The establishment and development of oak forests in the Ozark Mountains of Arkansas

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Abstract: The disturbance history of six mature white oak (*Quercus alba* L.) – northern red oak (*Quercus rubra* L.) – hickory (*Carya* spp.) stands in the Ozark Mountains of northern Arkansas were reconstructed using tree-ring and fire-scar analysis. Results indicate that all six stands originated in the early 1900s following timber harvesting and (or) fire. These disturbances initiated a pulse of oak-dominated establishment. Most sites were periodically burned during the next several decades. Abrupt radial growth increases in all stands during the 1920s to 1940s reflected additional disturbances. These perturbations likely provided growing space for existing trees, but did not result in increased seedling establishment. Thus, multiple disturbances were important in the origin and development of the stands studied. By the 1930s and 1940s, oak establishment was replaced by shade-tolerant, fire-intolerant non-oak species; few oak recruited into tree size classes after the 1950s. The decrease in oaks and the increase in non-oaks coincided with fire suppression. Few scars were recorded during the past 60–70 years. Prescribed fire may be an important management tool in regenerating oak forests in northern Arkansas.

Résumé : L'historique des perturbations dans six peuplements matures composés de chêne blanc (*Quercus alba* L.), de chêne rouge (*Quercus rubra* L.) et de caryer (*Carya* spp.) situés dans les monts Ozark du nord de l'Arkansas a été reconstitué grâce à l'analyse des cernes annuels et des blessures de feu. Les résultats indiquent que les six peuplements datent du début des années 1900 et se sont établis après une coupe, un feu ou les deux. Ces perturbations ont déclenché une vague d'établissement dominée par le chêne. La plupart des sites ont été périodiquement brûlés au cours de plusieurs des décades qui ont suivi. Des augmentations abruptes de croissance radiale dans tous les peuplements durant les années 1920–1940 indiquent qu'il y a eu d'autres perturbations. Ces perturbations ont vraisemblablement créé de l'espace pour la croissance des arbres existants mais n'ont pas eu comme effet l'établissement de nouveaux semis. Par conséquent, de multiples perturbations ont été importantes pour l'établissement et le développement des peuplements étudiés. Vers la fin des années 1930 et 1940, l'établissement du chêne a été remplacé par d'autres espèces tolérantes à l'ombre mais intolérantes au feu; peu de chênes ont été recrutés dans les classes de dimension des arbres après les années 1950. La diminution chez les chênes et l'augmentation chez les autres espèces ont coïncidé avec la suppression des feux. Peu de cicatrices de feu ont été notées au cours des derniers 60–70 ans. Le brûlage dirigé pourrait s'avérer un outil important pour régénérer les forêts de chêne dans le nord de l'Arkansas.

[Traduit par la Rédaction]

Introduction

The Ozark Mountains, a Paleozoic-age eroded plateau, are located in northern Arkansas and southern Missouri. The region consists of hilly to mountainous topography and has the most rugged terrain west of the Appalachian Mountains and east of the Rocky Mountains. Oak–hickory (*Quercus*–*Carya*) forests are the dominant cover type in the Ozarks (USDA Forest Service 1999). These forests have long attracted the attention of researchers interested in the silviculture and natural regeneration of upland oak (e.g., Johnson 1977; Sander et al. 1984; Graney and Murphy 1994; Dey et al. 1996; Larsen et al. 1997; Johnson et al. 2002). In a substantial portion of the region, relatively xeric conditions facilitate the accumulation of oak advanced reproduction and increase the regeneration potential of oaks (Larsen and Johnson 1998; Dey 2002*a*). Indeed, in the Ozark Mountains of Missouri, non-oaks tend to displace oaks only on the most mesic habitats (Johnson et al. 2002). Yet in the Ozark Mountains of northern Arkansas, successfully regenerating oak forests is considerably more difficult (Graney 1999; Spetich et al. 1999; Spencer 2001; Heitzman 2003). There, increased moisture provides a competitive advantage to non-oak species, thus hindering the establishment and (or) recruitment of oak seedlings. Studies from outside the Ozarks suggest that oak regeneration failures result either from inadequate establishment of oak seedlings or from the slow development of oak advanced reproduction relative to its faster growing competitors (Crow 1988; Loftis 1990; Lorimer 1993; Abrams 1998; Spetich and Parker 1998; Van Lear 2004).

The paucity of oak seedlings and saplings in some areas of the Ozarks contrasts with the dominance of oaks in the overstory. It is clear that the factors responsible for current regeneration problems were less important when today's ma-

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ture oak forests originated. A better understanding of the conditions that lead to the successful establishment and development of older oak forests would allow resource managers to recreate these conditions if their objective is to regenerate oaks.

Reconstructing the disturbance history of a forest can be accomplished by analyzing tree rings and fire scars. By examining tree age distributions, it is possible to determine when a stand originated as well as the date of any subsequent disturbances. However, because complex age structures make identifying the date of disturbances more difficult, radial growth patterns are another important reconstruction tool. Abrupt increases in radial growth are associated with tree release after a disturbance (Lorimer 1985; Lorimer and Frelich 1989). Dating fire scars also illustrates the disturbance history of forests. This technique is used to determine the frequency, intensity, and geographic extent of wildfire (Guyette and Cutter 1991; Guyette and Dey 1997; Guyette and Spetich 2003).

To better understand the current oak regeneration difficulties in northern Arkansas, we reconstructed the disturbance history of six mature oak stands in north-central Arkansas. The objectives of this project were to use tree-ring and fire-scar analysis to (1) reconstruct the disturbance history and patterns of tree establishment of each stand using age distributions and radial growth increments and (2) determine the importance of fire in the origin and development of each stand.

Materials and methods

Study areas

Six mature white oak (*Quercus alba* L.) – northern red oak (*Quercus rubra* L.) – hickory stands in north-central Arkansas (36.00°N, 92.15°W) were selected for study. The stands, located in the White River Hills and Springfield Plateau subsections of the Ozark Mountains (USDA Forest Service 1999), were in the Ozark National Forest in northern Stone County and southern Baxter County. Sites were no closer than 0.8 km from each other; the two most distant stands were 19 km apart. Elevations ranged from 213 to 426 m a.s.l. Soils were Clarksville and Noark very cherty silt loams (Ward 1983; Ward and McCright 1983), and slopes were 8%–40%. Site index for upland oak was 21 m at base age 50 years (C. Snow, Ozark National Forest, unpublished data).

All six stands had been commercially harvested from 1998 to 2000 using group selection. With this method, approximately one-sixth of the area in each stand was regenerated in 0.1- to 0.4-ha scattered openings. All merchantable trees in the openings were harvested and removed, while nonmerchantable trees greater than 2.5 cm dbh were killed by stem injection with the herbicide glyphosate. In addition, a commercial thinning from below was conducted in some of the forest matrix between the openings.

Data collection

In 2000 and 2001, three group selection openings in each stand were systematically selected for further study. Depending on stand size, the distance between the openings chosen was 152–610 m. In each selected opening, one 0.1-ha circular plot was established. Using chainsaws, a cross section was cut from all nonrotten stumps within the plots that possessed a ground-line diameter larger than 5 cm. The cross sections were tallied by species or species group (e.g., hickory). In most of the openings, at least several nonmerchantable trees had not been felled during harvesting. We felled such trees and removed cross sections from their stumps if the ground-line diameter exceeded 5 cm. In all, 467 sound cross sections were collected.

To estimate the preharvest species composition of each stand, we sampled the forest matrix between the openings. Portions of this area had been commercially thinned. One 0.02-ha circular plot was established 30.5 m north of the northern boundary of each opening sampled, and one 0.02-ha circular plot was established 30.5 m south of the southern boundary; six such plots were established in each stand. Plots were offset if they included skid trails or areas that were thinned. Within each plot, species and dbh were tallied for living trees with dbh greater than 11.5 cm. Understory trees smaller than this were sometimes damaged by logging equipment traveling to or from thinned areas and were not measured.

Data analysis

Tree cross sections were transported to the University of Arkansas-Monticello for preparation and analysis. Each cross section was sanded with progressively finer sandpaper so that individual tree rings were clearly visible. In 2002, 12 red oak and 12 white oak were cross-dated using skeleton plotting to create a master chronology for the study (Sheppard 2004). Next, 20–30 oak cross sections per stand were cross-dated using the master chronology as a guide (Fritts 1976). Because we wanted a long-term chronology of each stand, trees selected for cross-dating were relatively large and presumably old. In addition, we carefully examined all cross sections for the presence of fire scars. Any oak cross section with a fire scar was cross-dated, and the year of the fire scar(s) recorded. A total of 155 oak trees were cross-dated.

To identify periods of suppression and release, radial growth of the cross-dated trees was measured using Windendro (Regent Instruments Inc., Ste-Foy, Quebec, Canada). This software scans and measures annual growth increments to the nearest 0.01 mm. Radial growth information was summarized by averaging the increments from all cross-dated trees for a given year. The criteria of Lorimer and Frelich (1989) were used to distinguish between a major and minor release. A major release was indicated by a greater than 100% increase in radial growth over a 15-year period. A minor release was defined as a greater than 50% increase in radial growth over a 10-year period. These criteria, along with age distributions, were used to identify disturbance events in each stand.

Total tree age, but not radial growth increment, was determined for the non-cross-dated samples in each stand. For these trees, the age of each cross section was determined by counting the tree rings along one radius under a dissecting microscope. About 10% of the samples were independently recounted to check the precision of our work. The mean difference between the original counts and recounts was 2.1 years. Tree ages for both cross-dated and non-cross-dated trees were grouped by decade to reconstruct age distributions for each stand.

Results

Species composition

The forest composition in each stand was dominated by white oak, red oak (primarily northern red oak, with occasional black oak (*Quercus velutina* Lam.)), and hickory (Table 1). For trees with dbh greater than 11.5 cm, density ranged from 476 to 603 trees/ha and basal area varied from 26 to 34 m^2/ha. White oak was the most abundant species in each stand (relative density = 39%–57%) followed by red oak (relative density = 22%–37%). Hickory relative density ranged from 8% to 30%. Basal area was dominated by white oak and red oak. Combined, they accounted for 81%–93% of the basal area in each stand (Table 1). Associated species included flowering dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.) eastern redcedar (*Juniperus virginiana* L.), shortleaf pine (*Pinus echinata* Mill.), and black walnut (*Juglans nigra* L.).

Age distributions

The age distributions of the six stands exhibited a number of similarities. First, trees established in distinct pulses at all stands in the early 1900s (Fig. 1). Cohort establishment began in the first decade of the 1900s for stands 2 and 6. A separate establishment pulse began in stands 1, 3, 4, and 5 during the 1910s. The abruptness of these patterns is evidence that a disturbance such as timber harvesting and (or) fire removed all or major portions of the forest canopy and triggered a regeneration response. In all stands, abundant establishment continued for one to three decades after the initial disturbance(s), then generally decreased throughout the 20th century.

Second, few older trees were found in all stands (Fig. 1). Only 9 of the 467 trees that were aged had established prior to 1900; these individuals established in the mid- to late 1800s. Apparently, any relatively old trees growing in the six stands around 1900 were removed by disturbances or otherwise died by 2000–2001.

Third, species establishment patterns changed over time. Oaks, and to a lesser extent hickory, dominated early establishment in all stands (Fig. 1). These two taxa aggressively colonized the sites from the 1900s through the 1920s. In general, white oak established over a longer period and in greater amounts than red oak and hickory. With the exception of stands 1and 6, red oak establishment ceased by the 1930s and never resumed, while hickory establishment stopped by the 1940s in four of the six stands. White oak was able to establish in the developing stands better than red oak and hickory. Yet after the 1930s, white oak establishment also declined and ceased altogether by the 1940s to 1970s. Coincident with the cessation in oak and hickory establishment was increased establishment of shade-tolerant non-oak species such as flowering dogwood, red maple, and blackgum (Fig. 1). These species consistently established from the 1930s through the 1970s and 1980s; field observations indicated they were the most abundant seedlings and saplings in all stands.

Fire scars

Fire scars were found on cross-dated oak trees in every stand (Fig. 2). All stands, except stand 2, were burned repeatedly. The number of fire scars and separate fires recorded in each stand were as follows: stand 1: 9 scars and 6 fires; stand 2: 5 scars and 1 fire; stand 3: 13 scars and 6 fires; stand 4: 4 scars and 4 fires; stand 5: 13 scars and 6 fires; and stand 6: 7 scars and 4 fires.

Table 1. Stand characteristics of trees greater than 11.5 cm dbh at the six study sites.

Species	Density (trees/ha)	Relative density (%)	Basal area (m^2/ha)	Relative basal area (%)
Stand 1				
White oak	264	44	14	54
Red oak[a]	166	27	9	35
Hickories	148	25	3	11
Flowering dogwood	25	4	0	0
Other[b]	0	0	0	0
Total	603	100	26	100
Stand 2				
White oak	215	45	11	41
Red oak[a]	131	28	14	52
Hickories	106	22	2	7
Flowering dogwood	17	4	0	0
Other[b]	7	1	0	0
Total	476	100	27	100
Stand 3				
White oak	272	55	17	63
Red oak[a]	106	22	7	27
Hickories	91	18	3	10
Flowering dogwood	7	1	0	0
Other[b]	17	3	0	0
Total	493	100	27	100
Stand 4				
White oak	198	39	11	42
Red oak[a]	116	23	10	39
Hickories	148	30	5	19
Flowering dogwood	25	5	0	0
Other[b]	17	3	0	0
Total	504	100	26	100
Stand 5				
White oak	230	48	11	39
Red oak[a]	180	37	14	50
Hickories	49	10	2	7
Flowering dogwood	0	0	0	0
Other[b]	25	5	1	4
Total	484	100	27	100
Stand 6				
White oak	311	57	19	56
Red oak[a]	141	26	12	35
Hickories	42	8	1	3
Flowering dogwood	0	0	0	0
Other[b]	47	9	2	6
Total	541	100	34	100

[a]Mostly northern red oak with scattered black oak.
[b]Includes red maple, blackgum, eastern redcedar, shortleaf pine, and black walnut.

Fig. 1. Age distribution by decade for cross-dated and non-cross-dated trees >5 cm in stump diameter.

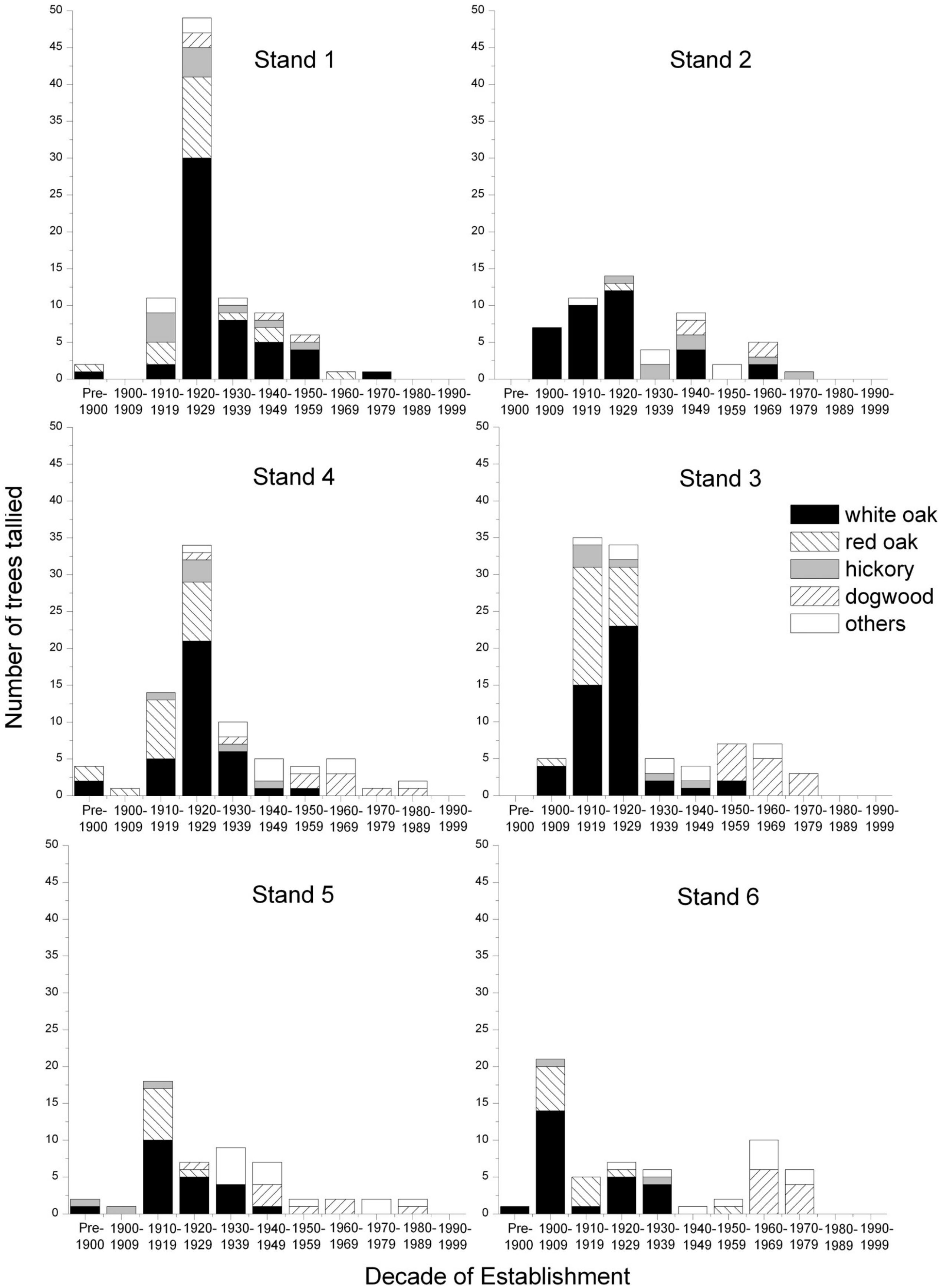
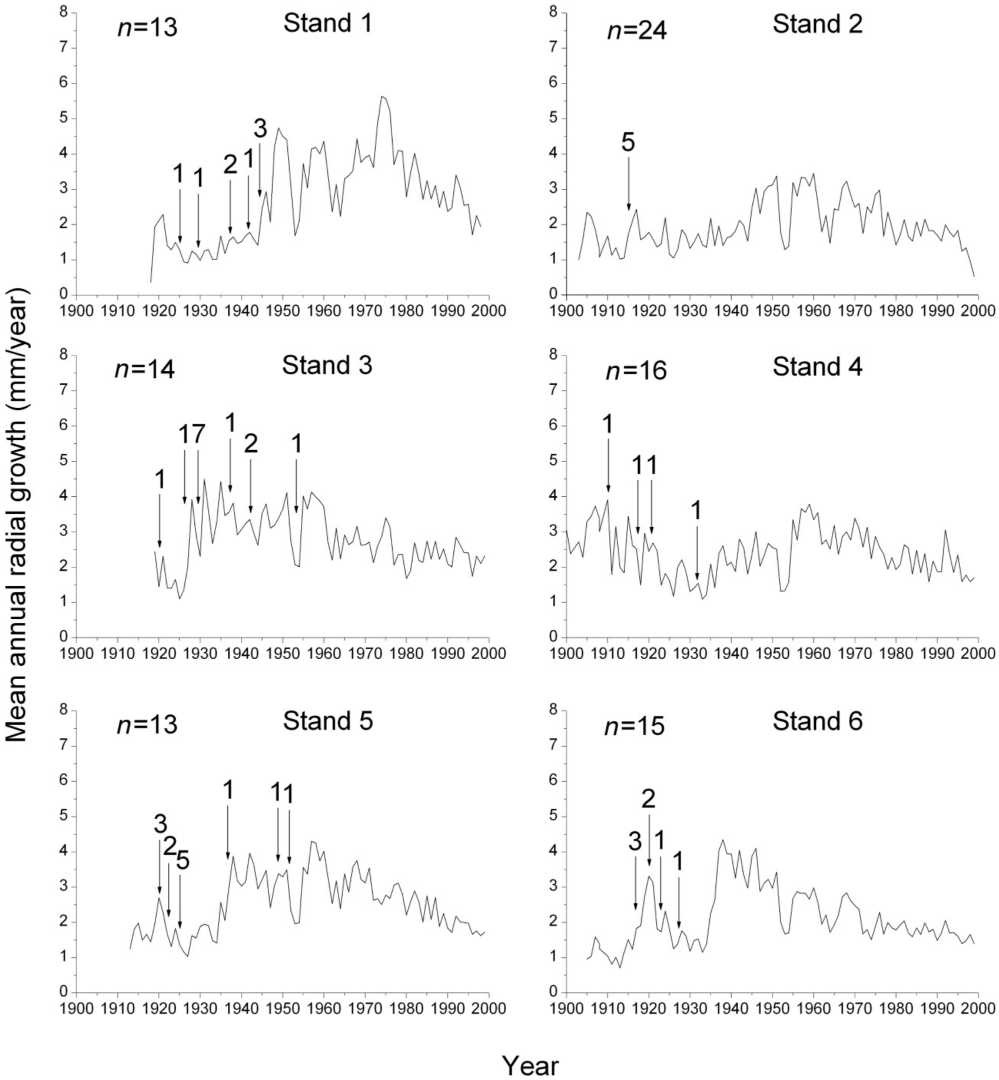


Fig. 2. Mean annual radial growth for cross-dated white oak. Arrows indicate fire-scar years. Numbers above arrows represent the number of fire scars found in a given year.



In all stands except stands 2 and 4, there were years in which only one tree was scarred and other years when multiple trees were scarred (Fig. 2). For example, for the trees in stand 1, one tree was scarred in 1924, 1927, 1942, and 1947, two trees were scarred in 1936, and three trees were scarred in 1944. Such differences may reflect the size and (or) intensity of fires in a particular year. Fire-scar frequency exhibited a distinct temporal pattern. In all stands, fire scars were observed within the 10-year period after stand establishment (Figs. 1 and 2). Clearly, early stand development was generally accompanied by frequent fires. Overall, fires were most frequent during the 1910s, 1920s, and 1930s. Fire scars were not recorded after 1915 in stand 1, after 1928 in stand 6, after 1933 in stand 4, and after the late 1940s and early 1950s in stands 1, 3, and 5. Few fire scars formed at the study sites during the past 60–70 years.

Oak radial growth and release patterns

A consistent radial growth pattern was observed in cross-dated white oak and red oak in the six stands. Patterns for white oak are illustrated in Fig. 2. Average radial growth of approximately 1–2 mm/year occurred after the initial establishment pulse until the 1920s (stand 3), 1930s (stands 4, 5, and 6), and 1940s (stands 1and 2). After this, growth increased dramatically until the late 1950s–1970s. Increment rates during this period of rapid growth generally ranged from 3 to 7 mm/year. Since the 1950s–1970s, radial growth in most stands slowly decreased for the rest of the 20th century.

The abrupt increases in radial growth during the 1920s–1940s were probably caused by reduced competition resulting from fires and (or) additional harvesting. In all stands, the percentage of trees displaying a major release during this period ranged from 21% to 52% (Table 2). The percentage of trees exhibiting a minor release ranged from 4% to 47%. The percentage of trees showing either a major or minor release ranged from 37% to 94%.

Discussion

Age distributions indicate that stand-initiating disturbances occurred during the early 1900s at each study area. These

Table 2. Percentage of cross-dated white oak and red oak in each stand showing either a major or minor release.

Stand	*n*	Approximate year of release	Major release (%)[a]	Minor release (%)[b]	Major or minor release (%)
1	23	1944	52	18	70
2	24	1944	33	4	37
3[c]	—	1925	—	—	—
4	28	1941	21	36	57
5	17	1935	47	47	94
6	20	1935	45	20	65

[a]100% radial growth increase over a 15-year period.
[b]50% radial growth increase over a 10-year period.
[c]Disturbance date was too close to the establishment date of the stand to calculate a release.

disturbances were probably timber harvests; the turn of the 20th century was a period of extensive forest exploitation in the Ozark Mountains (Sutton 2001). Between 1840 and 1890, the population of Arkansas increased from 100 000 to over 1 million residents. This increase coincided with the construction of railroads and a subsequent growth in timber harvesting to provide railroad ties and other wood products (Sutton 2001). Commercial logging in the Ozarks began by the late 1870s, and logging companies were well established in the region by the beginning of the 20th century (Bass 1981). In fact, 1909 was the year in which the greatest amount of lumber was cut in Arkansas (Strausberg and Hough 1997). By the 1920s, most forests of the state had been harvested. In 1929, the first field survey of Arkansas forest conditions found that of the 8.9 million ha of land remaining in forest, 8.1 million ha had been cut over (Bruner 1930).

Fire played an important role in the development of the stands studied. All sites had remnant fire scars, and most stands were burned repeatedly, suggesting that fires accompanied and (or) followed logging. These findings are consistent with historical accounts from the Ozarks. During the early 1900s, most Arkansans accepted spring and fall forest fires as routine and even desirable for clearing land, reducing insects, and controlling malaria (Koen 1939). Fred Lang, who was Arkansas's second state forester, noted it was common for one-third of the Ozarks and southern pine regions to burn each year (Strausberg and Hough 1997). E. Murray Bruner, a district forest inspector for the US Forest Service, lamented that "Fire has now become of such common occurrence during such a large part of every year that it is no exaggeration to say that fires literally run wild in the woods of Arkansas". (Bruner 1930). In 1930, he estimated that 5000 to 10 000 fires occurred annually in Arkansas forests, burning at least 0.8–1.2 million ha each year.

Our fire scar data indicate that most fires generally occurred during the 1910s, 1920s, and 1930s, with fewer fire scars since the 1940s. One explanation for the decreasing number of fire scars is that tree size and bark thickness increased as the stands aged. Larger trees with thicker bark are less likely to be scarred than smaller, thinner barked trees (Johnson et al. 2002). However, it is more likely that fire scars decreased because the 1930s marked the advent of significant fire suppression activities in the Ozarks. During this period, forest fires in Arkansas were increasingly considered a menace that needed to be extinguished at all costs. According to Bruner (1930), forest fires increased soil erosion, destroyed high-quality forage plants, drove out game, reduced tree regeneration, and damaged mature timber. Consequently, a large campaign was launched to educate the public on the importance of fighting forest fires (Bass 1981; Strausberg and Hough 1997). The campaign was effective in Arkansas and elsewhere; since the 1930s and 1940s there has been a dramatic reduction in periodic, low-intensity fires in Arkansas and throughout the southern and eastern United States (Lorimer 1993; Strausberg and Hough 1997; Brose et al. 2001; Sutton 2001).

The effects of fire suppression on species composition over the past 40 years were dramatic. Since the 1960s, most stands displayed a pronounced shift in species establishment from oak to shade-tolerant, fire-intolerant species. Such a pattern has been observed by other investigators in oak forests outside the Ozarks (Lorimer et al. 1994; Abrams et al. 1997; Abrams 1998; Abrams and Copenheaver 1999; Shumway et al. 2001). The lack of fire likely allowed the shade-tolerant species to outcompete the slower growing oaks and prevented oak regeneration from recruiting into the overstory.

Age distributions alone were inadequate for identifying every disturbance that occurred in each stand. The distributions were useful in determining when the stands originated. However, they failed to display any evidence of a second disturbance. Radial growth patterns clearly indicated that an additional major or minor release occurred in each stand decades after individuals started colonizing the site. Such disturbances were apparently intense enough to accelerate radial growth of the existing trees in the developing stand, but did not appear to create additional growing space for the establishment of a new cohort, or at least a cohort that survived until 2000–2001. The second disturbances that occurred in all stands during the 1920s to 1940s were most likely fires and (or) timber harvests that killed overstory trees and released understory and midstory stems. It is less likely that the cessation of a long-term drought was responsible for the release in each stand. The Palmer Drought Severity Index for 1920–1940 indicates a severe drought in 1925 and moderate droughts in 1926, 1931, 1934, and 1936 (National Oceanic and Atmospheric Administration 2004).

A regime of frequent disturbances favored oak. Indeed, the high levels of oak establishment indicate that conditions for oak regeneration were ideal. Most likely, repeated harvests and multiple low-intensity fires allowed oaks to persist in the understory and midstory by periodically eradicating competition of more shade-tolerant, less fire-tolerant species such as red maple and flowering dogwood. The importance of advanced reproduction in oak forests has been well documented (Sander 1972; Sander et al. 1984; Johnson et al. 2002). However, we were unable to ascertain whether trees became established as advanced reproduction, sprouts, or seedlings.

Oak establishment patterns differed between white oak and red oak. In most of the stands, white oak establishment occurred for several decades longer than for red oak. The window for white oak establishment was probably longer because it is more shade tolerant than red oak (Sander 1990). As the stands progressed in age and became more shaded, white oak continued to establish, while red oak was excluded. Once established, white oak was able to survive for extended periods as small-diameter trees.

Our results indicate that the mature forests we studied established and developed under frequently disturbed conditions in the early 1900s. In the absence of disturbance, oak establishment stopped and establishment of non-oak species predominated. There is growing recognition that oak forests in the Ozark Mountains and elsewhere in the eastern and southern United States have burned repeatedly for at least hundreds of years (Guyette and Cutter 1991; Abrams 1992; Guyette and Dey 1997; Brose et al. 2001; Dey 2002*b*; Guyette and Spetich 2003; Van Lear 2004). On many sites in northern Arkansas, mimicking these historical disturbances, including using fire (or a surrogate such as herbicides) as a management tool, appears to be necessary to naturally regenerate oak forests. Policies and societal attitudes that limit or exclude anthropogenic disturbances will probably lead to the gradual replacement of oak forests with non-oak species.

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