Prescribed Fire Affects Eastern White Pine Recruitment and Survival on Eastern Kentucky Ridgetops

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ABSTRACT: *Successful fire prevention and suppression efforts during the past 50 yr have resulted in the proliferation of eastern white pine (*Pinus strobus *L.) in the understory of oak-pine forests on the Cumberland Plateau. Along with red maple (*Acer rubrum *L.), increasing density of eastern white pine in these forests signals a change in plant species composition from species adapted to periodic surface fires, such as oaks (*Quercus *spp.) and yellow pines (*P. echinata *Miller and* P. rigida *Miller), to species adapted to longer fire-free intervals. In the Daniel Boone National Forest (DBNF) in eastern Kentucky, the USDA Forest Service has reintroduced fire to these ridgetop ecosystems. In March 1995 and March 1996, single prescribed fires were conducted on three different ridgetops in the Red River Gorge of the DBNF. Diameter and age of white pine stems were recorded prior to burning, two growing seasons post-burn (for 1995 and 1996 fires), and three growing seasons post-burn (for 1995 fires only). Nearly all white pine less than 2.0 cm dbh were killed after a single prescribed fire, and significant mortality (*$P < 0.05$*) was measured in size classes up to 6 cm dbh. Post-burn regeneration of white pine, however, was abundant at each site. Therefore, a single prescribed burn affected the age structure of white pine but will not have an important influence on long-term species composition of these stands. A fire return interval of at least 10 to 20 yr will be required to control white pine competition with fire-adapted species on the ridgetop ecosystems of the DBNF. South. J. Appl. For. 23(3): 144–150.*

Changes in fire regime and the loss of American chestnut (*Castanea dentata* (Marshall) Borkh.) are affecting forest composition in the Southern Appalachians (McCormick and Platt 1980, Arends and McCormick 1987, Lorimer 1993). Native Americans and early European settlers used fire (Pyne 1982, Delcourt and Delcourt 1987), and charcoal and pollen analyses suggest aboriginal use of fire in the Cumberland Plateau as long as 3000 yr B.P. (Delcourt and Delcourt 1997). Periodic fire maintained an upland forest composition of woody species such as pines (*Pinus rigida* Miller and *P. echinata* Miller), oaks (*Quercus* spp.) and American chestnut, and prevented tree species adapted to long fire-free intervals from becoming important in the overstory (Delcourt and Delcourt 1997). Organized forest fire protection began in the late 1930s in national forests (Pyne 1982), diminishing the role of fire on these lands. In the Daniel Boone National Forest (DBNF) in eastern Kentucky, fire-tolerant species have declined over the last 200 yr, and fire-sensitive species such as red maple (*Acer rubrum* L.) have increased (Delcourt and Delcourt 1997, Martin 1989). On oak-pine ridgetops in some parts of the DBNF, eastern white pine (*P. strobus* L.) regeneration has become more prevalent (Wehner 1991).

Eastern white pine extends from southern Canada through the Lake States and the northeastern United States, southward along the Appalachian Mountains to northern Georgia. Outlying populations also occur in eastern Kentucky (Wendel and Smith 1990). In the Clifty Wilderness Area of the Red River Gorge, white pine has been historically important on lower south-facing and upper north-facing slopes (Braun 1950, Wehner 1991). However, with fire suppression and openings created by partial cutting during the 1950–1970s, eastern white pine has become established in abundance on upland sites (Wehner 1991).

Intermediate in shade tolerance, white pine may grow in height at maximum rates in as little as 45% sunlight (Wendel and Smith 1990). White pine seedlings grow slowly the first 5 yr and then begin to develop longer

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leaders (McRae et al. 1994). Holla and Knowles (1988) report a mortality of 64% in the first 10 yr, but stems that reach 30 yr old may live 100 yr.

The ecological relationships between fire and white pine are complex. Fire effects on white pine are strongly related to size and age class distribution at the time of the fire. Prescribed fire is often used for seedbed preparation and competition control in white pine stands (Clinton et al. 1993, McRae et al. 1994). Periodic burning often results in new waves of seedling establishment (Holla and Knowles 1988). Young white pines have relatively thin bark and are susceptible to fire (Wendel and Smith 1990). As a consequence, fires occurring more frequently than once per decade could prevent white pine regeneration (Trotta 1980). Fires that damage white pine trees may lead to mortality for several years following a burn (Wendel and Smith 1990). Mature white pine trees are resistant to fire because of their thick bark (Hengst and Dawson 1994).

The USDA Forest Service has been using prescribed fire in the Red River Gorge Geological Area for nearly a decade to restore the role of fire to ridgetop ecosystems. White pine has become established on ridgetops since fire suppression and is therefore useful as an indicator of time since fire. White pine has thus become a focus for determining the success of prescribed fires. For Forest Service managers in the Stanton Ranger District, mortality of most white pine less than 3 m tall provides a first measure of the effectiveness of prescribed fires (Richardson 1995). However, there has been no documentation of the effects of this prescribed burning program on white pine mortality and subsequent establishment. Our study sought to understand the effects of prescribed fire on understory white pine in oak-pine ridgetop ecosystems. Our objectives were to measure the effects of a single prescribed fire on white pine mortality and seedling establishment.

Methods

Site Description

The DBNF Stanton Ranger District includes the Red River Gorge Geological Area which is located in the Cliff Section of the Cumberland Plateau (Braun 1950). The geological substrate is composed of shales and siltstones of the Upper and Lower members of the Breathitt Formation and the Corbin Sandstone of the Lee Formation (Weir and Richards 1974). Permanent study plots are located on three noncontiguous ridgetops in Powell, Wolfe, and Menifee counties: Whittleton, Pinch-Em-Tight, and Klaber Ridges. Whittleton Ridge has soils of the subgroup Typic Hapludult and composed of Gilpin silt loam, a moderately deep, well drained soil with a lower subsoil of silty clay loam (Hayes 1993). Klaber Ridge has the subgroups Typic and Aquic Hapludults, and are classified as Latham-Shelocta silt loam, moderately deep, moderately well drained, slowly permeable clayey soils (Avers et al. 1974). Soils at Pinch-Em-Tight are Typic and Lithic Dystrochrepts, of Alticrest-Ramsey-Rock outcrop complex, moderately deep and shallow, well drained with surface layer and subsoil of sandy loam (SCS 1975, Hayes 1993). Pinch-Em-Tight soils are the most well drained and acidic. The region has a temperate, humid and continental climate with an evenly distributed average annual precipitation of about 113 cm. Mean daily maximum and minimum temperatures in January are 6°C and –6°C, and in July are 30°C and 17°C. Mean annual temperature is 12°C (Hill 1976).

Study plots are located in stands mostly dominated by scarlet oak (*Q. coccinea* Muench.) and chestnut oak (*Q. prinus* L.), with some white (*Q. alba* L.) and black oak (*Q. velutina* Lam.). Hard pines (*P. rigida* Miller, *P. virginiana* Miller, and *P. echinata* Miller) dominate the most xeric areas. Red maple is abundant in midstory to overstory positions. Sourwood (*Oxydendrum arboreum* [L.] DC), blackgum (*Nyssa sylvatica* Marshall) and dogwood (*Cornus florida* L.) are common in the understory. A few large eastern white pines occur in the overstory; white pine is plentiful as regeneration and at times dense in the understory and midstory. Larger white pine, and the seed source for the ridgetops, occur primarily on lower slopes. Heath shrubs, such as mountain laurel (*Kalmia latifolia* L.) and blueberry (*Vaccinium* spp.), are common throughout.

Experimental Design

In collaboration with USDA Forest Service personnel at the Stanton Ranger District, we selected three ridges for prescribed fire research in the winter of 1995. Each ridge was divided into three treatment areas: one burned in March 1995, one burned in March 1996, and one left as an unburned control. Treatment areas on Pinch-Em-Tight and Whittleton Ridges averaged 18 ha each; treatment areas on Klaber Ridge were larger and averaged 36 ha each. Study plots were located at random within each treatment area, with the condition that any location within 15 m of the slope break, a trail, or any human disturbance was rejected. We installed eight plots in each treatment except at Pinch-Em-Tight Ridge. That site is topographically narrow and traversed with trails and campsites, and we could fit only six plots per treatment. For the 1995 burn site, these plots were laid out systematically in a line, 30 m apart along the top of the ridge. The centers of all plots were permanently marked, and two trees in each plot were tagged and located (azimuth and distance to plot center) for future reference.

Fire Prescription

USDA Forest Service personnel of the Stanton Ranger District conducted the prescribed fires of 1995 and 1996. These were begun with drip torch by firing line from the highest point and the ridges first. Strips were pulled downslope into the wind from the ridges. Point-source and strip firing were used to increase intensity to acceptable levels if backing and flanking fires were not of sufficient intensity (>0.3 m flamelength). (Richardson 1995). The prescribed burns of 1995 and 1996 were all within prescription parameters.

The Pinch-Em-Tight Ridge 1995 burn began at approximately 11:00 a.m. on March 15, 1995, with air temperature of 20°C, relative humidity of 29%, and winds from the northeast at 0 to 1.6 km/hr. The Whittleton Ridge 1995 burn began at approximately 1:40 p.m. on March 15, 1995, with air temperature at 22°C, relative humidity of 29%, and winds from the north to northeast at 1.6 to 3.2 km/hr. The Klaber Ridge

1995 burn began approximately at 10:30 a.m. on March 17, 1995, with air temperature of 17°C, relative humidity of 46%, and winds from the north to northeast at 1.6-3.2 km/h. Fuel moisture was indicated by fuel sticks which were 11% moisture by weight for all three 1995 burns. Flame heights for the three burns were 0.3–0.9 m. (Richardson 1995)

On March 13, 1996, the Klaber Ridge 1996 burn began at approximately 3:17 p.m., and the Pinch-Em-Tight Ridge 1996 burn began at approximately 3:45 p.m. Air temperature was 18°C, relative humidity was 25%, winds were from the south at about 1.6–4.8 km/h. Fuel sticks were within parameters, and flame heights for both burns were 0.3–0.9 m. (Richardson 1996). A north or east wind direction was required to burn Whittleton Ridge to prevent smoke blowing over the adjacent highway. In 1996 we could not burn this ridge, and therefore have data only from the unburned and 1995 burned treatments.

We measured flame temperatures using six different Tempilac® temperature-sensitive paints (Cole et al. 1992) representing a range from 93°C to 576°C. A stripe of each paint was painted on 3 × 7 cm aluminum tags and vertically down 6 × 10 cm strips of mica. The aluminum tags were stapled to stakes made from saplings at heights of 15, 45, and 75 cm. The sapling stakes and the mica sheets were placed at 4 m from each plot center on north, south, east, and west bearings. The mica sheets were inserted into the ground to a depth of 9 cm below the surface of the litter. For the prescribed fires in this study, surface (where mica sheet met remaining forest floor) temperatures ranged from 316°C to 398°C in 1995, and from 204°C to 315°C in 1996. Temperatures 0.5 cm below the surface (within the Oe and Oa horizons) were in the 204–315°C range in 1995, and from 93–203°C in 1996. A few hot spots were recorded on Pinch-Em-Tight Ridge, possibly due to patches of mountain laurel. The spring of 1996 was wetter than that in 1995, and less litter burned in the 1996 fires.

White Pine Sampling

Within a 0.05 ha circular plot centered on each permanently installed plot, all white pine stems and new seedlings were counted and aged by counting branching whorls (Shaw 1914), and diameter at breast height (dbh) was measured for all white pine stems at least 2 cm dbh. Age estimates may be somewhat inexact, since even fairly small white pine stems may have lost a whorl or two and the nodes for dropped branches become imperceptible. Still, by using age-classes, these data allowed us to characterize age structure. Since we did not tag individual trees, some measurement error may have resulted in recording densities for different sampling dates. However, the magnitude of such error was small compared to the very large differences in white pine densities measured before and after burning (see below). For the 1995 burns, we gathered data in February 1995 (pre-burn), in August 1996 (late in the second growing season post-burn), and in September 1997 (after the third growing season post-burn). We measured the 1996 burn areas in July 1995 (pre-burn), and in September 1997, two growing seasons after burning. New seedlings that established after the fire (based on age determination) were tallied separately and excluded from post-burn mortality calculations. Percent mortality was calculated as:

$$\% \text{ mortality} = [1 - (\text{stems post-burn}/\text{stems pre-burn})]*100.$$

Diameters of all tree species at least 2.0 cm were measured in a 0.01 ha circular plot centered on each permanently marked plot. These were used to characterize the vegetation composition of the treatment areas. The relationship between diameter and height was determined from 90 eastern white pine trees sampled on the three ridges since the Forest Service defines objectives for mortality by height.

Statistical Analysis

Using the JMP® statistical package (SAS Institute 1995), the nonparametric Wilcoxon signed-rank test for paired samples was conducted on plot density differences between two sampling dates within each treatment. We used a significance of $P < 0.05$ to test the null hypothesis that the mean density difference between sampling dates within a treatment equaled zero. We tested differences in densities from pre-burn to two growing seasons post-burn for the unburned, 1995 and 1996 burn sites, and for pre-burn and three growing seasons post-burn for the unburned and the 1995 burn sites. Because of high variability in white pine density among ridges, we analyzed the data using plots within ridge as the experimental unit ($n = 8$ for Klaber and Whittleton Ridges, $n = 6$ for Pinch-Em-Tight Ridge). This resulted in a pseudo-replicated analytical design (Hurlburt 1984).

Results and Discussion

Species Composition and Stand Structure

Oaks dominated the overstories (stems ≥ 10 cm dbh) of the three ridges, with densities of 52 to 67% of the total stems, and basal areas of 54 to 78% of the total (Table 1). Differences in overstory species composition among the three study areas were primarily because Klaber Ridge had a higher density and basal area of red maple, and Pinch-Em-Tight had a higher density and basal area of hard pine species. Eastern white pine was a minor component of the overstory throughout (densities 3–5% of the total; Table 1).

Whereas the overstory was dominated by oaks, the midstory (2–10 cm dbh) was dominated by red maple and white pine. On Klaber and Whittleton Ridges, red maple dominated the density and basal area of trees 2.0–10.0 cm dbh (Table 1). On Pinch-Em-Tight Ridge, eastern white pine and red maple together dominated stand density and basal area in the midstory. No red oaks (*Q. coccinea* Muench. or *Q. velutina* Lam.), or hard pines between 2.0 and 9.9 cm dbh were found on Klaber and Whittleton Ridges; on Pinch-Em-Tight, these species were represented in low numbers. The dominance of red maple and white pine in the midstory suggests that with longer fire-free intervals, these forests will become increasingly dominated by red maple (Swan 1970, Lorimer 1984) and white pine (Wehner 1991).

Density and Age Distribution of Eastern White Pine

The density of eastern white pine was quite variable among ridges and even among treatment areas within a ridge.

Table 1. Density (stems/ha) and basal area (m^2/ha) of live trees prior to prescribed burning on Pinch-Em-Tight, Klaber, and Whittleton Ridges, Daniel Boone National Forest, Kentucky.

	Pinch-Em-Tight		Klaber		Whittleton	
	Density	BA	Density	BA	Density	BA
	(at least 10.0 cm dbh)					
Species						
Acer rubrum	94	1.5	164	3.0	87	1.7
Quercus spp.[1]	107	8.4	139	11.1	136	11.7
Quercus spp.[2]	220	7.3	215	7.6	279	10.0
Pinus spp.[3]	126	9.3	38	3.2	25	2.6
Pinus strobus	25	2.0	32	0.8	19	0.3
Other spp.[4]	50	0.6	44	1.6	74	1.7
Total	622	29.1	632	27	620	28.0
	(2.0–9.9 cm dbh)					
Acer rubrum	473	1.3	589	0.8	967	2.0
Cornus florida	92	0.3	202	0.2	101	0.3
Quercus spp.[1]	46	0.1	0	0.0	0	0.0
Quercus spp.[2]	61	0.2	47	0.1	43	0.2
Pinus spp.[3]	76	0.2	0	0.0	0	0.0
Pinus strobus	550	1.2	264	0.3	72	0.1
Other spp.[5]	260	0.7	450	0.6	274	0.5
Total	1,558	4.0	1,552	2.0	1,457	3.1

[1] *Quercus* spp. include *Q. coccinea* and *Q. velutina.*
[2] *Quercus* spp. include *Q. alba,* and *Q. prinus.*
[3] *Pinus* spp. include *P. echinata, P. rigida, P. virginiana.*
[4] Other spp. (≥ 10.0 cm dbh) include *Carya glabra, C. tomentosa, Magnolia acuminata, Nyssa sylvatica, Oxydendrum arboreum,* and *Tsuga canadensis.*
[5] Other spp. (2.0–9.9 cm dbh) include *Amelanchier arborea, Carya glabra, C. tomentosa, Ilex opaca, Kalmia latifolia, Magnolia acuminata, M. macrophylla, Nyssa sylvatica, Oxydendrum arboreum, Sassafras albidum,* and *Tsuga canadensis.*

Pinch-Em-Tight had a total of 2160 white pine stems/ha, and Whittleton Ridge had 353 stems/ha (Figure 1). Among the three treatment areas on Pinch-Em-Tight, the unburned area had more than 3000 white pine stems/ha less than 2.0 cm dbh compared to about 700 stems/ha for the other two treatment areas. For stems at least 2.0 cm dbh, the unburned treatment area had 1193 white pine stems/ha and a basal area of 4.1 m^2/ha. Still, the age structure for white pine was similar among the ridges. Altogether, 99% of white pine stems were less than 41 yr old, and 91% less than 31 yr old. The small and steady decline in stem density across the youngest four age-classes (1-31 yr old) suggests fairly even recruitment and low mortality of white pine during the past 30 yr.

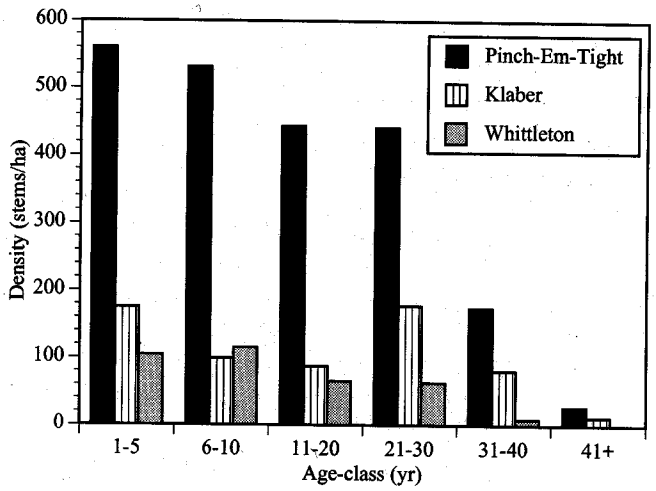

Figure 1. Mean density by age class of eastern white pine on all treatment areas on Pinch-Em-Tight, Klaber, and Whittleton Ridges in Daniel Boone National Forest, Kentucky.

Effects of Fire on White Pine Mortality

By the second growing season after the 1995 fires, we measured 82–90% mortality of all eastern white pine stems on the burned sites. Two growing seasons after the 1996 fires, we measured 72% mortality at both burned sites. Somewhat lower mortality after the 1996 burns may be due to lower fire temperatures compared to 1995.

Two growing seasons after the fires in both years, 95 to 100% of white pine stems less than 2.0 cm dbh had died (Table 2). White pine densities less than 2.0 cm dbh between pre-burn and post-burn sampling dates were significantly different for the burned sites ($P < 0.05$), and for the unburned site on Whittleton Ridge (19%; $P < 0.05$). While the 19% mortality on the unburned site was significant, it was still far below the mortality on the burned sites.

Sixty-nine to 88% of white pine 2.0–5.9 cm dbh died following the 1995 burns ($P < 0.05$), and 51–64% died following the 1996 burns ($P < 0.05$). We observed no mortality in the unburned areas for this diameter class for the same time period (Figure 2). For the 6–9.9 cm dbh class, 19–80% of the white pine had died two growing seasons after the 1995 fires (significant for Klaber, $P < 0.05$), compared to 6–32% after the 1996 fires ($P < 0.05$ for Klaber). In the unburned areas, 21% of this size class died at Whittleton between the 1995 and 1996 sampling dates ($P = 0.18$), and 18% at Klaber between the 1996 and 1997 sampling dates ($P = 0.11$). Some decreases in the 10–13.9 cm dbh class were due to movement into the next larger size class. White pines at least 14 cm dbh were not affected by the fires.

Three growing seasons after the 1995 fires, additional mortality was observed for the 2–5.9 and 6–9.9 cm dbh

Table 2. Density and mortality of eastern white pine less than 2.0 cm dbh on unburned, sites burned in 1995, and sites burned in 1996 on three ridgetops in the Daniel Boone National Forest, Kentucky.

	Burned 1995 plots[1]			Unburned 1995 plots[1]			Burned 1996 plots[2]			Unburned 1996 plots[2]		
Site	Pre-burn	Post-burn	Mortality (%)	Pre-burn	Post-burn	Mortality (%)	Pre-burn	Post-burn	Mortality (%)	Pre-burn	Post-burn	Mortality (%)
	····(stems/ha)····			····(stems/ha)····			····(stems/ha)····			····(stems/ha)····		
Pinch-Em-Tight	720	3	99.6	3,130	2,814	10	690	30	96	3,157	3,333	0
Klaber	425	3	99	573	607	0	263	5	98	755	645	15
Whittleton[3]	253	13	95	313	255	19	—	—	—	—	—	—

[1] The pre-burn sampling date was in January 1995. Prescribed fire was conducted on burned sites in March 1995. The post-burn sampling date was 2 growing seasons after fire on the burned sites in August 1996. Percent mortality excludes seedlings established after date of prescribed fires based on seedling age.

[2] The pre-burn sampling date was in July 1995. Prescribed fire was conducted on burned sites on March 13, 1996. The post-burn sampling date was 2 growing seasons after fire on the burned sites in September 1997. Percent mortality excludes seedlings established after date of prescribed fires based on seedling age.

[3] Due to adverse wind conditions, Whittleton Ridge was not burned in 1996.

classes on Whittleton (33%) and Klaber Ridges (36%) (Figure 2). Field observations of live tree vigor suggested that very little, if any, mortality would occur after the third growing season post-burn.

While young white pines have relatively thin bark and are susceptible to fire (Wendel and Smith 1990), white pines have increasing bark thickness with increasing dbh (Hengst and Dawson 1994). Apparently white pine stems at least 14 cm dbh are sufficiently mature to have developed fire-resistant bark. Stems at least 6.0 cm dbh have enough bark to resist heat to some degree (<74% mortality), but these trees made up only 5–12% of the white pine on these ridgetops. The majority of stems on these ridges fall into the less than 6 cm dbh classes. These size classes suffered high rates of fire-induced mortality.

We found a strong relationship ($r^2 = 0.92$, $P < 0.0001$) between white pine diameter and height:

$$Ht\ (\mathrm{m}) = 1.05 + 0.72 * dbh\ (\mathrm{cm})$$

The Forest Service prescribed fire management objectives determine success of the fires by the mortality of most white pine less than 3.0 m tall. Based on this regression, we estimate that 98% of trees less than 3.0 m tall (or 2.7 cm dbh) died following the 1995 fires, and 95% died following the 1996 fires.

We estimated a fire return interval needed to control white pine regeneration using stem mortality based on age-class combined across ridges. The 1995 fires caused 100% mortality in the 1–5 yr old age-class, 98% mortality in the 6–10 and 11–20 yr old age-classes, and 76% mortality of the 21–30 yr old age-class. The 1996 fires caused 76% mortality in the 1–5 yr old age-class, greater than 95% mortality in the 6–10 and 11–20 yr old age-classes, and 76% mortality of white pine trees in the 21–30 yr age-class. White pine trees older than 31

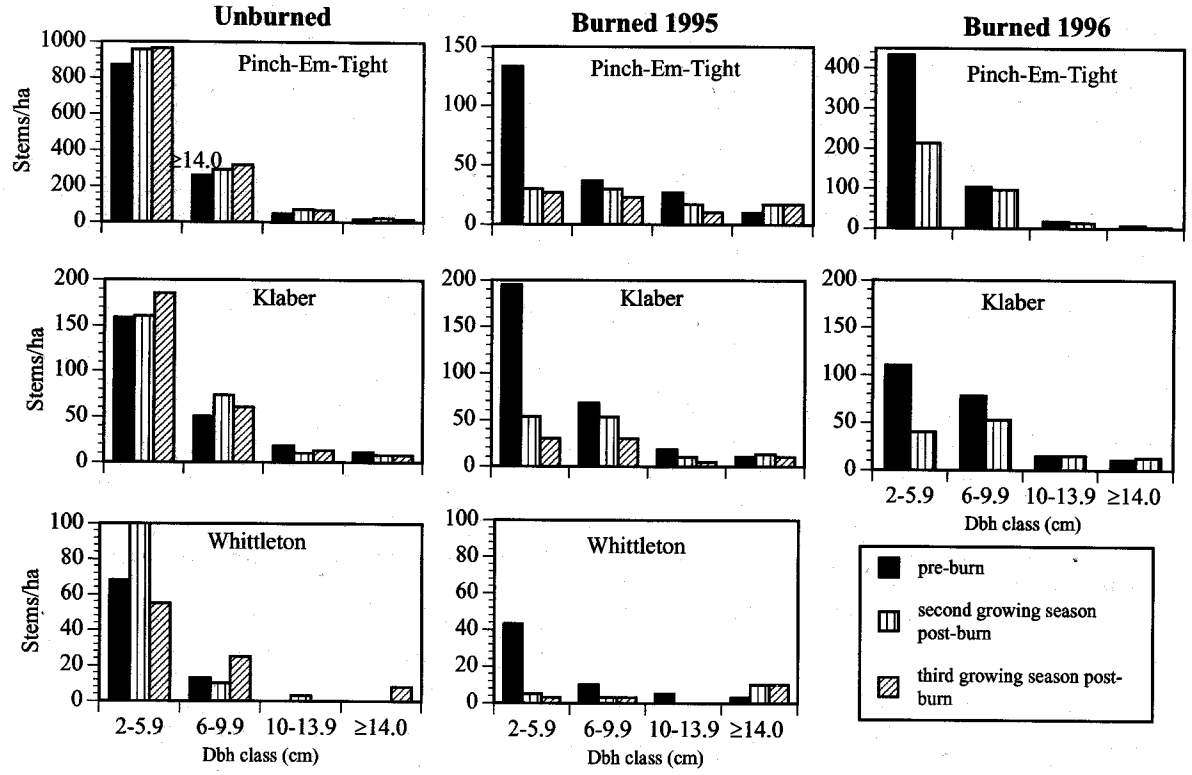

Figure 2. Mean density of eastern white pine by size class for stems at least 2.0 cm dbh on all treatment areas of three ridgetops in Daniel Boone National Forest, Kentucky. Note that for Pinch-Em-Tight Ridge, scales for y-axes differ for each treatment area to accommodate the high densities on the unburned site.

yr survived in both the 1995 and 1996 burn treatments. This suggests that a fire return interval of less than 20 yr would be necessary to control white pine in the understory. Trotta (1980) estimated a higher fire frequency of once per decade to prevent white pine regeneration. Because of white pine's ability to mature quickly, reduction of white pine in these stands may require a higher fire return interval than our data indicate.

Effects of Fire on White Pine Recruitment

The effect of the prescribed burns on white pine seedling recruitment depended partly on amount of seed fall. In 1996, two growing seasons after the 1995 burns, recruitment since the fires (1- and 2-yr-old seedlings) was lower on the burned sites than on the unburned sites for all ridges (Table 3). Since white pine seeds are dispersed in the fall (Wendel and Smith 1990), some buried seed at the burned sites may have been destroyed by the fires, and seed fall in 1995 may not have been good. A better seed year for white pine apparently occurred in 1996. In 1997, recruitment in the 1995 burned areas was greater than in 1996 for all ridges. Also, recruitment two growing seasons post-burn in the 1996 burned areas exceeded that for the 1995 burned areas (Table 3).

With a good seed fall, the prescribed fires apparently facilitated white pine seedling establishment. On Klaber and Whittleton Ridges in 1997, white pine recruitment on the 1995 burned areas was much higher than on the unburned areas (Table 3). We measured greater recruitment on the Pinch-Em-Tight control area than the burned areas in 1996 and 1997, but this reflected the strong seed source and higher density of stems. Prescribed burning for white pine seedbed preparation in other forest types aims at removing much of the forest floor L and F layers (McRae et al. 1994). In this study, prescribed fires burned only the uppermost layer of litter; in most areas some litter and the entire organic horizon remained intact (unpublished data). Still, it appears that a combination of even minimal seedbed preparation and a good seed year promoted white pine recruitment. Since the positive effect of fire persisted into the third growing season after the 1995 burns, the fires also likely contributed to a light environment favorable to white pine seedling establishment. In measuring white pine recruitment we did observe some hard pine sprouting, but very few hard pine seedlings. The low number of hard pine seedlings could be due in part to a higher light requirement for germination or establishment, which would not be achieved without opening the canopy more.

Management Implications

A single prescribed fire in this forest type nearly removed fire-intolerant white pine trees from the understory and midstory. Fire achieved Forest Service objectives in killing most white pine trees less than 3 m tall. However, periodic prescribed fires will be needed to maintain the effect and to encourage fire-tolerant species such as oaks and hard pines. Studies of oak regeneration indicate that repeated fires help to control competing vegetation, promoting oak establishment and growth (Thor and Nichols 1974, Nyland et al. 1983,Van Lear and Waldrop 1989). Our data show that while some oak seedlings become established on these ridgetops, few reach the shrub stratum (Arthur et al. 1998). In addition to white pine, increasing abundance of red maple since fire suppression (Delcourt and Delcourt 1997) competes with oak species on these ridges. With red maple's ability to sprout following a disturbance such as fire, we have found that repeated fire is necessary to reduce red maple competition with other fire adapted species (Arthur et al. 1998). Olson and Weyrick (1987) reported that repeated fires were necessary to promote white pine regeneration in New Hampshire, but burning one stand six times in 7 yr eliminated almost all white pine saplings and poles. On ridgetops in the Red River Gorge Geological Area, control of dense eastern white pine regeneration would help to maintain oaks and other fire-tolerant species. Long-term study of how fire affects stand composition should clarify appropriate fire return intervals in terms of increasing the proportion of oaks and hard pines on these sites and reducing the importance of white pine.

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Table 3. Density of new white pine seedlings established after March 1995 and March 1996 prescribed burns on all treatment areas of three ridgetops in the Daniel Boone National Forest, Kentucky.

	Unburned		Burned 1995		Burned 1996	
Site	1996[1]	1997[2]	1996	1997	1996	1997
	(seedlings/ha)					
Pinch-Em-Tight	343	2,140	33	87	—	107
Klaber	148	233	20	413	—	113
Whittleton	60	55	5	105	—	—

[1] 1996 densities include 1 and 2 yr old seedlings for unburned and burned 1995 treatments.
[2] 1997 densities include 1, 2, and 3 yr old seedlings for unburned and burned 1995 treatments and 1 and 2 yr old seedlings for the burned 1996 treatments.

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