An experimental evaluation of fire history reconstruction using dendrochronology in white oak (*Quercus alba*)

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Abstract: Dendrochronological analysis of fire scars on tree cross sections has been critically important for understanding historical fire regimes and has influenced forest management practices. Despite its value as a tool for understanding historical ecosystems, tree-ring-based fire history reconstruction has rarely been experimentally evaluated. To examine the efficacy of dendrochronological analysis for detecting fire occurrence in oak forests, we analyzed tree cross sections from sites in which prescribed fires had been recently conducted. The first fire in each treatment unit created a scar in at least one sample, but the overall percentage of samples containing scars in fire years was low (12%). We found that scars were created by 10 of the 15 prescribed fires, and the five undetected fires all occurred in sites where fire had occurred the previous year. Notably, several samples contained scars from known fire-free periods. In summary, our data suggest that tree-ring analysis is a generally effective tool for reconstructing historical fire regimes, although the following points of uncertainty were highlighted: (*i*) consecutive annual burns may not create fire scars and (*ii*) wounds that are morphologically indistinguishable from fire scars may originate from nonfire sources.

Résumé : L'analyse dendrochronologique des cicatrices de feu sur des sections radiales de tronc d'arbre a été d'une importance cruciale pour comprendre les régimes des feux passés et a influencé les pratiques d'aménagement forestier. Malgré sa valeur comme outil de compréhension des écosystèmes passés, la reconstitution de l'historique des feux basée sur les cernes annuels des arbres a rarement été évaluée de façon expérimentale. Afin d'examiner l'efficacité de l'analyse dendrochronologique pour détecter les feux dans les forêts de chênes, nous avons analysé des rondelles d'arbre provenant de stations où des brûlages dirigés avaient été effectués récemment. Le premier feu dans chaque unité de traitement a engendré une cicatrice de feu dans au moins un échantillon mais le pourcentage global d'échantillons contenant une cicatrice les années où il y a eu un feu était faible (12 %). Nous avons trouvé que des cicatrices sont causées par 10 des 15 brûlages dirigés, et les cinq feux non détectés sont tous survenus dans les stations où un feu s'était produit l'année précédente. Il est intéressant de noter que plusieurs échantillons contenaient des cicatrices correspondant à des périodes où il n'y avait pas eu de feux. En somme, nos données indiquent que l'analyse dendrochronologique est un outil généralement efficace pour reconstituer les régimes des feux passés bien qu'elles aient fait ressortir les points d'incertitude suivants : (*i*) les brûlages annuels consécutifs peuvent ne pas provoquer de cicatrices de feu et (*ii*) des blessures qui sont morphologiquement similaires à des cicatrices de feu peuvent avoir une origine autre que le feu.

[Traduit par la Rédaction]

Introduction

The structure, composition, and dynamics of many forested ecosystems are inextricably linked to periodic fire (Christensen 1993; Swetnam 1993; Moore et al. 1999; Veblen and Kitzberger 2002). Beginning ca. 1930, fire has been largely excluded from most forests in the United States by an effective government policy of fire suppression. In many cases, this policy has led to significant and unintended alterations of forest structure and composition (Oberle 1969; Dodge 1972; Pyne 1982). Due to its historical importance as an ecological process, an emphasis has been placed on restoring fire in many forest ecosystems (Anderson and Brown 1983; Covington et al. 1997; Trammell et al. 2004; Chiang et al. 2005). To develop ecologically defensible fire restoration plans, dendrochronological analysis of fire-scarred tree samples has been a primary resource for understanding historical fire regimes (Swetnam and Baisan 1996; Brown et al. 2001; Guyette et al. 2002; Grissino-Mayer et al. 2004). In oak forests of eastern North America, tree-ring-based analyses have deepened our knowledge of how fire influenced the formation of these systems and have suggested a link between periodic fire and oak recruitment (Sutherland 1997; Schuler and McClain 2003; Soucy et al. 2005).

The dendrochronological method for obtaining fire history information relies on the assumption that fire scars in tree samples accurately portray the historical fire regime (Gutsell and Johnson 1996; Baker and Ehle 2001; Lentile et al. 2005; Van Horne and Fulé 2006). Scar formation has been linked

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to fire characteristics such as temperature and duration, and field studies have demonstrated that fire scars are formed on oaks (*Quercus* spp.; Gill 1974; McClaran 1988; Guyette and Stambaugh 2004). Smith and Sutherland (1999), working with relatively small (4–23 cm diameter) oak stems, showed that low-intensity prescribed fire produced scars and that wounds were readily compartmentalized. Guyette and Stambaugh (2004) provided evidence of scar formation in post oak (*Quecus stellata* Wangenh.) owing to both historical and prescribed fires. These studies, among others (e.g., Johnson and Gutsell 1994; Fulé et al. 2003), provide a basis for confidence in the dendrochonological method of fire history reconstruction, but much remains unknown. For instance, a fundamental limitation in fire history reconstruction is that the likelihood of scar formation during any given fire is not well understood, particularly for oak species (but see McClaran 1988; Guyette and Stambaugh 2004).

White oak (*Quercus alba* L.) is the most widespread oak in eastern North America (Iverson et al. 1999) and an important component of many forest ecosystems (Braun 1950; Burns and Honkala 1990). *Quercus alba* is found as an overstory dominant in forests across a range of topographic and edaphic conditions, but advanced regeneration is often scarce (Rubino and McCarthy 2003; McEwan and Muller 2006). This contrast has served as evidence of "recruitment failure" in *Q. alba*, and a long-term loss of canopy dominance across much of its range is anticipated (Abrams 2003). This loss of *Q. alba* canopy dominance is part of a larger oak-to-maple transition that has been linked to fire suppression in forests of eastern North America (Lorimer 1984; Crow 1988; Van Lear and Watt 1993). Concern about this transition has led to experimental reintroduction of fire in oak forests via prescribed burning (Brose et al. 1999; Blankenship and Arthur 2006; Albrecht and McCarthy 2006), even though the historical role of fire in these systems remains unclear. Because of its abundance in eastern North America, its rot resistance, and its long life span, *Q. alba* is potentially valuable for use in fire history reconstruction (Rubino and McCarthy 2000; Shumway et al. 2001); however, little is known about the reliability of fire scar analysis in this species.

We collected cross sections from *Q. alba* trees in areas with a known history of recent prescribed fire to examine the efficacy of fire history reconstruction using dendrochronology. The primary objective of the work was to answer the question "Can the known fire history be accurately reconstructed using dendrochronological methods?" Specifically, we documented fire scar occurrence in relation to fire frequency, topographic aspect, and tree size. Morphological aspects of historical wounds and prescribed fire scars were also compared.

Materials and methods

Study site description

This study was conducted in the Arch Rock (AR) (39°12′N, 82°23′W) and Watch Rock (WR) (39°11′N, 82°23′W) sites of the Vinton Furnace Experimental Forest located on the unglaciated Allegheny Plateau of southeastern Ohio (Sutherland and Hutchinson 2003). The sites are underlain by sandstone and siltstone and the soils are moderately acidic silt loam alfisols (Boerner and Sutherland 2003). The topography is dissected and characterized by narrow ridges, steep slopes, and shallow valleys (Sutherland and Hutchinson 2003). The climate is humid continental and mean annual temperature and precipitation are 11.3 °C and 1024 mm, respectively (Sutherland et al. 2003). Forest harvesting for charcoal production occurred in the area ca. 1850–1875, and the vegetation has since regenerated into mixed oak forest (Hutchinson et al. 2003). Each site was divided into the following three treatment units (approximately 25 ha each): frequent burning, infrequent burning, and an unburned control (Sutherland et al. 2003). Within the frequent burn units, surface fires were applied every spring (March–April) from 1996 to 1999. The WR frequent unit was then burned again in November 2004, and the AR frequent unit was burned in April 2004. Fires were applied to the infrequent burn units in the springs of 1996 and 1999, and the AR infrequent unit was burned again in the spring of 2005.

Prescribed fire behavior varied substantially because of topography, weather conditions, and fuels. Generally, the surface fires were low intensity, with flame lengths in the range of 0.25–0.75 m. Flame lengths ≥1 m occurred occasionally, generally on south-facing slopes when fuels were dry and relative humidity was <25% (T.F. Hutchinson, personal observation). From 1996 to 1999, estimates indicated that an average of 79% of the landscape burned per fire (Hutchinson 2004).

Field sampling

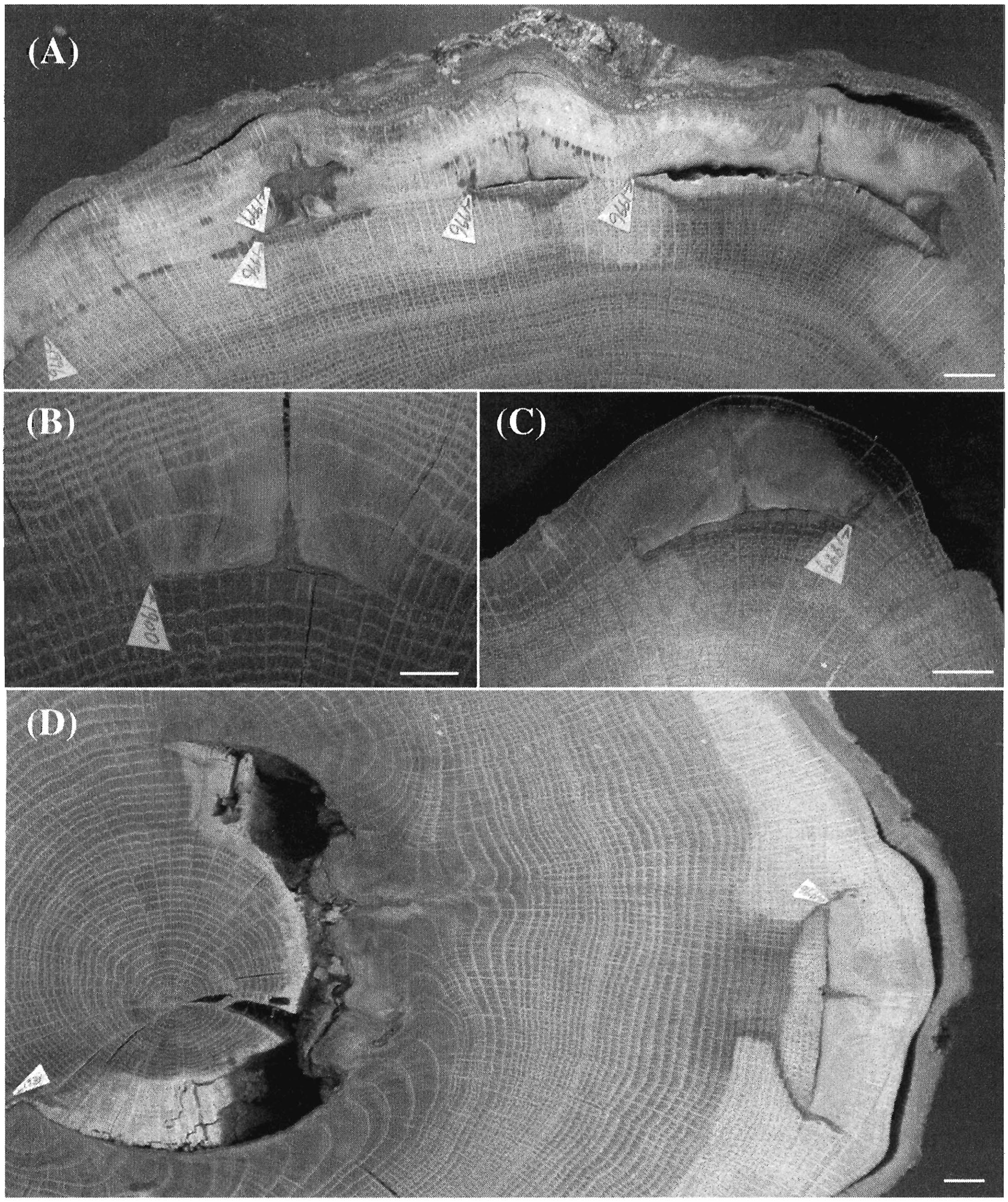
In all treatment units at both sites, *Q. alba* trees were marked for collection during February of 2005. Trees were selected to represent a range of stem diameters, from the largest stems available in the stand (approximately 60 cm) to stems approximately 10 cm in diameter. Features that might indicate the presence of fire, such as external wounds or bark scorch, were not considered during tree selection. Fifteen stems were marked in each of the four burn units and five stems were marked in each of the two controls. Trees were felled in 2005 (May–October) and basal cross sections were collected from the stem at an approximate height of 15 cm above the forest floor.

Sample preparation and data collection

Following collection, each sample was surfaced with a power planer and then sanded with a belt sander and a series of increasingly finer grit belts. Sanding belts progressed sequentially through the following six levels of roughness (ANSI standards; Orvis and Grissino-Mayer 2002): 40-grit (425–500 μm), 100-grit (125–149 μm), 150-grit (74–105 μm), 220-grit (53–74 μm), 320-grit (32.4–36 μm), and 400-grit (20.6–23.6 μm). In some instances, 500-grit (16.7–19.7 μm) sandpaper was used for polishing. Surface preparation was complete when each sample had a surface on which anatomical features of the tree-ring were apparent under a 40× microscope (Stokes and Smiley 1968).

Each sample was then analyzed to collect fire history information following typical dendrochronological methodology (Stokes and Smiley 1968). First, each tree-ring in each sample was counted. Second, graphical ("skeleton") plots that highlight years of abnormally low tree growth ("pointer

Fig. 1. Historical and prescribed fire scars on *Quercus alba* stems from an oak forest in southeastern Ohio. (A) Scars from prescribed fires in 1996 and 1999; (B) fire scar from 1900; (C) scar from a prescribed fire in 1999; (D) scarring from a historical fire (1931) and a prescribed fire (1996) with similar orientation on the stem axis. Scale bars = 1.0 cm.



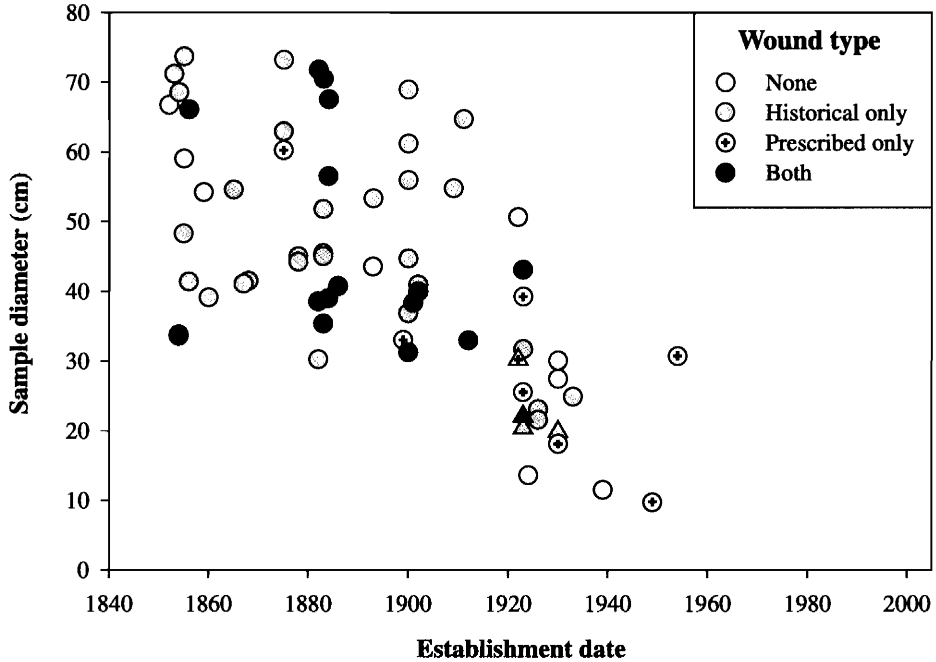
years") were constructed (Schweingruber et al. 1990). Third, these plots were used to cross-date samples against a regional master chronology. Finally, all wound events were dated to the calendar year in which they occurred.

Analytical methods

Temporal patterns of tree establishment, sample size distributions, and wound occurrence were examined by plotting each sample's establishment date against its diameter (e.g., McEwan et al. 2006). For this graphical analysis, stems from treatment units were categorized as containing either no wounds, historical wounds only, prescribed fire wounds only, or both historical and prescribed fire wounds. Data from all treatment units were then entered into the fire scar analysis software FHX2 (Grissino-Mayer 1995; Grissino-Mayer 2001; Forest Research Tools 2005). All wound events were plotted and a composite chronology was developed for each treatment unit (Grissino-Mayer 2001). Fire years were identified as those during which two or more wounds were found on a particular treatment unit.

Morphological comparisons were made between historical wounds and prescribed fire scars based on three characteristics. First, we compared the length of each wound tangential with the stem axis. The second comparison was of stem di-

Fig. 2. Establishment date – diameter relationships and wound presence on tree basal cross sections that experienced prescribed fires in a southeastern Ohio oak forest. Circles represent *Quercus alba* stems and the four triangles represent *Quercus prinus*. Open circles, no wounding; shaded symbols, stems with historical wounds only; open symbols with a plus sign, stems with prescribed burn wounds only; solid circles, stems with both historical and prescribed burn wounds.



ameter at the time of wound occurrence. This value was derived for each sample by summing two radii (offset 90°) from the wound event to the stem pith. The last comparison was made between the proportions of the stem circumference scarred during wound events. This value was calculated by dividing the scar length by the circumference ($C = \pi \times d$) of the stem at the time of scarring. Comparisons were made between wound events occurring prior to 1970 and scars that formed as a result of prescribed fires. Wounds formed during the intervening period (1970–1995) can be confidently ascribed to nonfire events (e.g., falling limbs), as there is no knowledge of fire at the Vinton Furnace Experimental Forest during this period (Martin Dale, Research Forester, USDA Forest Service, retired, personal communication). Prior to analysis, all data were screened using the D'Agostino omnibus test (D'Agostino et al. 1990). Nonparametric Wilcoxon rank-sum *t* tests were used for the comparisons because of irreconcilably skewed distributions (Zar 1999). Normality screening and *t* tests were accomplished using NCSS (Hintze 2001).

Results

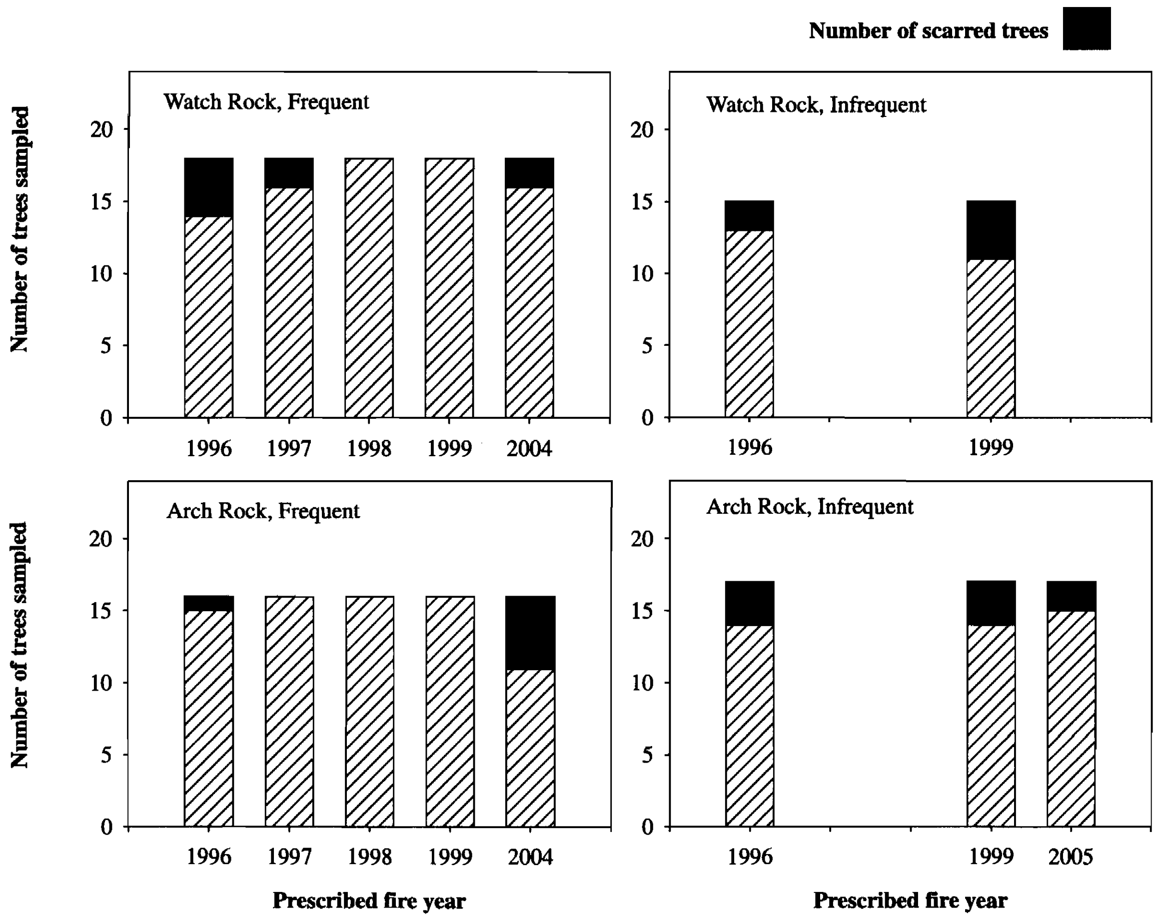
We collected basal cross sections from 77 trees. The vast majority of these were *Q. alba* (n = 73) with the other samples coming from *Quercus prinus* L. (n = 4) that were unintentionally broken during the felling operation and sampled opportunistically. The number of samples collected in each treatment unit was variable due to opportunistic sample collection. In the WR site, 18 samples were collected from the frequent burn unit, 15 samples were collected from the infrequent unit, and six samples were collected in the control. In the AR site, 16 trees were sampled from the frequent burn unit, 17 trees were sampled from the infrequent unit, and five samples were collected in the control. Across all sites, sample tree diameter at 1.4 m (diameter at breast height) ranged from 9 to 64 cm.

Scars from both the historical period and known prescribed fire years were found on samples collected from our study site (Fig. 1). Prescribed fires created multiple scars in some trees (Fig. 1A). Fire scar morphology was typified by the following four characteristics: (*i*) an inverted T-shaped wound, (*ii*) curling wound wood, (*iii*) accelerated growth in the immediate vicinity of the wound, particularly in the wound wood, and (*iv*) discoloration of the wood near the point of wounding (Figs. 1B and 1C; also see Smith and Sutherland 1999). Some samples exhibited wounds from both historical and prescribed fires, and these scars were often oriented similarly on the stem (Fig. 1D).

The oldest stems in our sample originated ca. 1860, and only three stems established after ca. 1935 (Fig. 2). Sample diameter ranged from 10 to 74 cm. Both historical wounds and prescribed fire scars were found across a range of stem diameters and ages (Fig. 2). The nine samples that were free from scars (Fig. 2, open circles) also exhibited a wide range of sizes and ages. Notably, several of the largest stems (sample diameters >60 cm) exhibited prescribed fire scars.

Fire scars were present in at least one sample from 10 of the 15 prescribed fires (Fig. 3). Summing across all units and prescribed fire years, scarring occurred on a very low percentage (12.6%) of the total samples. The largest percentage of scarred samples from a single prescribed fire was five of 16 (31%) on the AR frequent unit in 2004 (Fig. 3). No scars were formed in five of the six fires that were conducted following a fire the previous year (Fig. 3). For all

Fig. 3. Scar occurrence on stems that experienced prescribed fires in a southeastern Ohio oak forest. Two study sites (Watch Rock and Arch Rock) were each divided into two burn units (frequent and infrequent). Each histogram bar depicts the total number of samples exposed to fire in the given site during the given prescribed fire year. The solid portion of the histogram bar depicts the number of those stems exhibiting fire scars.



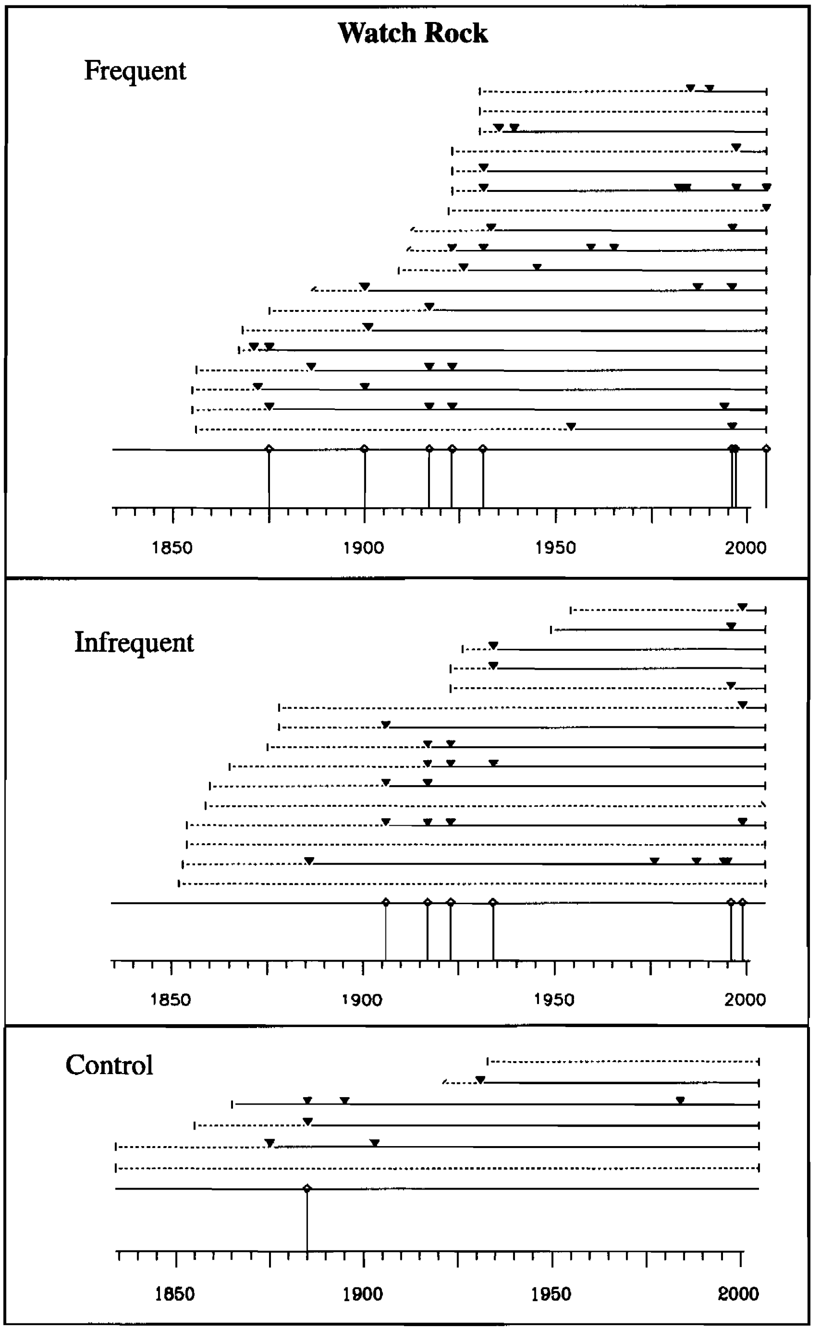
six of these fires, only two scars were formed across a total of 102 samples (AR frequent: 18 samples × 3 fires; WR frequent: 16 samples × 3 fires).

The majority of samples contained some wounding (Figs. 4 and 5). In the WR site, 33 of the 39 samples exhibited one or more wound events. Fire years, identified as years during which scarring occurred within a given treatment unit on more than one sample, were documented only between 1875 and ca. 1936 and during the prescribed fire years (Fig. 4). Scars from prescribed fires occurred on stems that had been previously wounded and also on those that had not (Fig. 4). Wounding that had all four characteristic fire scar features occurred in trees from the WR area between ca. 1970 and the beginning of the prescribed fires, although no single year exhibited wounds in more than one sample per unit. These wounds, although similar in morphology to fire scars, can be attributed confidently to nonfire events because these sites almost surely did not experience fires during this period (Martin Dale, Research Forester, USDA Forest Service, retired, personal communication).

In the AR treatment units, only eight samples were free of any wounding, and the majority contained more than one wound event (Fig. 5). Fires were recorded during the period 1900–1936 and during the prescribed fire years (Fig. 5). Notably, one stem in the AR infrequent unit exhibited a wound in 2003, even though it is known that fire did not take place during that year. Moreover, one sample from the AR control unit contained a scar from 2004 that had characteristic fire scar features. It is positively known that this treatment unit did not experience fire during 2004.

Historical wounds and scars caused by prescribed fires were similar in length, even though they occurred on trees of different sizes and influenced different proportions of the stem circumference. Mean ± SE sample diameter at the time of wounding was significantly smaller for historical wounds (14.6 ± 1.0 cm) than for prescribed fire scars (40.1 ± 3.2) ($P < 0.001$) (Fig. 6A). The proportion of the stem circumference wounded during any given event was larger for historical wounds (16.1 ± 1.8) than for prescribed fire scars (7.4 ± 1.6) ($P < 0.001$), probably because of their smaller size at the time of wounding (Fig. 6B). Even so, wounds caused by historical factors were similar ($P = 0.6$) in length (8.9 ± 0.9 cm, mean ± SE) to prescribed fire scars (8.01 ± 1.4 cm) (Fig. 6C). Meaningful comparison of wound duration (years for a wound to close entirely) was not possible because mean duration for historical wounds (11.6 ± 1.3 years) was

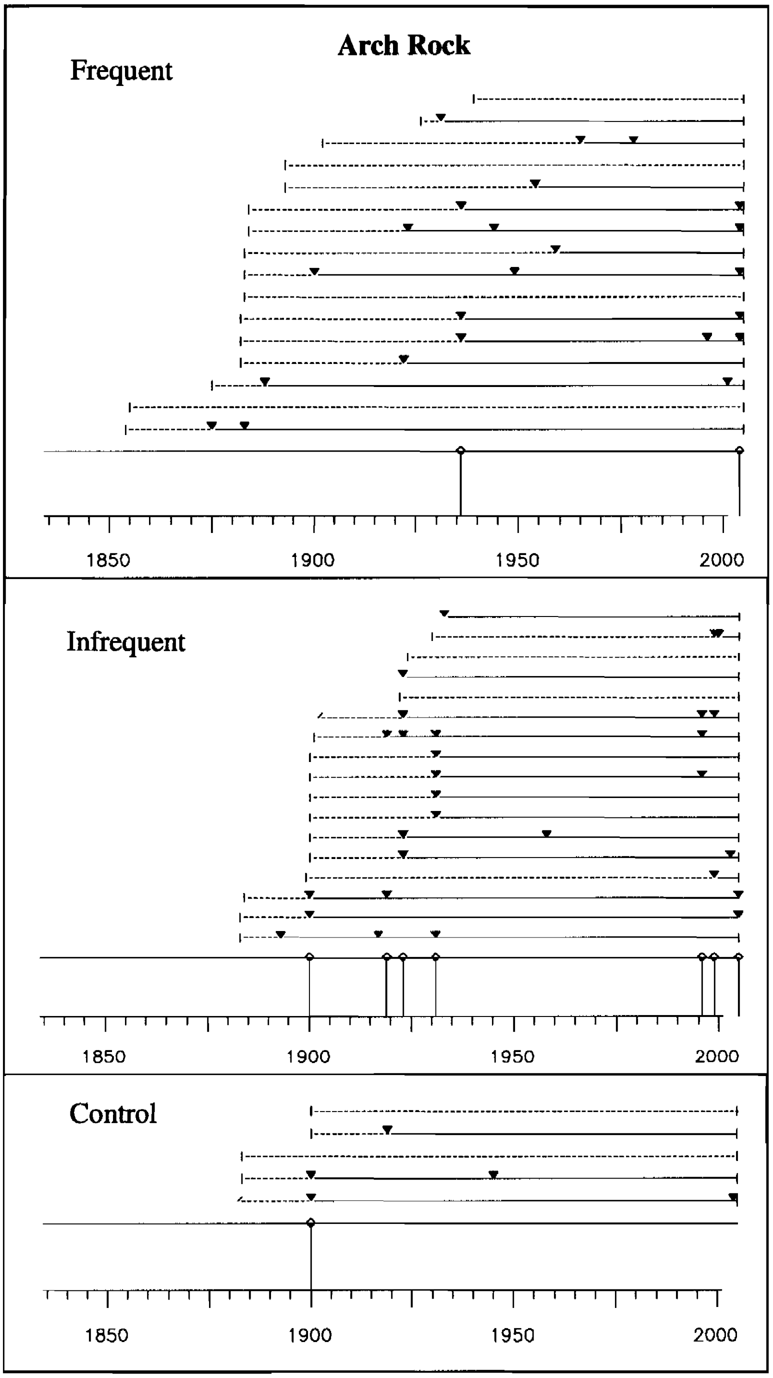
Fig. 4. Fire history diagram constructed from samples collected in three treatment units of the Watch Rock study site in a southeastern Ohio oak forest using the FHX2 fire history program. Within each panel, lines represent the growth years of an individual tree. Along each line, triangles indicate wound events and lines are dashed prior to the occurrence of a wound event and solid afterward. A solid line near the bottom of the panel represents a composite upon which diamonds are located if that year is represented by a wound event in more than one sample. These are considered fire years and the diamond composite marker is connected to the chronology (at the bottom of the panel) indicating the date of that fire year.



greater than the longest possible duration for the prescribed fire wounds (9 years). The minimum time for closure of a historical wound was <1 year and the maximum was 62 years, a notable duration given that the stem was without apparent exterior wounding at the time of sampling.

Wounding was more severe and occurred on slopes with a variety of aspects in smaller stems (Fig. 7). Stems <10 cm in basal diameter at the time of wounding exhibited the greatest injury extent (in proportion to total circumference), while stems >40 cm basal diameter exhibited smaller injuries (Fig. 7). In stems that were small when wounded, scarring occurred across topographic aspects: for stems >20 cm in basal diameter at the time of wounding, scarring occurred almost exclusively on slope aspects from intermediate to

Fig. 5. Fire history diagram constructed from samples collected in three treatment units of the Arch Rock study site in a southeastern Ohio oak forest using the FHX2 fire history program. Structure of the figure is the same as that of Fig. 4.

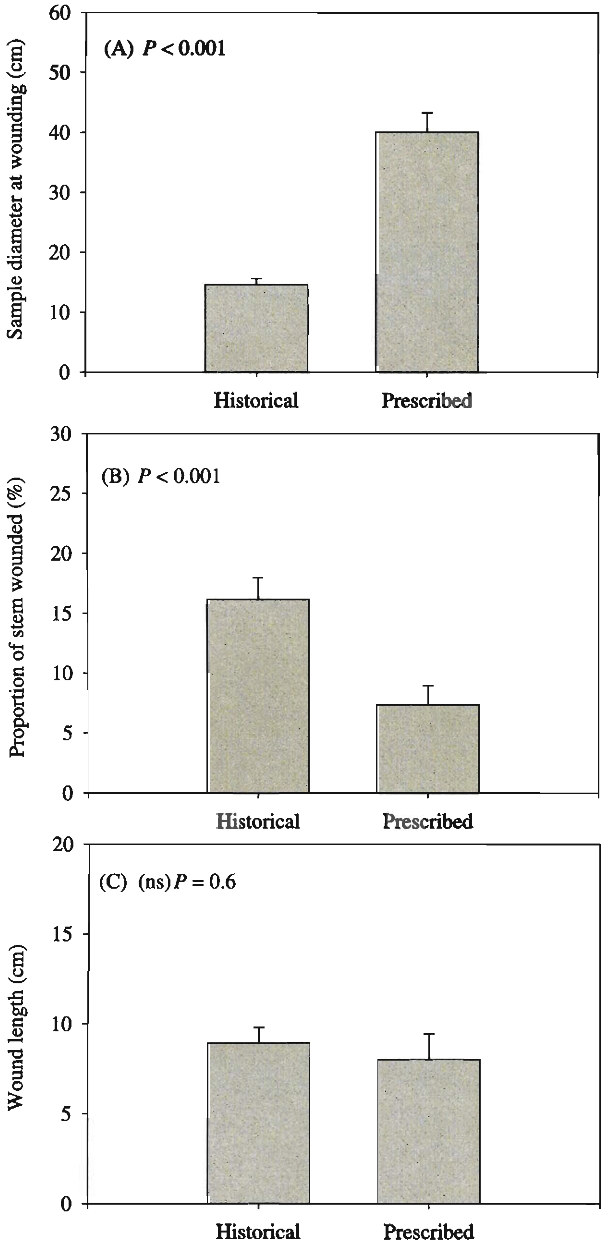


southwest facing (Fig. 7). Wounding occurred on large samples (>60 cm) in prescribed fire years; however, a small proportion of the total stem circumference was wounded in these instances (Fig. 7).

Discussion

Samples collected from *Q. alba* stems contained scarring minimally sufficient to document the known prescribed fire history. This supports the use of dendrochronology for reconstructing fire history in oak forests. Dendrochronology has been used extensively in western North America (Brown et al. 2001; Fulé et al. 2003; Grissino-Mayer et al. 2004) and is an increasingly important tool in eastern deciduous ecosystems as well (Cutter and Guyette 1994; Shumway et al. 2001; Schuler and McClain 2003). Research based on dendrochronological analysis of fire scars relies upon the assumption that fires are accurately recorded in tree cross sec-

Fig. 6. Characteristics of historical wounds and prescribed fire scars in tree-ring samples collected in a southeastern Ohio oak forest. (A) Sample diameter at time of wounding; (B) proportion of stem wounded; (C) wound length. Histogram bars represent the means and error bars are ±1 SE. Probability values are derived from nonparametric Wilcoxon *t* tests.



tions (Van Horne and Fulé 2006). Smith and Sutherland (1999) demonstrated that scars are created by prescribed fire in small oaks, and Guyette and Stambaugh (2004) found that prescribed fire scars are formed in *Q. stellata*. Our experimental test of dendrochonology as a tool for fire history reconstruction in *Q. alba* demonstrates the validity of fire history reconstruction in this important species.

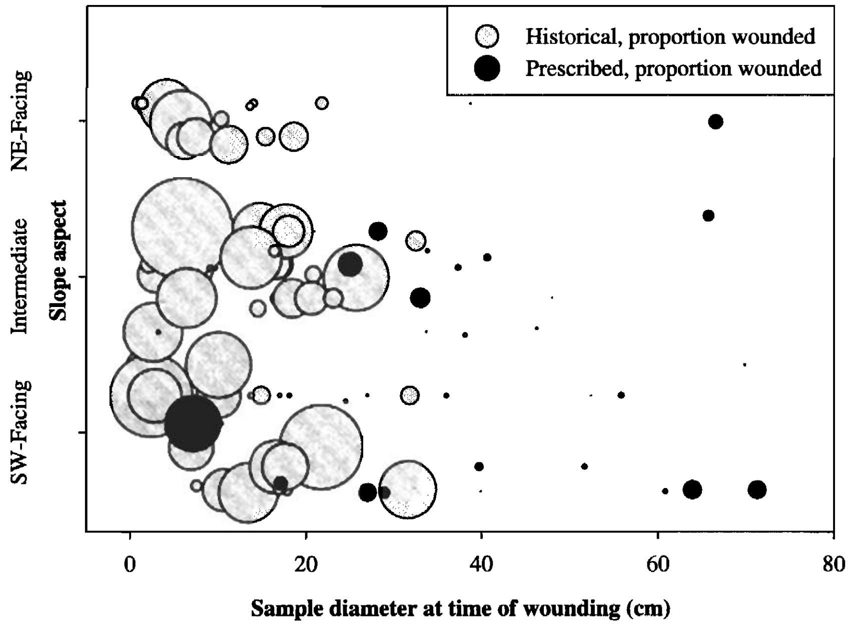
Even though the fire history was generally reconstructed, the percentage of trees scarred was low (12.6%). Wound occurrence data are scarce in the literature because typical fire history methodology employs targeted sampling of stems exhibiting external scarring (Swetnam and Baisan 1996; Van Horne and Fulé 2006). The largest percentage of scarred samples during any given fire in our study (31%) was substantially lower than the overall value of 57% found by Guyette and Stambaugh (2004) for *Q. stellata*. Our results also suggest scar occurrence at a lower level than Lentile et al. (2005) reported for ponderosa pine (*Pinus ponderosa* P. & C. Lawson), where 23.6% of stems in low-intensity fires exhibited incipient fire scars. The low level of scarring in our study may be partially explained by the location of sampled trees within the burn units. Due to the logistics of tree felling and collecting samples in steep terrain, most samples were collected on or near ridge tops, which typically burned at lower intensities than midslope positions. Even so, the low percentage of trees exhibiting wounding in our study suggests that the prescribed fires were of relatively low intensity and *Q. alba* is relatively well insulated against fire injury.

Fires that occurred in the third and fourth consecutive years of burning did not create fire scars. This is likely due to fuel limitations, which would limit fire intensity (Graham and McCarthy 2006), reduce stem heating, and thus reduce the probability of cambial injury (Bova and Dickinson 2005). On these study sites from 1996 to 1999, there was less unconsolidated litter (the primary fuel that carries fires) on sites where fire had occurred the previously year (328 g/m^2) than on sites without fire the previous year (444 g/m^2) (Hutchinson 2004). This difference in fuel level apparently translated into greater fire intensity. In 1999, prescribed fires in the infrequent unit followed a 2-year burning hiatus and were significantly hotter (166 °C) than fires in the frequent units (112 °C), which followed three previous consecutive annual burns (Hutchinson et al. 2005*a*).

The reduction in fuels, reduction in fire intensity, and corresponding lack of scarring from fires that occur in consecutive years indicate that annual fire regimes may be undetected in tree-ring analyses of *Q. alba*. Furthermore, these data suggest that fire history chronologies in oaks may have a "blind spot" in the year following a detected fire event. If so, fire histories developed using fire scars on tree-ring samples from oak forests should be seen as providing minimum estimates of fire return (e.g., Cutter and Guyette 1994; Soucy et al. 2005). This is important because, although repeated annual prescribed fires were not detected, they were present in the landscape and had an ecological effect (Hutchinson et al. 2005*a*, 2005*b*). In fact, the fires that occur in the six "blind spot" years were similar to other years in percent area burn estimates (Hutchinson 2004), and these undetected fires induced mortality in understory seedlings and saplings (Hutchinson et al. 2005*b*). To better understand the historical role of fire in oak ecosystems, an empirical link must be made between fuel loadings, flame characteristics, and the formation of fire scars on tree boles (Bova and Dickinson 2005).

Wounds that precisely resembled fire scars were present from years in which fire had not occurred. Unlike coniferous trees, in which scars can often be confidently ascribed to fire by wound morphology and the presence of charcoal, oak wounds usually close rapidly and only seldom contain charcoal (Smith and Sutherland 1999; Smith and Sutherland

Fig. 7. Slope aspect and stem size influence wound occurrence and severity in samples collected from a southeastern Ohio oak forest. Slope aspect was first transformed following Beers et al. (1966). Sample diameter at the time of wounding was plotted against this aspect variable and points in the scattergram were sized according to the proportion of total stem circumference wounded during any given event. The circle sizes in the legend represent wounding that would influence 20% of a stem axis and the largest circle in the figure represents wounding along 86% of that stem's circumference.



2001). The nonfire wound events found in our samples suggest that fire history reconstructions in oak forests that consider a single scar to be evidence of fire may overestimate the historical prevalence of fire in those ecosystems.

Overall, our findings of unrecorded prescribed fires, low percentages of scarred stems during other prescribed fires, and the presence of nonfire wounds that were morphologically identical to fire scars, emphasize that there is uncertainty inherent to tree-ring-based reconstruction of fire history in oak forests. To minimize this uncertainty, we suggest that 15–20 older samples over approximately 25 ha should be considered a minimum sample density for fire history reconstruction in oak forests. Furthermore, future studies in oak forests should establish a priori an explicit definition of fire wound morphology that could include the four morphological features listed above. Nonfire wounds with similar morphology to fire scars were found in our study, but these were found on only one sample per treatment unit per year. Therefore, in addition to morphological criteria, we suggest that a minimum of at least two samples with characteristic wounds should be present to infer a fire (e.g., Brose and Waldrop 2006). An event that could be particularly troublesome in fire history reconstruction from oak forests is selective logging, which will produce scars that are morphologically similar to those created by fire and will be replicated within the landscape. Wounds caused by logging are typically much larger than fire scars (Guyette and Stambaugh 2004); however, more work is needed to define wound features that will effectively distinguish these two disturbances.

Establishing morphological criteria for recognition of a fire scar and requiring landscape replication of scarring should minimize the inclusion of nonfire wound events in fire chronologies. These chronologies, however, should be seen as providing minimum estimates of fire return given our discovery of a blind spot in our prescribed fire reconstruction. In particular, periods in the tree-ring record where fire is apparently frequent (e.g., biannual) should elicit carefully consideration from researchers owing to the possibility that annual fires were taking place but did not create fire scars.

The existing *Q. alba* canopy found in many eastern deciduous forests developed during and following frequent and intensive anthropogenic disturbance in the late 1800s and early 1900s. Our data indicate that most of the existing canopy trees experienced at least one wound event at some point in their history and that many were scarred by fires in the early 1900s. To mimic the conditions prevalent during this period, prescribed fire is increasingly applied to oak forest landscapes (Arthur et al. 1998; Albrecht and McCarthy 2006). Although some uncertainty is inherent to the procedure, fire scar analysis using *Q. alba* is an effective means for better understanding historical fire regimes and may provide guidance in the development of fire management plans for modern forests.

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