FIRE HISTORY OF A TEMPERATE FOREST WITH AN ENDEMIC FIRE-DEPENDENT HERB

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Abstract: A dendroecological fire history study was conducted for The Nature Conservancy's Narrows Preserve on Peters Mountain, Virginia, where the predominant vegetation is oak (*Quercus* L.)-dominated forest containing some other hardwoods and pines (*Pinus* L.). The site encompasses all the known habitat of the endangered and endemic Peters Mountain mallow (*Iliamna corei* Sherff.), a perennial herb that requires fire for seed germination and habitat maintenance. Fire scars from 73 pines indicate frequent burning in the past (Weibull median composite fire interval = 2.2 years), primarily during the dormant season. Fire frequency exhibited little temporal variability from the beginning of the fire chronology in 1794 until the 1940s, despite changing land uses. However, the incidence of fire declined subsequently with the advent of effective fire protection measures. Ageing trees near the mallow population indicates that the fire-tolerant chestnut oak (*Quercus montana* Willd.) recruited relatively continuously under frequent fire, but that other species were established primarily during the fire protection era. The decline in burning appears to have permitted an increase in tree density that likely inhibits the growth and recruitment of mallow plants. Our results suggest that reintroducing frequent fire would be an appropriate technique for managing the mallows and the greater Peters Mountain landscape. [Key words: Appalachian Mountains, dendrochronology, disturbance, fire regime, fire scar, tree ring, vegetation dynamics.]

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INTRODUCTION

Fire is a key process controlling vegetation development in many ecosystems, for example, the coniferous forests of northern and western North America (e.g., Johnson, 1992; Peet, 2000). The role of fire in temperate deciduous forests is less clear. Increasingly, fire is viewed as an important process in temperate forests (e.g., Abrams, 1992; Lorimer et al., 1994; Brose et al., 2001; Dyer, 2001), but they are not as flammable as some other ecosystems (Bond and van Wilgen, 1996) and the historic role of fire has been a topic of debate (e.g., Russell, 1983; Clark and Royall, 1996; Abrams and Seischab, 1997). In this paper, we report a dendroecological study to examine fire history on a temperate forest landscape inhabited by an endemic, fire-dependent herbaceous plant species, the Peters Mountain mallow (*Iliamna corei* Sherff.). The presence of this plant strongly suggests that fire has played a long and crucial role on the landscape, while its endemic status necessitates research to develop a scientific basis for prescribed burning or other management techniques.

BACKGROUND: PETERS MOUNTAIN MALLOW AND FIRE IN THE APPALACHIAN MOUNTAINS

The Peters Mountain mallow is an endangered, federally protected perennial herb endemic to shallow soils on sandstone outcrops of Peters Mountain in the Appalachian Mountains of Virginia (Baskin and Baskin, 1997). Autecological research (Baskin and Baskin, 1997) uncovered a large bank of dormant, water-impermeable seeds whose germination in the natural environment is triggered only by fire. Moreover, the mallow plants resprout after burning. Fire is essential not only for mallow regeneration but also for maintaining open-canopy conditions that permit the growth, flowering, and fruiting of the shade-intolerant mallow plants (Buttrick, 1992).

The mallow was discovered in 1927 growing among widely spaced trees (Strausbaugh and Core, 1932). Its population declined from about 50 plants in 1927 to three individuals by 1989 (Baskin and Baskin, 1997). The decline is thought to have been largely a consequence of reduced burning and increased forest canopy closure during the fire protection era (Caljouw et al., 1994). In 1992, The Nature Conservancy (TNC) purchased the land inhabited by the mallow, creating the 130 ha Narrows Preserve (Caljouw et al., 1994). Subsequently, experimental burns by TNC have resulted in a larger but highly fluctuating mallow population (Edwards and Allen, 2003).

The combination of life-history traits exhibited by the Peters Mountain mallow appears to suit it to habitats with a short fire interval (cf. Rowe, 1983; Grime, 2001). The plant is virtually identical autecologically to the closely related *Iliamna rivularis* (Dougl. ex Hook.) Greene, a widespread species abundant after fire in coniferous forests of western North America (Baskin et al., 1997), where fire has been demonstrated to play an important ecological role (Peet, 2000). Peters Mountain mallow may derive from an *Iliamna* population that became established with the eastward expansion of western vegetation during the warm, dry Hypsithermal Interval

(Baskin et al., 1997). Peters Mountain mallow is one of two Eastern *Iliamna* species that are closely related to the widespread *I. rivularis* (Slotta and Porter, 2006). The other Eastern species, *I. remota* Greene, has a few small disjunct populations in northern Illinois, northern Indiana, and western Virginia. The Virginia populations of *I. remota* are approximately 80 km east of the Peters Mountain mallow. Recent genetic work (Slotta and Porter, 2006) suggests that the *Iliamna* in Virginia resulted from two separate introductions—an earlier introduction that led to the establishment of Peters Mountain mallow and a later event that brought about the *I. remota* populations.

The fire regime under which *Iliamna* has been maintained is of interest because of its implications for the fire ecology of Eastern temperate forests in general and for the management of *Iliamna* specifically. However, the role of fire in the Appalachian Mountains and other temperate forest landscapes throughout eastern North America is obscured by recent human land uses. First, the capital-intensive logging episode, which affected the Appalachian region between the 1880s and 1920s (Brose et al., 2001), disrupted forest structure and function and also generated abundant slash that, after drying, fueled intense and destructive fires. Second, the fire protection efforts that emerged in response to the devastation have diminished the role of fire.

Conceptual models of Appalachian fire history suggest that fire had been important for vegetation development before the industrial logging period. Brose et al. (2001) proposed that low-intensity surface fires burned Appalachian oak forests periodically, perhaps about once per decade, from before European settlement until the shift to high-intensity, stand-replacing fires associated with the logging boom. Williams (1998) suggested that fires, mostly of low intensity, occurred infrequently in Appalachian pine stands before European settlement but gradually increased in frequency after settlement; the logging episode brought a shift to intense fires. These intense fires occurred so frequently as to preclude the development of new forests on the cutover lands until fire frequency was reduced at the beginning of the fire-protection era (Brose et al., 2001). The fire-oak hypothesis (e.g., Abrams, 1992, 2003; Lorimer et al., 1994) contends that oak forests throughout eastern North America developed over centuries of periodic surface burning that impeded the establishment of fire-intolerant mesophytic competitors. Mature oak (*Quercus* L.) trees, particularly those in the white oak subgenus (*Leucobalanus*), are relatively fire-resistant because of their thick bark and ability to compartmentalize rot, while oak seedlings thrive in the aftermath of fire because of their strong sprouting ability and the open understory conditions that result from burning (Abrams, 1992, 2003; Lorimer et al., 1994; Brose et al., 2001). In the absence of fire, stand density increases and oaks are replaced by more shade-tolerant hardwoods, a phenomenon observed widely today after decades of fire exclusion.

Paleoecological data from fire-scarred trees (e.g., Taylor, 2000; Grissino-Mayer et al., 2004) and sediment charcoal (e.g., Kennedy et al., 2006) offer a means to clarify the role of fire prior to the unprecedented land uses of the past century and to place recent alterations of the fire regime into a longer historical context. Fire history data also provide quantitative guidance for restoration efforts (McEwan et al., 2007). Numerous dendroecological fire chronologies have been developed for coniferous

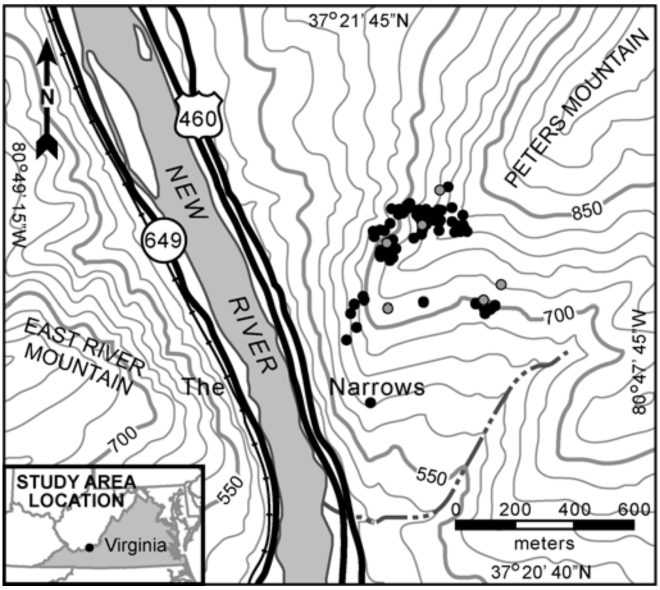

Fig. 1. Study area. The black points on Peters Mountain indicate the locations of the 73 fire-scarred trees included in the study. The gray points show the locations of the 6 fire-scarred trees that were sampled but not dated.

forests in western North America (e.g., Wolf and Mast, 1998; Taylor, 2000; Grissino-Mayer et al., 2004). Relatively few such fire chronologies have been published for temperate forests in eastern North America (Harmon, 1982; Mann et al., 1994; Sutherland et al., 1995; Shumway et al., 2001; Guyette et al., 2003; Schuler and McClain, 2003; McEwan et al., 2007), except for the Ozark Plateau near the western margin of the temperate forest (e.g., Guyette et al., 2002). The objectives of the fire history study reported here are, generally, to expand knowledge about fire regimes of temperate forests and, particularly, to provide details relevant to the ecology and management of the Peters Mountain mallow and Narrows Preserve. Consequently we address (1) the frequency of fires as recorded by fire scars; (2) whether there is evidence of frequent burning prior to the logging episode; (3) historic fire seasonality; and (4) whether tree establishment dates in the vicinity of the mallows reflect changes in fire frequency.

METHODS

Study Area

Peters Mountain is in the Ridge and Valley physiographic province at approximately 37°21 N, 80°48 W (Fig. 1). The New River flows along the base of the mountain and through the Narrows water gap. The west- and northwest-facing sides of Peters Mountain within the Narrows are rugged, sloping at approximately

35° and containing ledges of thick-bedded sandstone along the ridge crest. The south side of the mountain is gentler and slopes at about 20°. The study site for our research includes both sides of the mountain at 610–820 m elevation.

The climate is humid and continental (Bailey, 1978) but relatively dry because of its location within a rain shadow in the interior of the Appalachian highlands. Average annual precipitation at Glen Lyn, Virginia, 5 km northwest of the study site at 465 m elevation, is 930 mm (NCDC, 2002). This is one of the driest locations in Virginia.

Oak-dominated forests are the principal vegetation cover on Peters Mountain and other ridges of the Appalachian Mountains (Braun, 1950; Adams and Stephenson, 1983). Chestnut oak (*Quercus montana* Willd.) is the dominant tree species of dry mountain slopes and is the most fire-tolerant Appalachian oak (McQuilkin, 1990; Abrams, 2003). Pines and oaks occupy the driest sites, including rock outcrops, ridgetops, and upper south- or west-facing slope facets, while a diverse mix of oaks and mesophytic species inhabit moister sites on lower slopes and in valleys (Braun, 1950). At the Narrows Preserve, the fire-scarred pines (mostly Virginia pine, *Pinus virginiana* Mill., but also some Table Mountain pine, *P. pungens* Lamb., and pitch pine, *P. rigida* Mill.) were scattered throughout the oak-dominated stands on dry sites.

The Appalachian Mountains are subject to both lightning-ignited and anthropogenic fires (Lafon et al., 2005). On Peters Mountain, for example, a small lightning-ignited fire in June 2004 stimulated the establishment of approximately 60 mallow seedlings in an area from which the plants had been absent previously (Anonymous, 2004). Numerous ignition sources exist for anthropogenic fires because of widespread human land use around Peters Mountain. The New River and the Narrows have provided a travel corridor from presettlement times until the present (GCHS, 1982). A highway (U.S. 460) traverses the east side of the river today (Fig. 1), but of potentially greater significance as an ignition source was the Virginian Railroad that operated along the east bank during 1907–1977 (GCHS, 1982; Caljouw et al., 1994). Other important land uses include small farms, forestry, and electric transmission lines. Also, the small towns of Narrows and Rich Creek are 1.7 km upriver and 3.7 km downriver, respectively, from the Narrows. The earliest European settlement in the vicinity occurred in the mid 1770s (GCHS, 1982).

Extensive logging occurred on Peters Mountain during the 1920s (Caljouw et al., 1994). An aerial photograph taken in the late 1930s (currently on file with the USDA Forest Service in Blacksburg, Virginia) reveals that the south side of Peters Mountain was covered with a mix of small trees and open areas, suggesting recent timbering and/or fire. The west and northwest-facing slopes had a relatively continuous canopy of larger trees; this forest possibly escaped logging because of the rugged terrain (Caljouw et al., 1994). Today the forest on the west and northwest slopes is occupied by large chestnut oak trees mixed with smaller oaks, other hardwoods, and pines.

Field Methods

During 2005, a chain saw was used to obtain full or partial cross-sections from 79 living and dead fire-scarred pines, 73 of which we were able to date and analyze (Fig. 1). We collected cross-sections from each fire-scarred pine that we found on the western end of Peters Mountain, regardless of the number of scars on the tree. Collecting numerous samples was necessary to obtain the most complete record possible and to reduce the probability of missing fires that were not recorded by many trees. The location of each fire-scarred specimen was recorded using a GPS unit.

To investigate tree establishment dates in the vicinity of the mallows, two 20 × 50 m quadrats were established near the plants, one on the northwest-facing slope and the other on the southeast-facing slope. The purpose of our study was not to characterize tree age structure across the landscape, in which case more plots would be needed. Rather, our interest was in whether changes in fire history, particularly fire suppression, led to changes in tree establishment that might influence the mallow habitat. Within each plot, we used an increment borer to obtain two cores from opposite sides at the base of each living tree that had a stem diameter at breast height (DBH) $\geq$ 5.0 cm. Heart rot prevented the coring of 10 trees, including nine chestnut oaks with DBH of 26.0–53.0 cm. Most (8) of the decayed chestnut oaks were in the (apparently unlogged) plot on the northwest side of the mountain. A total of 146 trees was cored.

Sample Preparation and Analysis

We glued the increment cores to wooden mounts, and surfaced all cross-sections and cores with a belt sander to reveal tree rings and fire scars. To ensure precise annual dating of the fire scars, a master chronology was developed for the pines, and the tree rings for all pine cores and cross-sections were crossdated visually (Stokes and Smiley, 1968; Yamaguchi, 1991). The rings were measured using a Velmex measuring system and J2X software, and then crossdated statistically using the COFECHA program (Grissino-Mayer, 2001a). Because of their temporal extent relative to the other pines sampled at Peters Mountain, the two oldest cross-sections (from Table Mountain pine trees) were crossdated against a 272-year long Table Mountain pine chronology developed for a site 35 km away (DeWeese, 2007). We did not crossdate the tree rings of hardwood trees from the plots because they were used solely for creating graphs of age structure with decadal resolution.

Fire scars were dated to the year of formation, and scar seasonality was designated according to the scar position relative to the annual ring (Grissino-Mayer, 2001b): earlywood, latewood, dormant, or undetermined. We used the FHX2 program (Grissino-Mayer, 2001b) to archive, graph, and analyze fire scar data. For purposes of fire interval calculation, dormant-season scars were assigned the date of the postscar ring (i.e., they were assumed to result from spring fires). To characterize the central tendency in fire return intervals, FHX2 was used to calculate the Weibull Median Interval (WMI) as well as the widely used Mean Fire Interval (MFI). Lower and Upper Exceedance Intervals (LEI and UEI) were computed to estimate the range of variability within the Weibull-modeled distribution. These intervals bracket the range in which 75% of the fire intervals would be expected to fall. FHX2 conducts analyses only for the intervals covered by "recorder" years, which are the years that follow the initial scar on a tree. The initial wound increases the susceptibility of the tree to subsequent scarring. Additionally, tree rings are not considered recorder rings if they formed after a tree has healed over a wound, or during a time when some of the scars may be obscured by decay. Designating recorder years is a standard, necessary practice to ensure that fire interval calculations are based on intervals when data exist (i.e., to prevent erroneously computing fire intervals that are too long).

Because of uncertainties inherent in analyzing fire scars (e.g., Baker and Ehle, 2001; Van Horne and Fulé, 2006), we obtained three sets of estimates for WMI, MFI, LEI, and UEI. First, the composite fire interval was calculated on the basis of all fires recorded by all trees at the study site. Second, the filtered composite fire interval was based only on the "major" fires recorded by a minimum of two trees and 25% of the samples. These fires potentially were more extensive or severe than other fires. Because filtering disregards potentially small-extent ("minor") fires, it offers a more conservative and possibly more reliable estimate of how frequently fire affected a large portion of the landscape. Third, the point fire interval was based on individual samples instead of the composite of all samples. It is considered a useful estimate of fire frequency for any point on the landscape, albeit conservative because fires usually do not scar every tree they burn.

To explore temporal changes in fire activity, and specifically to place the fire-protection era and the 1920s logging episode into a longer context, we calculated the mean number of fire scars per recording tree per decade. The mean number of scars per recording tree provides an index of fire activity that permits a comparison across decades with different sample sizes of recording trees. We used correlation analysis (Zar, 1999) to assess whether the mean number of scars per recording tree changed over time.

We created tree age histograms to portray tree age structure for the plots. For cores that did not intersect the pith, we used the width and curvature of the innermost rings to estimate the pith date (Applequist, 1958). Because the age histograms were created with 10-year age classes, we excluded 25 trees for which more than 10 years would be added using the pith estimator. The excluded trees were 17 chestnut oaks and eight other oaks.

RESULTS

Fifty-three fires were recorded by 171 scars for the period 1794–2005 (Fig. 2). For the period beginning in 1867, the first year with two or more scarred trees (Grissino-Mayer et al., 2004), and ending in 1976, the last year with a scar, the various analyses yielded MFI and WMI estimates of 2.2–18.4 years (Table 1).

The mean number of fire scars per recording tree per decade (Fig. 3) declined over time between the 1790s and 2000s, as indicated by correlation analysis (r = -.654, P = .001, df = 20). Omitting the early period with only one recording tree yields a similar result (i.e., a declining incidence of fire between the 1860s and

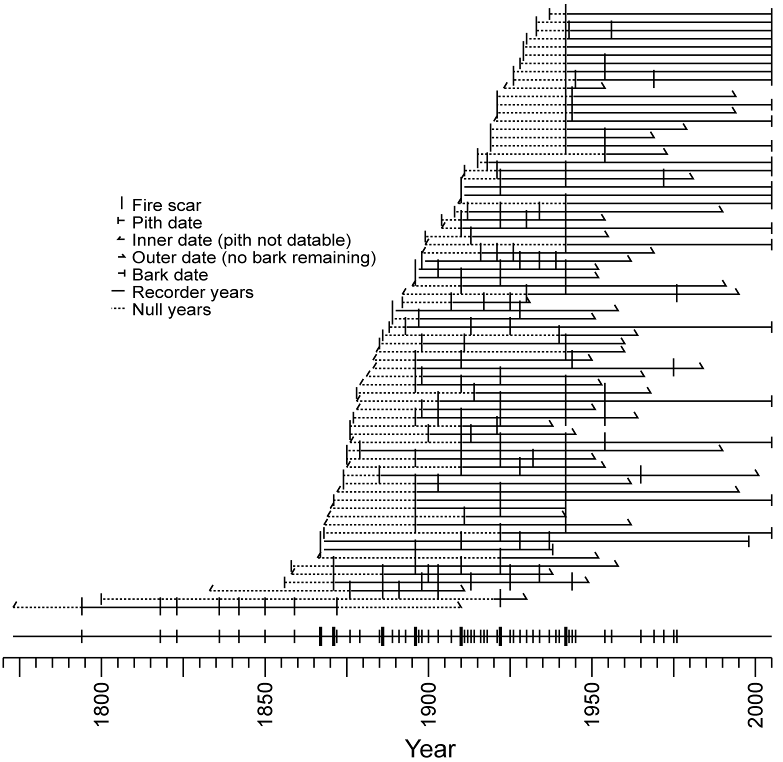

Fig. 2. Record of fire scars for each tree. The horizontal lines signify the time spanned by each tree, except the horizontal line at bottom is the composite fire axis depicting the time spanned by all the trees. The vertical lines indicate the dated fire scars on each tree. For the composite fire axis at the bottom, the long, heavy vertical lines indicate the major fires recorded by $\geq$25% of trees, while the short, thin vertical lines designate the minor fires.

Table 1. Fire Interval Calculations for Peters Mountain, 1867–1976

	MFI	WMI	SD	LEI	UEI	Range	Number of intervals
Composite fire interval	2.5	2.2	1.9	0.7	4.5	1–9	44
Filtered composite fire interval	12.5	12.3	5.4	6.9	18.2	4–20	6
Point fire interval	18.4	16.7	12.1	6.3	32.1	3–79	92

2000s; r = -.830, P < .001, df = 13). The negative trend appears primarily to be a consequence of low fire activity since the 1950s, a suggestion confirmed by the lack of significant correlation for the 1790s–1940s (r = -.316, P = .233, df = 14) and for the 1860s–1940s (r = -.342, P = .368, df = 7).

Scar seasonality could be determined for 109 of the 171 fire scars. Of these, 93.6% (102 scars) were in the dormant position, while 1.8% (2 scars) were in the earlywood and 4.6% (5 scars) were in the latewood.

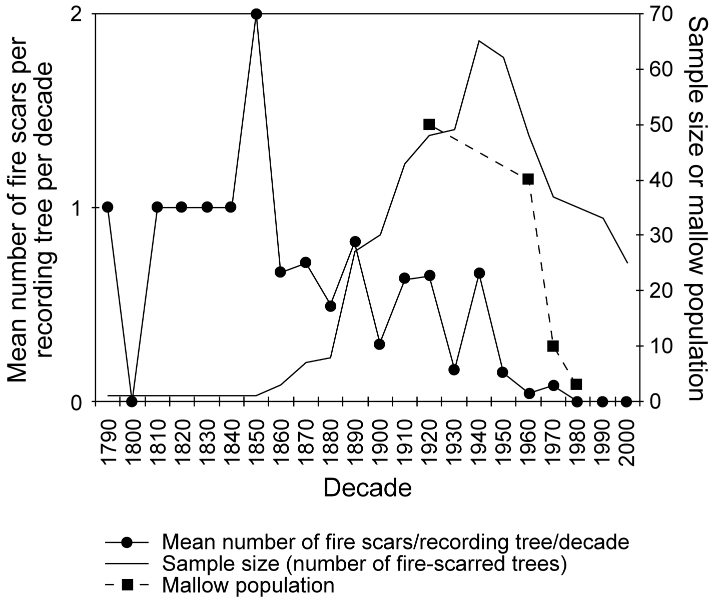

Fig. 3. Temporal trend in fire activity, as indicated by the mean number of fire scars per recording tree pre decade. Sample size and Peters Mountain mallow population (estimated from Baskin and Baskin, 1997) are shown on the second y-axis for reference.

Chestnut oak, the most abundant tree species in the two plots, with 69% of total basal area and 47% of total tree density, had establishment dates ranging from the early 1800s to the 1970s (Fig. 4A). Three other oak species comprised 23% of basal area and 31% of density: northern red oak (*Quercus rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), and black oak (*Q. velutina* Lam.). These oaks were established during the 1930s–1970s (Fig. 4B). Other hardwood species accounted for 2% of basal area and 9% of density: sourwood (*Oxydendrum arboreum* [L.] DC), red maple (*Acer rubrum* L.), and pignut hickory (*Carya glabra* [Mill.] Sweet). These hardwoods were established during the 1940s–1980s (Fig. 4C). Pines (Virginia pine and Table Mountain pine) comprised 7% of basal area and 12% of density. Pine establishment dates were mostly in the 1960s–1970s, with a few as early as the 1890s (Fig. 4D).

DISCUSSION

Fire Frequency

The short fire interval demonstrates that, historically, Peters Mountain was highly prone to fire. Fires occurred approximately every two years, and even more frequent (annual) burning was not uncommon. However, the fire interval statistics do not imply that fires burned every point on the landscape at a 2.2 year interval.

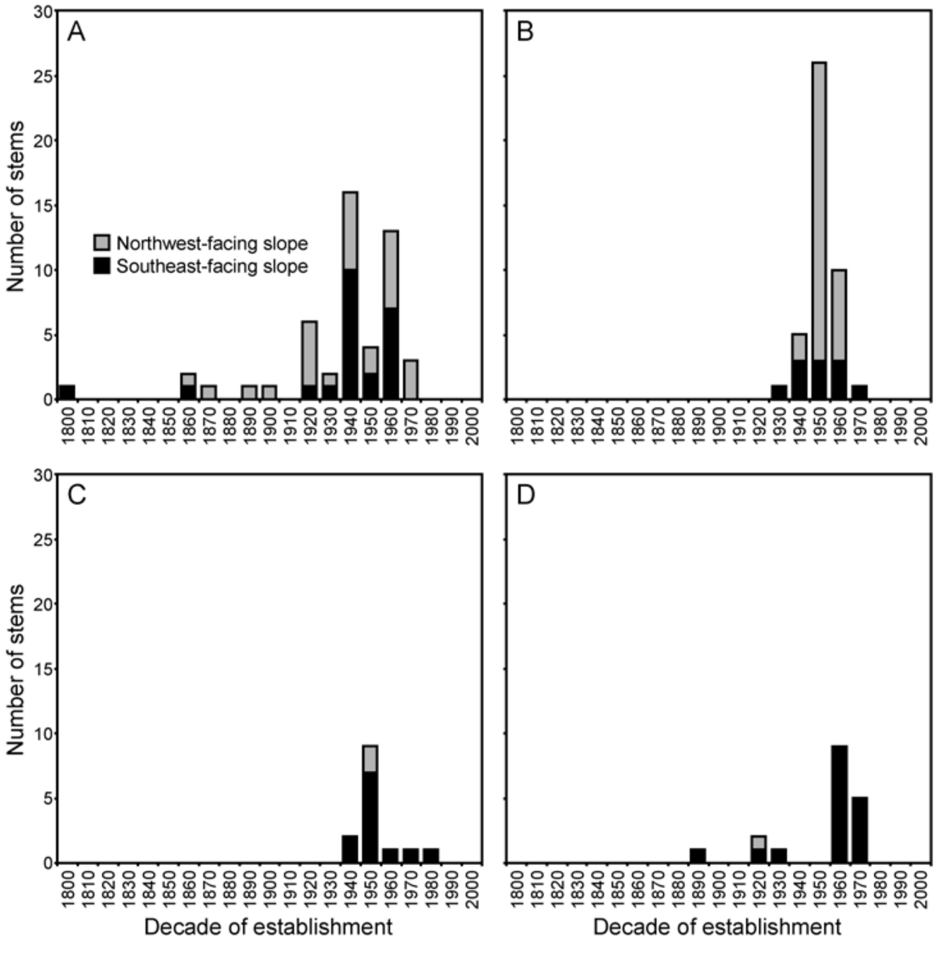

Fig. 4. Tree establishment dates for two plots in the vicinity of the Peters Mountain mallow: (A) chestnut oak, (B) other oak species, (C) other hardwood species, and (D) pines.

Instead they indicate that fires typically occurred somewhere within the study site at a 2.2 year interval. The fire regime may have been characterized by frequent small-extent fires. Some fires were recorded by only one or a few trees, possibly indicating they were limited in extent. Had more trees been available to sample, we may have discovered additional small-extent fires and arrived at a shorter composite fire interval. For example, we did not detect the lightning fire of 2004 simply because its extent was small and it did not scar any trees.

The more conservative estimates of MFI and WMI for the filtered composite fire interval suggest that potentially larger-extent fires occurred at 12–13 year intervals. These are longer intervals but nonetheless indicate a frequent fire regime (i.e., less than a 25 year interval; Pyne et al., 1996). Actually, the filtered composite fire interval may underestimate the frequency of large-extent fires. Even some "minor" fires were recorded on widely separated trees, possibly reflecting extensive fires that were too mild to scar many trees. This scenario is plausible given that fuel accumulation would have been light under the frequent burning at Peters Mountain.

The MFI and WMI estimated from the point fire intervals reveal that at any point on the landscape fire occurred quite frequently (at intervals of approximately 17–18 years), regardless of the size of the past fires. This is also a conservative estimate because a tree often fails to record a fire that actually burns it (Van Horne and Fulé, 2006).

The frequent burning is consistent with expectations for Peters Mountain based on the presence of the fire-adapted mallow. Unfortunately the population and spatial distribution of the mallow before 1927 are unknown, but post-1927 population dynamics appear to be related closely to the fire regime (Fig. 3). One question about mallow ecology is how an apparently stable population was maintained between the censuses of 1927 and 1962 (i.e., into the fire-protection era). Baskin and Baskin (1997) suggested three possible scenarios: (1) continued rejuvenation from seeds, (2) persistence of plants that had existed before fire protection began, or (3) a combination of rejuvenation and persistence. On the basis of our fire chronology it appears that both mechanisms should have been possible (scenario 3) until the 1940s, after which the incidence of fire declined and rejuvenation from seeds would have been improbable. The apparent lag between this decline in burning and the drop in mallow abundance likely reflects temporary population maintenance via the persistence of existing plants (scenario 2) in the open, high-light conditions. The encroachment of competing vegetation under reduced fire activity during the 1950s and 1960s would have degraded the mallow habitat, stressing the plants and contributing to the declining population.

Presumably the frequent burning we recorded at Peters Mountain maintained a favorable mallow habitat since the beginning of the fire chronology in the 1790s. The association of the species with fire implies that fire has been a common feature of the Peters Mountain landscape as long as *Iliamna* has inhabited it. Baskin et al. (1997) hypothesized that *Iliamna* is not well adapted to fire regimes of the Eastern deciduous forests and therefore has not been able to spread from the site it colonized on Peters Mountain. This scenario appears to suggest that Peters Mountain is/was more fire-prone than many other locations in the Appalachian Mountains and eastern North America. Indeed, other published fire chronologies for sites in the Appalachian Mountains, Midwestern United States, and Northeastern United States yield longer composite MFI and/or WMI calculations than the 2.2 year WMI for Peters Mountain. These estimates range between 5 and 18 years (Mann et al., 1994; Sutherland et al., 1995; Shumway et al., 2001; Guyette et al., 2003; Schuler and McClain, 2003; McEwan et al., 2007).

The relative dryness of the climate at Peters Mountain may have contributed to unusually favorable burning conditions compared to other humid temperate landscapes. Also, the landscape clearly had abundant ignition sources, whether anthropogenic or natural. However, the exceptionally short composite fire interval is partly a consequence of our large sample size and thorough record of fire compared to the studies cited above (14–33 scarred trees). Differing sample sizes may obscure intersite differences, but comparing point fire intervals helps to alleviate this problem. Point fire intervals reported for sites in eastern Tennessee (MFI = 12.7 years; Harmon, 1982) and southern Indiana (WMI = 20.3 years; Guyette et al., 2003) suggest that the point fire interval at Peters Mountain was not exceptional.

If an understanding of the historic variability (spatial and temporal) in fire regimes is to emerge for the Eastern forest region, fire history research is needed for numerous additional sites. In the past it was thought that decay of fire-scarred trees might be too great to permit fire history reconstructions in the humid East (Frost, 1998), but the development of multiple fire chronologies demonstrates the feasibility of fire history research in the region. Now efforts are needed to locate more sites, such as Peters Mountain, with abundant fire-scarred trees preserving as complete a record as possible of past fires. A standard suite of fire interval calculations should be reported to facilitate comparisons between sites.

Temporal Trends in Fire Frequency

Clearly fires occurred frequently at Peters Mountain during the 1920s when extensive logging was underway. However, our results indicate that a similar frequency of burning had occurred previously and continued subsequently until the 1940s. Therefore our results suggest that changes in land use—including settlement and increasing population, railroad operation, and the extensive logging episode—caused little temporal variation in fire frequency. The finding that high fire frequency characterized this entire period, and was not limited to the logging boom or railroad era, suggests that a variety of ignition sources operated. The finding also provides support for arguments (e.g., the fire-oak hypothesis) that fire has played a long and important role in Eastern temperate forest ecosystems. It suggests a possible need to revisit conceptual models of Appalachian fire history that propose a gradual increase in burning that culminated in an anomalous peak in fire activity during the logging period. Some other Appalachian fire history research also suggests that fire frequency was not unusually high during the early 20th century (Shumway et al., 2001).

The fire regime changed rapidly under the fire protection efforts of the last 50–60 years. This is in contrast to the relative stability in fire frequency at Peters Mountain under various land uses before the 1950s. Such a decline in burning has been documented in other Appalachian fire chronologies (Harmon, 1982; Shumway et al., 2001; Schuler and McClain, 2003; McEwan et al., 2007) and is consistent with the well known success of fire protection efforts (Brose et al., 2001).

Fire Seasonality

Fire seasonality at Peters Mountain resembles that found in other fire history studies in or near the Appalachian Mountains (Shumway et al., 2001; McEwan et al., 2007). The importance of dormant-season fires is consistent with the pattern of anthropogenic and lightning ignitions observed today (Lafon et al., 2005). Anthropogenic fires occur primarily in the dormant season, specifically spring and fall, when weather conditions (e.g., humidity, wind speed) and continuous dead fuels favor burning. Lightning-ignited fires are less common and occur mostly in spring and summer. Despite the limited incidence of growing season burns from either human or natural causes at Peters Mountain, they may have played an important role in maintaining open stand conditions and high light availability. This is because overstory trees and other plants are particularly susceptible to mortality during the growing season (Whelan, 1995). Additionally, the burn season may influence the flowering, germination, and/or survival of the Peters Mountain mallow, as has been found for other fire-dependent species (e.g., Platt et al., 1988; Spier and Snyder, 1998). More experimental research would be necessary to determine the influences of fire seasonality on the population dynamics of Peters Mountain mallow. Reintroducing a fire regime that resembles the historic fire regime could be a prudent approach for restoring the mallow and maintaining plant species diversity (cf. Spier and Snyder, 1998).

Tree Establishment Dates

The age structure of the forest near the mallows indicates that chestnut oak established on and inhabited the site throughout the period of frequent burning. It should be recalled that most of the trees excluded from the age class histograms because of heart rot or missed pith were chestnut oak, some of which were large and probably old. If included in the histograms they may have augmented the pattern of long-term, relatively continuous chestnut oak recruitment. Our results are consistent with the fire-oak hypothesis: oaks survived and thrived under a regime of frequent burning. Because of its tolerance to fire, chestnut oak would have been particularly well suited for the frequent burning on Peters Mountain. The other hardwoods (including other oaks) are less fire-tolerant than chestnut oak; they appear to have been favored by the reduction in burning after the 1940s. Some of these other hardwood species are reported to have expanded in white oak (*Quercus alba* L.) or chestnut oak-dominated forests in other areas of eastern North America during recent decades in part because of reduced fire activity (e.g., Harrod et al., 1998; Abrams, 2003).

Our age structure histograms suggest that the decline in burning ca. 1950 permitted tree density to increase near the mallows. This apparent increase likely contributed to the decline in the mallow population. Some of the tree establishment in the southeast-facing plot may simply reflect postlogging forest regrowth after burning diminished. However, in the apparently unlogged northwest-facing plot the post-1940s tree establishment seems to represent a density increase in a formerly more open, fire-maintained stand. Disturbance caused by the chestnut blight (*Cryphonectria parasitica* [Murr.] Barr), which affected southwestern Virginia during the 1920s (Lutts, 2004), is another factor that potentially contributed to tree establishment.

The tree age data presented here portray specifically how fire regime changes have influenced the forest near the mallows, but they also align with general expectations such as the fire-oak hypothesis. Extending our work by investigating tree age structure across numerous plots at Peters Mountain could yield additional insights about the relationship between fire history and forest dynamics.

CONCLUSIONS

Peters Mountain provides compelling evidence for the importance of fire on a temperate forest landscape. First, it has an herbaceous plant species whose life history is closely linked to fire. Second, tree age structure near the mallow plants appears to reflect the influence of historic burning and fire suppression. Third, Peters Mountain contains numerous fire-scarred pines that permitted the development of a fire chronology based on an unusually large sample size, even in comparison to many western U.S. fire chronologies (cf. Kou and Baker, 2006). This quite thorough record of fire reveals that burning occurred frequently before and during the extensive logging episode, until the advent of effective fire control efforts in the mid-20th century. The fire chronology presented here is consistent with the view that some temperate deciduous forests developed under frequent burning (e.g., Abrams, 1992, 2003; Brose et al., 2001), and it augments the handful of other fire chronologies that have been created for Appalachian forests. Similar to those other chronologies, the Peters Mountain fire chronology reveals that fire frequency declined during the mid-20th century. At the time of our sampling in 2005, 38 years had elapsed since the last recorded fire, and 63 years had passed since the last major fire in 1942. These intervals greatly exceed the MFI and WMI estimates for the past fire regime.

The discovery of the mallow population in 1927 occurred at a time of frequent fire, and its decline followed a reduction in fire frequency. Our study supports the need for TNC to restore a regime of frequent fire that will help maintain the mallow and other fire-associated vegetation on Peters Mountain. Nonfire treatments also may be necessary if vegetation structure and function are to be restored in the mallow habitat. For example, cutting some of the trees that encroached under fire suppression could help create open forest conditions similar to those that probably existed historically. These open conditions and the consequent high light availability may be as important as the fires themselves for the long-term survival of the shade-intolerant mallows.

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