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Long-term changes in forest structure and species composition of an upland oak forest in Arkansas

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Abstract

Describing long-term dynamics in oak stands is hindered by a lack of archival data. In this study, archival data from the 1934 inventory of a 673-ha area within the Sylamore Experimental Forest were compared to a recent 2002 inventory to quantify changes in forest structure and species composition of this upland oak forest in the Ozark Mountains of Arkansas. When established in 1934, the Sylamore Experimental Forest was typical of the unharvested forests of the region that had a long history of frequent fires. Some improvement cutting was conducted after establishment and a fire prevention program was implemented, but little management occurred after 1960. From 1934 to 2002, total tree density increased from 364 to 1032 trees/ha and basal area from 10 to 23 m^2/ha. Increases occurred among understory, midstory, and overstory trees for most species. However, declines were observed for Ozark chinkapin (*Castanea ozarkensis* Ashe.) and black oak (*Quercus velutina* Lam.). Chestnut blight (*Cryphonectria parasitica* (Murrill) Barr.) is the most probable cause of the decline in chinkapin, but the decreases in black oak are less understood.

In both inventories, oaks and shortleaf pine (*Pinus echinata* Mill.) dominated the overstory and midstory. Species composition changes primarily occurred in the understory. Among these smaller trees, fire-intolerant and shade-tolerant species were more important in 2002 than in 1934, while most oaks and shortleaf pine decreased in importance over time. We attribute the changes in forest structure and species composition primarily to changes in the disturbance regime. Before the 1920s, the study area burned repeatedly for at least 100 years. Frequent fires reduced tree establishment and recruitment and resulted in the relatively understocked conditions observed in 1934. In contrast, effective fire suppression beginning in the 1920s facilitated tree establishment and recruitment, increased the importance of fire-intolerant species, and resulted in the overstocked conditions observed in 2002.

Keywords: Disturbance ecology; Fire; Forest stand dynamics; Ozark Mountains; Upland oak forest

1. Introduction

For decades, the stand dynamics of oak (*Quercus*) forests in the central and eastern United States has been a topic of interest and concern to natural resource managers and scientists. Oak cover types encompass 52% of the timberland in the region, and the oak-hickory (*Carya*) group is the largest forest type in the United States (Johnson et al., 2002). The timber of many oak species has high commercial value, and acorns are an important food source for a variety of wildlife. Yet oak forests face an uncertain future. On many sites, oaks are being replaced by shade-tolerant, fire-intolerant species (Lorimer, 1993; Lorimer et al., 1994). This has largely been attributed to fire suppression in central and eastern forests over the past 60–80 years that has favored fire-sensitive species over fire-adapted oaks (Abrams, 1992; Brose et al., 2001; Van Lear, 2004).

Despite the widespread interest in oak stand dynamics, long-term monitoring of particular oak forests is rare. Sites where trees have been measured over extended periods (>50 years), such as the Harvard Forest in Massachusetts (Foster and Aber, 2004) and the Fernow Experimental Forest in West Virginia (Schuler, 2004), are quite rare. The financial and institutional challenges of establishing and maintaining long-term plots or records are considerable. Therefore, more common approaches to describing forest stand dynamics include computer modeling (Dixon, 2002), tree-ring and fire-scar analysis (Oliver, 1978;

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Grissino-Mayer, 2001), and old-growth studies (Spetich and Parker, 1998; Shumway et al., 2001). These reconstructive and predictive techniques are useful, but lack the continuity of long-term measurements.

Oak-hickory forests are the dominant vegetation in the Ozark Mountains of northern Arkansas and southern Missouri. The Ozarks have been the site of many field studies examining the stand dynamics and management of upland oak forests (e.g., Liming and Johnston, 1944; Johnson, 1977; Sander et al., 1984; Graney and Murphy, 1994; Dey et al., 1996; Larsen et al., 1997). However, we are unaware of any studies in the Ozarks that described forest stand dynamics over a >50-year period using long-term records.

In 1934, the USDA Forest Service established the 1736-ha Sylamore Experimental Forest (SEF) on the Ozark National Forest in north-central Arkansas. This area was chosen as a research site because of its variety of forest conditions typical of the Ozarks (Kuenzel, 1934). Beginning in the mid-1930s, the SEF supported an active program of timber management research. By 1960, however, research interest in the SEF had waned, and a continued decline in research and management has characterized the last 40 years.

The entire SEF was inventoried by the Forest Service in 1934. In 2000, many of the original field tally sheets from the 1934 inventory were discovered in excellent condition. Finding these archival data presented a rare opportunity to study the long-term dynamics of an upland oak forest. The objectives of this study were to (1) inventory portions of the SEF in 2002 to describe species composition and stand structure characteristics, including basal area, density, and tree sizes; (2) compare the 1934 and 2002 inventories and document any changes in species composition and stand structure; (3) provide ecological explanations for why these changes occurred.

2. Study site

The SEF is located on the Springfield Plateau subsection of the Ozark Mountains in Stone County, Arkansas (36.1°N, 92.2°W). It is about 25 km north of the town of Mountain View and is on the Sylamore Ranger District of the Ozark-St. Francis National Forest (Fig. 1). Topography is steep and highly dissected with elevations ranging from 152 to 335 m. The moderately to excessively well-drained soils on the SEF are low in organic matter and fertility. Typical site indices at 50 years are 18.3 m for shortleaf pine (*Pinus echinata* Mill.) and 16.8 m for white oak (*Quercus alba* L.). Soils consist of Noark-Clarksville and Moko-Estate-Portia very cherty silt loams. The climate is temperate, with an average growing season of 180–200 days and a mean annual precipitation of 122 cm (Ward, 1983).

The Ozark Mountains had a long history of frequent fires and widespread grazing, especially after settlement accelerated in the 1830s (Strausberg and Hough, 1997). Even after being proclaimed as the Ozark National Forest in 1907, the early efforts at fire prevention and grazing regulation were largely ineffective. On the SEF, an effective fire prevention program only became implemented on the area after its establishment as the SEF in 1934. Prior to this, the only recorded activities on the area included a very light cutting of high quality white oak in 1876 and a diameter limit harvest (date not specified) of white oak and shortleaf pine on a small portion of the northwest corner but outside the study area (Lawson, 1961). Research treatments from the 1930s through the 1950s generally focused on field testing a variety of improvement cuttings and natural regeneration harvests. Improvement cuts removed mature, overmature, high-risk, and poor-quality trees to release desirable stems; stands that were considered to be too dense were also thinned. The amount of cutting on the SEF during this period was probably not extensive. Lawson (1961) reported that nearly all stands on the forest suffered from a lack of silvicultural management. There is no record or knowledge of harvesting on the SEF after 1960. In 1998 and 2002, prescribed burns were conducted over the entire SEF by the Forest Service. For both burns, backing fires were set from the ridgetops and allowed to burn down slope (Ronnie Anderson, Ozark-St. Francis National Forest, Mountain View, Arkansas, Personal communication).

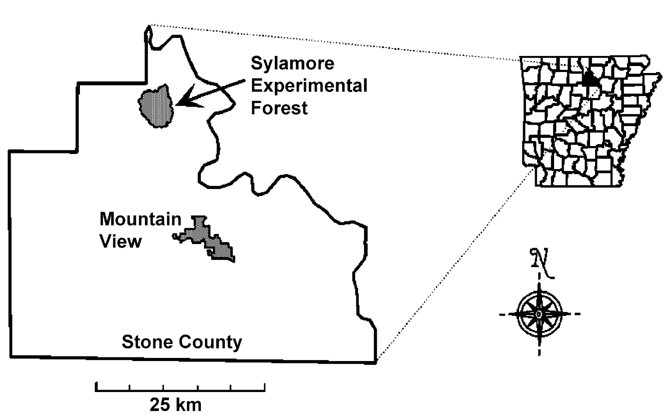

Fig. 1. Location of the Sylamore Experimental Forest in Stone County, Arkansas.

3. Methods

3.1. 1934 inventory

All of the SEF was inventoried at the time of its establishment in 1934. For this study, inventory data were available for most of sections 7 (259 ha), 17 (207 ha), and 18 (207 ha) in Township 16 North, Range 11 West. This represents 39% of the total area of the SEF. The 1934 inventory used the strip-cruise method (Kuenzel, 1934). Six to eight north-south cruise strips were established within each section. Strips were placed at 201-m intervals beginning 100.5 m from the section corners. All living trees ≥12.7 cm DBH within each 20.1-m wide strip were tallied by species or species group and DBH; these strips represented a 10% sample of the area. Those trees that were judged to be unmerchantable as timber were recorded as culls. In some but not all instances, the specific defect was recorded. Recorded defects included crooked, decayed, fire scar, forked, hollow, and staghead (major crown dieback) (Kuenzel, 1934). A 2.0-m wide regeneration strip was also established within each strip; living trees ≥4.1 cm DBH and <12.7 cm DBH were tallied by species or species group and DBH. None of the strips or trees sampled were permanently marked.

Field crews in the 1934 inventory recorded the information on tally sheets. A total of 145 tally sheets were completed for sections 7, 17, and 18. Each tally sheet indicated the starting and ending distance along a given transect, so the area covered by each sheet was known. However, this area varied among tally sheets because field crews usually recorded data until a given sheet was full.

3.2. 2002 inventory

From May to August 2002, an inventory was conducted in sections 7, 17, and 18 of the SEF using the line-plot method. As in the 1934 inventory, six to eight roughly north-south transect lines were equally spaced at 201 m intervals within each section. No attempt was made to reestablish the original cruise strips. Instead, 0.04-ha circular plots were established on each transect at 124-m intervals. In each plot, living trees >15.2 cm DBH were tallied by species and DBH. A total of 201 plots were established representing a 1% sample of the area. Nested within each 0.04-ha plot were three 0.004-ha circular plots. Plot centers were placed at azimuths of 10°, 130°, and 250° and 7.62 m from the 0.04-ha plot center. In the 0.004-ha plots, living trees with a DBH of 4.1–15.1 cm were tallied by species and DBH.

3.3. Calculations

Some species were grouped by genus in 1934. Although trees were tallied by species in 2002, it was necessary to duplicate the 1934 groupings in order to compare the two inventories. Although the inventories used different size breaks between the nested plots or strips, all trees were tallied by DBH, which enabled subdividing trees into common size classes for calculations. For each inventory, density (trees/ha) and basal area (m^2/ha) were calculated for each species or group and by the following three canopy positions: overstory (trees >24.1 cm DBH), midstory (trees 14.1–24.1 cm DBH.), and understory (trees 4.1–14.0 cm DBH). Because the 1934 data were recorded on tally sheets representing different areas, the ratio estimation procedure was used to calculate weighted means and associated statistics (Husch et al., 1982). The weighting factor was the area represented by each of the 145 tally sheets. For the 2002 inventory, density and basal area were calculated for species and canopy positions for each of the 201 fixed-radius plots, and the means and associated statistics were determined. No direct statistical comparison was made between means in 1934 and 2002 because of the widely different sampling procedures used. However, the 95% confidence interval was calculated for each parameter, and values for the 1934 and 2002 inventories were compared to determine if overlap occurred.

Importance values (IV = 100 × (relative density + relative basal area)/2) were calculated for each species or species group by strata. Calculations for 1934 were based on individual tally sheets, and means and associated statistics were then determined by the ratio estimation procedure as previously described. Calculations for 2002 were based on individual plot values, and means and associated statistics were calculated. Diameter distributions were constructed across all strata and for the following six different species or groups: black oak (*Quercus velutina* Lam.), white oak, other oak group, shortleaf pine, hickory, and other species.

4. Results

4.1. Understory vegetation

Nineteen species or species groups were analyzed to compare density, basal area, and importance value in 1934 and 2002. The total tree density and basal area in the understory (4.1–14.0 cm DBH) were substantially higher in 2002 than in 1934, increasing from 240 to 688 trees/ha and from 0.9 to 3.6 m^2/ha (Table 1). In 1934, the understory was mostly black oak, flowering dogwood (*Cornus florida* L.), white oak, and hickory. In 2002, dogwood and hickory remained the dominant species. Density and basal area of 15 species or species groups increased from 1934 to 2002. In contrast, Ozark chinkapin (*Castanea ozarkensis* Ashe) and black oak decreased in density, basal area, and importance between the two inventories.

4.2. Midstory vegetation

The total tree density and basal area in the midstory (14.1–24.1 cm DBH) was considerably greater in 2002 than in 1934, increasing from 51 to 194 trees/ha and from 1.5 to 5.5 m^2/ha (Table 2). In 1934, black oak, shortleaf pine, hickory, and white oak were the major midstory species. These same taxa, except black oak, remained dominant in 2002. Black oak decreased in importance from 27 to 8%. Thirteen species or species groups increased in density and basal area from 1934 to 2002, while declines were observed in chinkapin.

4.3. Overstory vegetation

Overstory (>24.1 cm DBH) density and basal area approximately doubled from 1934 to 2002, increasing from 73 to 150 trees/ha and from 7.2 to 14.2 m^2/ha (Table 3). In 1934, overstory trees were chiefly black oak, shortleaf pine, and white oak. These species, along with the other oak group (predominantly northern red oak (*Quercus rubra* L.)), were dominant in 2002. However, black oak decreased in importance from 30 to 10%. Eleven species increased in density and basal area from 1934 to 2002. Similar to the understory and midstory stratum, overstory chinkapin decreased in all parameters.

4.4. Diameter distributions

Substantial changes occurred in the shape and amplitude of the diameter distributions of all species and groups from 1934 to 2002 (Fig. 2). Black oak and white oak displayed

Table 1
Mean density, basal area, and importance value for the understory stratum in 1934 and 2002 on the Sylamore Experimental Forest (standard error in parentheses)

Species or species group	Density (trees/ha)		Basal area (m^2/ha)		Importance value (%)	
	1934	2002	1934	2002	1934	2002
Acer spp.	6.7 (1.5)	28.5 (5.8)*	0.02 (0.004)	0.14 (0.032)*	2.1 (0.4)	3.8 (0.9)
Carpinus caroliniana	0.0 (0.0)	11.5 (3.8)*	0.00 (0.000)	0.05 (0.021)*	0.0 (0.0)	1.9 (0.5)*
Carya spp.	43.2 (3.9)	114.7 (11.8)*	0.15 (0.014)	0.68 (0.069)*	17.5 (1.6)	21.3 (1.8)
Castanea ozarkensis	15.7 (3.2)	2.7 (1.1)*	0.06 (0.012)	0.02 (0.011)	5.3 (0.8)	0.5 (0.2)*
Cornus florida	42.2 (5.8)	121.6 (11.7)*	0.13 (0.018)	0.44 (0.044)*	14.1 (1.3)	17.8 (1.6)
Fraxinus spp.	2.2 (0.5)	15.0 (3.2)*	0.01 (0.003)	0.08 (0.017)*	1.8 (0.4)	2.8 (0.6)
Juniperus virginiana	1.6 (0.6)	33.9 (7.9)*	0.01 (0.003)	0.18 (0.047)*	1.0 (0.5)	3.3 (0.8)
Liquidambar styraciflua	5.8 (1.4)	14.6 (3.3)	0.02 (0.005)	0.09 (0.021)*	2.3 (0.5)	2.8 (0.7)
Nyssa sylvatica	1.3 (0.4)	42.3 (6.2)*	0.01 (0.002)	0.20 (0.032)*	0.6 (0.2)	6.0 (0.9)*
Ostrya virginiana	0.0 (0.0)	51.6 (7.1)*	0.00 (0.000)	0.19 (0.032)*	0.0 (0.0)	6.8 (1.0)*
Pinus echinata	13.1 (3.3)	68.5 (13.6)*	0.08 (0.015)	0.45 (0.088)*	9.2 (1.4)	6.3 (1.0)
Quercus alba	43.6 (4.8)	42.3 (6.0)	0.14 (0.014)	0.32 (0.046)*	18.1 (1.4)	8.7 (1.3)*
Quercus stellata	5.5 (1.5)	5.8 (2.6)	0.03 (0.006)	0.04 (0.017)	4.5 (1.1)	0.6 (0.3)*
Quercus velutina	47.5 (5.0)	20.0 (5.4)*	0.19 (0.019)	0.11 (0.028)	18.9 (1.3)	1.8 (0.4)*
Other oak group[a]	0.6 (0.2)	25.8 (5.8)*	<0.01 (0.001)	0.15 (0.031)*	0.5 (0.2)	3.3 (0.7)*
Robinia pseudoacacia	2.3 (1.1)	0.4 (0.4)	0.01 (0.005)	<0.01 (0.003)	0.6 (0.2)	<0.1 (<0.1)*
Sassafras albidum	6.8 (1.7)	43.9 (9.5)*	0.02 (0.009)	0.26 (0.045)*	2.7 (0.7)	6.4 (1.0)*
Ulmus spp.	0.0 (0.0)	11.5 (2.6)*	0.00 (0.000)	0.06 (0.015)*	0.0 (0.0)	1.7 (0.4)*
Other species[b]	1.9 (0.6)	33.1 (5.4)*	0.01 (0.003)	0.14 (0.024)*	0.9 (0.4)	4.3 (0.7)*
Total	240.0 (17.0)	687.5 (36.5)*	0.89 (0.056)	3.60 (0.182)*	100.0 (0.0)	100.0 (0.0)

An asterisk indicates the 95% confidence intervals in 1934 and 2002 do not overlap; no asterisk means overlap occurs.
[a] Other oak group includes *Quercus marilandica*, *Q. muehlenbergii*, *Q. shumardii*, *Q. rubra*, and *Q. falcata*.
[b] Other species includes *Acer negundo*, *Aesculus pavia*, *Amelanchier arborea*, *Asimina triloba*, *Bumelia lanuginosa*, *Celtis occidentalis*, *Cercis canadensis*, *Crataegus* spp., *Diospyros virginiana*, *Frangula caroliniana*, *Hamamelis vernalis*, *Juglans nigra*, *Lindera benzoin*, *Magnolia acuminata*, *Morus rubra*, *Platanus occidentalis*, *Prunus serotina*, *Ptelea trifoliata*, *Tilia americana*, *Vaccinium* spp., and *Viburnum rufidulum*.

reverse-J diameter distributions in 1934, but irregular and rather flat distributions had developed by 2002, because of a decline in density of the smaller DBH classes. For black oak, the density of the medium and larger DBH classes was similar in 1934 and 2002. In contrast, white oak displayed large density increases in 2002 especially in the medium DBH classes. The other oak group was virtually non-existent across all DBH classes in 1934, but it displayed a pronounced bimodal distribution in 2002 with peaks at 8 and 30 cm DBH. Shortleaf pine displayed an irregular distribution in 1934 with peaks at 5 and 30 cm

Table 2
Mean density, basal area, and importance value for the midstory stratum in 1934 and 2002 on the Sylamore Experimental Forest (standard error in parentheses)

Species or species group	Density (trees/ha)		Basal area (m^2/ha)		Importance value (%)	
	1934	2002	1934	2002	1934	2002
Acer spp.	0.3 (0.1)	5.0 (1.2)*	0.01 (0.002)	0.14 (0.034)*	0.7 (0.3)	2.5 (0.6)*
Carya spp.	7.2 (0.6)	24.2 (2.2)*	0.20 (0.017)	0.67 (0.066)*	15.8 (1.3)	15.4 (1.5)
C. ozarkensis	1.9 (0.3)	0.8 (0.7)	0.05 (0.008)	0.02 (0.017)	3.6 (0.6)	0.3 (0.2)*
C. florida	0.4 (0.1)	1.6 (0.4)*	0.01 (0.003)	0.03 (0.009)*	0.8 (0.2)	0.8 (0.2)
Fraxinus spp.	1.3 (0.3)	5.2 (1.1)*	0.03 (0.007)	0.15 (0.031)*	2.5 (0.5)	3.1 (0.6)
J. virginiana	0.3 (0.2)	6.9 (1.9)*	0.01 (0.004)	0.17 (0.046)*	0.7 (0.3)	3.4 (0.8)*
L. styraciflua	1.0 (0.1)	10.4 (2.3)*	0.03 (0.005)	0.30 (0.068)*	2.8 (0.5)	5.5 (1.0)
N. sylvatica	1.3 (0.2)	4.0 (0.8)*	0.04 (0.006)	0.11 (0.022)*	2.5 (0.4)	2.3 (0.5)
P. echinata	10.7 (1.3)	44.3 (6.9)*	0.31 (0.037)	1.26 (0.192)*	19.5 (2.1)	15.1 (1.8)
P. serotina	0.1 (0.1)	2.1 (0.7)*	<0.01 (0.002)	0.06 (0.019)*	0.3 (0.2)	1.2 (0.4)
Q. alba	7.1 (0.6)	44.4 (3.6)*	0.19 (0.016)	1.31 (0.107)*	13.8 (1.1)	26.1 (1.9)*
Q. stellata	2.6 (0.4)	2.3 (0.9)	0.07 (0.012)	0.06 (0.025)	6.0 (1.1)	1.0 (0.4)*
Q. velutina	15.4 (1.3)	15.7 (2.4)	0.44 (0.036)	0.48 (0.071)	27.0 (1.6)	7.8 (1.1)*
Other oak group[a]	0.9 (0.2)	15.2 (1.8)*	0.02 (0.006)	0.47 (0.057)*	1.6 (0.4)	9.1 (1.1)*
S. albidum	0.1 (0.1)	5.8 (1.2)*	<0.01 (0.002)	0.13 (0.027)*	0.3 (0.2)	3.3 (0.6)*
Other species[b]	0.7 (0.1)	6.0 (1.2)*	0.02 (0.004)	0.16 (0.031)*	1.9 (0.4)	3.2 (0.6)
Total	51.3 (2.2)	194.0 (7.6)*	1.43 (0.061)	5.53 (0.213)*	100.0 (0.0)	100.0 (0.0)

An asterisk indicates the 95% confidence intervals in 1934 and 2002 do not overlap; no asterisk means overlap occurs.
[a] Other oak group includes *Q. marilandica*, *Q. muehlenbergii*, *Q. shumardii*, *Q. rubra*, and *Q. falcata*.
[b] Other species includes *A. arborea*, *C. canadensis*, *D. virginiana*, *J. nigra*, *M. acuminata*, *M. rubra*, *O. virginiana*, *R. pseudoacacia*, *T. americana*, and *Ulmus* spp.

Table 3
Mean density, basal area, and importance value for the overstory stratum in 1934 and 2002 on the Sylamore Experimental Forest (standard error in parentheses)

Species or species group	Density (trees/ha)		Basal area (m^2/ha)		Importance value (%)	
	1934	2002	1934	2002	1934	2002
Acer spp.	0.2 (0.1)	0.9 (0.4)	0.01 (0.005)	0.07 (0.031)	0.3 (0.1)	0.7 (0.3)
Carya spp.	5.2 (0.6)	8.4 (1.3)	0.39 (0.045)	0.58 (0.094)	6.3 (0.6)	5.0 (0.8)
C. ozarkensis	0.9 (0.2)	0.2 (0.2)	0.07 (0.016)	0.01 (0.013)	1.0 (0.2)	0.5 (0.5)
Fraxinus spp.	0.7 (0.1)	5.0 (1.2)*	0.06 (0.015)	0.50 (0.115)*	1.0 (0.2)	3.6 (0.7)*
J. virginiana	0.2 (0.1)	0.9 (0.3)	0.01 (0.005)	0.06 (0.020)	0.4 (0.3)	0.9 (0.4)
L. styraciflua	2.1 (0.3)	6.5 (1.5)*	0.27 (0.041)	0.63 (0.146)	3.9 (0.7)	4.7 (1.0)
N. sylvatica	2.8 (0.3)	1.7 (0.5)	0.30 (0.037)	0.23 (0.076)	3.8 (0.4)	1.2 (0.4)*
P. echinata	20.8 (2.4)	31.9 (3.9)	1.87 (0.206)	3.20 (0.391)*	24.6 (2.2)	21.1 (2.2)
P. serotina	<0.1 (<0.1)	0.7 (0.3)	<0.01 (0.001)	0.05 (0.028)	0.1 (0.1)	0.3 (0.2)
Q. alba	13.4 (0.8)	44.9 (3.5)*	1.69 (0.118)	4.28 (0.318)*	22.1 (1.3)	29.3 (2.0)*
Q. stellata	2.0 (0.4)	1.8 (0.6)	0.16 (0.031)	0.14 (0.047)	3.5 (0.8)	2.1 (0.8)
Q. velutina	22.9 (1.4)	17.3 (2.4)	2.22 (0.139)	1.45 (0.204)*	30.2 (1.5)	10.2 (1.3)*
Other oak group[a]	1.5 (0.4)	26.9 (2.9)*	0.13 (0.034)	2.81 (0.313)*	2.3 (0.6)	18.2 (1.8)*
S. albidum	0.1 (<0.1)	1.0 (0.4)*	0.01 (0.007)	0.09 (0.036)	0.1 (0.1)	0.8 (0.3)
Other species[b]	0.3 (0.1)	2.0 (0.6)*	0.03 (0.010)	0.15 (0.047)*	0.4 (0.1)	1.3 (0.4)
Total	73.0 (2.6)	150.2 (5.2)*	7.23 (0.250)	14.25 (0.530)*	100.0 (0.0)	100.0 (0.0)

An asterisk indicates the 95% confidence intervals in 1934 and 2002 do not overlap; no asterisk means overlap occurs.
[a] Other oak group includes *Q. marilandica*, *Q. muehlenbergii*, *Q. shumardii*, *Q. rubra*, and *Q. falcata*.
[b] Other species includes *J. nigra*, *P. occidentalis*, *R. pseudoacacia*, *T. americana*, and *Ulmus* spp.

DBH, but density in 2002 showed a fairly steady decline with increasing DBH classes. Pine density was about the same in 1934 and 2002 for the 25- to 35-cm DBH classes; for both larger and smaller DBH classes, density in 2002 exceeded that in 1934. Hickory and the other species group, which represent the most shade-tolerant species in this forest community, displayed reverse-J distributions in 1934. This distribution pattern was retained in 2002, although the density was considerably greater for nearly all DBH classes.

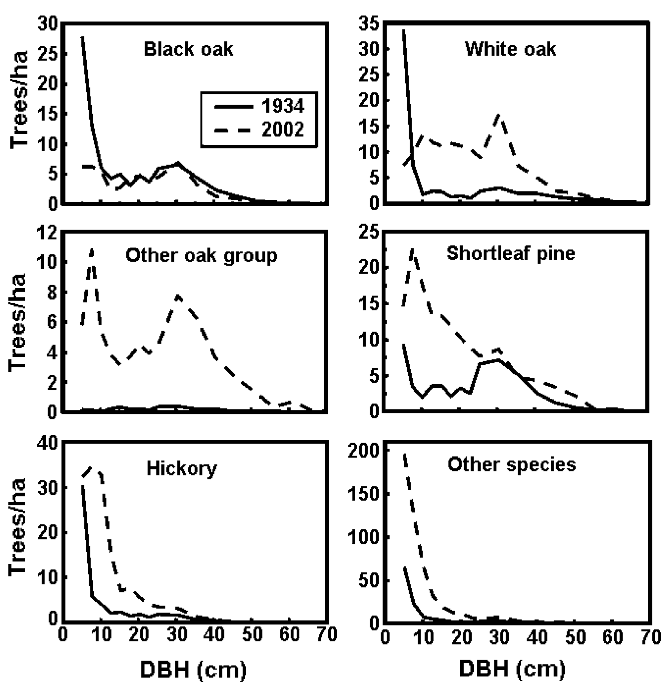

Fig. 2. Diameter distributions for black oak, other oak group, white oak, hickory, shortleaf pine, and all other species in 1934 and 2002 on the Sylamore Experimental Forest in northern Arkansas (see Table 1 footnote for species in other oak group).

4.5. Cull trees

Overall, 3% of the midstory trees in 1934 and 15% of the overstory trees were classified as being culls. Type of defect was unspecified for about two-thirds of the cull trees. Fire scarring was the most common reason recorded by field crews for classifying trees as culls, and it was indicated as being the cause for 26% of the midstory culls and 18% of the overstory culls. Being hollow or decayed was the second most common type of recorded damage, accounting for 5% of the midstory culls and 8% of the overstory culls. Being classified as a cull also differed greatly among species; for example, the percentage of overstory trees that were classified as being culls follows for selected species: blackgum (*Nyssa sylvatica* Marsh.) 48, sweetgum (*Liquidambar styraciflua* L.) 42, chinkapin 30, post oak (*Quercus stellata* Wangenh.) 24, white oak 20, black oak 19, hickory 15, and shortleaf pine 1%.

5. Discussion

Tree density and basal area were considerably greater on the SEF in 2002 than in 1934. Including all strata, density increased from 364 to 1032 trees/ha and basal area rose from 10 to 23 m^2/ha. Other investigators in northern Arkansas have reported similar results. Foti (2004) used General Land Office (GLO) surveyors' notes of the original land survey of the Ozark Mountains from 1818 to the 1850s to quantify the structure of pre-European settlement forests. He found that pre-settlement Ozark forests were more open than today, with an average tree density of 128 trees/ha. Thirty-four to 60% of section corners were located in prairies, savannas, or open savannas. Anderson et al. (2003) also used GLO notes to estimate that presettlement tree density in the Ozarks ranged from 94 to 188 trees/ha, and noted that current densities range from 741 to 2471 trees/ha.

A change in disturbance regime is most likely responsible for the changes observed on the SEF over the past 70 years. There is growing evidence that forests in the region have burned frequently and repeatedly for at least several centuries. Fire-scar analysis indicates that Native Americans during the 1600s, 1700s, and early 1800s burned the Arkansas and Missouri Ozarks at intervals of 3–18 years (Guyette and Cutter, 1991, 1997; Cutter and Guyette, 1994; Guyette and Spetich, 2003). Fires remained frequent following European settlement of the Ozarks beginning in the 1820s. Engbring (2005) dated fire scars on shortleaf pine to reconstruct the fire history of the SEF. From 1820 to 1900, the SEF burned at intervals of 1–13 years with a median fire interval of 2 years. Fires were especially frequent from 1850 to 1887, and the 1860s were marked by near annual burning.

Timber harvesting in the Ozarks reached its peak in the early 1900s, and harvests were often followed by fires (Bass, 1981). Consistent with this, Soucy et al. (2005) dated tree rings and fire scars from six mature oak stands in the vicinity of the SEF and observed repeated disturbances and fires from 1900 to the 1930s. Fires on the SEF continued during the early 1900s. Engbring (2005) reported a median fire interval of 2 years on the SEF from 1901 to 1930, when fires burned every 1–4 years. The high percentage of fire-scarred and hollow cull trees in the 1934 inventory of the SEF also indicates a history of frequent fires.

In the early 1900s, initial attempts to prevent and suppress forest fires on the Ozark National Forest were generally unsuccessful (Bruner, 1930; Koen, 1939). However, public education and a growing appreciation of the National Forest, as well as improved roads and communications, helped fire prevention to be successful by the 1930s (McGuire, 1941; Strausberg and Hough, 1997; Soucy et al., 2005). Effective fire prevention was reflected in the SEF fire chronology. From 1925 to 1960, there was an abrupt decrease in fire frequency on the SEF (Engbring, 2005). Later, fire frequency sharply increased during 1960–1975, perhaps resulting from local opposition to changes in Forest Service grazing policies (Strausberg and Hough, 1997). In addition, fire scars from six wildfires and two prescribed burns were recorded on the SEF between 1982 and 2002.

This abundance of historical evidence indicates that in 1934, the SEF had been frequently burned for at least 100 years and perhaps longer. These repeated fires limited the establishment and recruitment of new stems and resulted in a forest having a relatively low density and basal area. In fact, the structure of the forest in 1934 represents a point slightly above C-line stocking (50% stocking) on Gingrich's (1967) upland oak stand density diagram. Fire prevention beginning in the 1920s and 1930s and continuing to 1960 created conditions conducive for tree establishment and recruitment and resulted in the current stand structure. The forest in 2002 is precisely at A-line stocking (100%) on the oak stand density diagram.

Overstory and midstory strata on the SEF in 1934 were dominated by oaks and shortleaf pine. A long period of frequent fire would have favored these taxa due to their biological adaptations to fire, including ability to germinate on burned-over mineral soil, sprouting ability, thick bark, and resistance to rotting after scarring (Lawson, 1990; Van Lear and Watt, 1993). In contrast, periodic fire would have discriminated against thin barked, fire-intolerant species such as red maple (*Acer rubrum* L.), flowering dogwood, black cherry (*Prunus serotina* Ehrh.), and blackgum (Abrams, 1992). Species having a low resistance to fire were relatively uncommon on the SEF in 1934, and many stems of these species were either hollow or had fire scars.

Almost every species increased in density and basal area from 1934 to 2002. Although oaks and shortleaf pine were the most important overstory and midstory species in both inventories, by 2002 shade-tolerant and fire-intolerant species, such as red maple, blackgum, dogwood, and eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), had become increasingly important in the understory. In fact, these and other species surpassed understory oaks in importance. Shade-tolerant species have an important advantage over oaks because they can make significant height growth under a closed canopy where they increase in both size and number until a nearly continuous subcanopy or a multi-storied layer of vegetation develops (Lorimer, 1993). Such shaded conditions do not favor the establishment and recruitment of oaks and pine, which are intolerant or intermediate in shade tolerance (Abrams and Downs, 1990; Abrams, 1992). The silvicultural key to recruiting both oak and pine reproduction involves maintaining the stand's stocking to ecologically acceptable levels (Baker et al., 1996; Larsen et al., 1999). The total basal area of all canopy positions was about 10 m^2/ha in 1934, which is only slightly below the recommended after-cut level of 11 m^2/ha for upland oak stands under uneven-aged silviculture in the Ozarks (Larsen et al., 1999). This low stocking level would have been favorable to the development of existing reproduction and the establishment of new reproduction. However, in 2002 total basal area was 23 m^2/ha, which far exceeded the maximum recommended level of 17 m^2/ha at the end of an uneven-aged cutting cycle (Larsen et al., 1999). The high stocking level in 2002 would have suppressed the establishment and development of all reproduction expect the most shade-tolerant species.

However, the replacement of oaks and pine in lower canopy positions by shade-tolerant, fire-intolerant species was far from complete. Although understory oaks and pine decreased in importance since 1934, 94 oaks/ha and 68 pine/ha occurred in the understory in 2002. Furthermore, the midstory in 2002 included 78 oaks/ha and 44 pine/ha. This suggests that some individuals of these species have successfully established and recruited after the 1930s, and will remain important on the SEF in the future.

Yet how could fire- and disturbance-adapted oaks and pine persist under conditions of fire suppression? There are several possible explanations. First, the SEF has not been free of timber harvesting since 1934. Improvement cuts and regeneration harvests during the 1930s, 1940s, and 1950s (Lawson, 1961) would have reduced stocking and might have created environmental conditions favorable for oaks and pine.

Second, while fire suppression on the SEF was successfully implemented in the 1920s and 1930s, the forest has not been completely fire-free since then (Engbring, 2005). Effective fire suppression was reflected in the relatively low number of fires recorded between 1925 and 1960 and in the dramatic increase in tree densities. Since 1960, however, the forest has again burned, especially from 1960 to 1975. Fires during this period would probably have stimulated oak and pine establishment and recruitment. Yet the intensity and/or frequency of these fires were apparently not so high as to eliminate fire-intolerant species.

A third explanation for the continued importance of oaks and pine in lower canopy positions involves site conditions. The SEF includes a landscape of various topographic positions and aspects. In general, oak and pine regeneration is more competitive on drier sites such as ridgetops and south- and west-facing slopes (Johnson et al., 2002). In fact, data from the SEF indicate that oaks and pines are the most important species on ridgetops and drier aspects, but are less important in hollows and on north- and east-facing slopes (Heitzman et al., 2006). Consequently, the rugged topography and often xeric conditions of northern Arkansas in general and the SEF in particular may facilitate the continued development of an oak-pine forest, even in the absence of large-scale disturbances.

Although most species increased in density and basal area between inventories, there was a pronounced decrease in black oak density throughout all canopy positions. This decline was not anticipated, and contrasts with the general pattern of white oak and other oaks. Speculatively, the decrease in black oak may involve a combination of silvical factors. Black oak is less shade tolerant than white oak, sprouts less than northern red oak, and is shorter-lived than either species (Sander, 1990). Also, harvesting on the SEF from the 1930s to the 1950s may have discriminated against black oak and favored northern red and white oak.

There was also a marked decrease in importance of Ozark chinkapin. This can be largely explained by the chestnut blight fungus (*Cryphonectria parasitica* (Murrill) Barr.), which was introduced into the United States about 1900 via imported Asiatic chestnut seedlings. By 1940, the spread of this fungus had nearly eliminated the American chestnut (*Castanea dentata* (Marsh.) Borkh.), but also affected Ozark chinkapin, though not as severely (Edmonds et al., 2000). Fire suppression may also be involved in the decline of this species because chinkapin is able to recover from fire and other disturbances by sprouting (Campbell et al., 1991).

6. Conclusions

In 1934, the SEF was representative of forests in the Ozark Mountains. It had been burned frequently for at least 100 years; was dominated by oaks, shortleaf pine, and hickory; and was understocked. Ozark chinkapin was a common understory species. In 2002, decades of fire suppression resulted in a vastly different forest structure. Tree density had nearly tripled and basal area had more than doubled. Although the SEF remained an oak-pine-hickory forest, fire-sensitive non-oaks had increased in importance especially in the understory. Chestnut blight had virtually eliminated chinkapin. Archival data allowed us to quantify long-term changes in forest structure and to better understand the impacts of a changing disturbance regime over the past 70 years.

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