red oak forests on North Fork Mountain are likely to transition to stands dominated by more shade-tolerant northern hardwood species. Such forest type conversion may forecast future forest health problems at a time when global warming trends are expected to shift species distributions to the north (Iverson and Prasad 1998). The xeric nature of the site likely will prevent some species from being established, but as our study illustrates, the absence of oak recruitment for most of the 20th century suggests other species will replace northern red oak as canopy gaps are created by individual tree mortality and storm damage.

This study encompasses a period that preceded the fire control era when use of fire for subsistence objectives was still acceptable. It documents that oak recruitment occurred at the study site in the Ridge and Valley during this period of relatively frequent fires. It does not establish a functional link between oak recruitment and periodic fires, but it does illustrate that fire did not inhibit oak recruitment nor did fire represent a catastrophic, stand-replacing event. We conclude that xeric oak forests, like the one that we studied on North Fork Mountain, are resilient to fire. Experimental use of fire on such sites, combined with the control of herbivores, likely will yield a greater understanding of how fire influenced species composition and stand structure and whether fire is a practical means of perpetuating them. Long-term studies may be needed before experimental use of fire can duplicate the effects of past fire regimes. However, to achieve many resource and societal objectives, it is essential to engage in such studies to better understand how fire may alter and possibly perpetuate oak forests that persisted for millennia but are in decline today.

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The fire history of an oak stand located near Pike Knob, Pendleton County, WV is described. A 156-year fire history chronology was developed from 1846 to 2002 and fire intervals ranged from 7 to 32 years for a single forest stand. The Weibull median fire interval was 14.76 years for one or more trees scarred during a single year, and 17.11 years when at least two trees were scarred during a single year. Oak recruitment ceased after 1937, during an unusually long fire-free interval, offering indirect support of the important role of fire in perpetuating oak forests of the region.

Keywords: northern red oak, fire history, fire interval, Palmer Drought Severity Index

Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania