RESEARCH ARTICLE

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Response of Understory Vegetation and Tree Regeneration to a Single Prescribed Fire in Oak-Pine Forests

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ABSTRACT: Successful fire exclusion since the 1940s has contributed to shifts in understory species composition in oak-pine forest communities in the Cumberland Plateau of Kentucky, USA, exemplified by a lack of oak (*Quercus* L.) regeneration and an increase in regeneration of fire-sensitive species. On ridgetop sites in Daniel Boone National Forest, the U.S. Forest Service is using prescribed fire to maintain oak-pine communities, a management practice that could also affect understory species composition and richness. We examined the four-year effects of a single, late-winter prescribed fire on understory vegetation and tree regeneration. There was a nonsignificant trend of increased species richness in burned areas, mostly due to an elevated number of herbaceous species. There were no significant effects of fire on herb and shrub cover. Higher densities of oak, yellow-poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum* L.) seedlings in burned areas occurred only in the second growing season after fire. Total sprouting, especially of red maple and flowering dogwood (*Cornus florida* L.), was higher for two growing seasons following fire. Fire promoted regeneration by fire-tolerant and fire-intolerant species alike. The use of prescribed fire to maintain density of fire-tolerant tree species and reduce proliferation of fire-intolerant tree species will probably require more frequent fires, higher intensity fires, or both.

Respuesta de la Hojarasca de a Vegetación y Regeneración de Árboles a un Único Fuego Recetado en los Bosque de Oak-Pine

RESUMEN: La exitosa exclusión del fuego desde 1940 ha contribuido a los cambios en la composición de hojarasca específica en las comunidades de bosques de oak-pine en Cumberland Plateau de Kentucky, USA, ejemplificado con una falta de regeneración de *Quercus* L. y un aumento en la regeneración de plantas sensibles al fuego. En los sitios de cumbres en el Bosque Nacional Daniel Boone, el Servicio de Bosques de USA está usando el fuego recetado para mantener las comunidades de oak-pine, una práctica de manejo que podría también afectar la composición específica y riqueza de la hojarasca. Examinamos los efectos de cuatro años de quema simple, al final del invierno, en la regeneración de hojarasca de vegetación y de los árboles. Hubo una tendencia no significativa a aumentar la riqueza de especies en las áreas quemadas, mayormente debido a un elevado número de especies herbáceas. No hubo efectos significativos del fuego en la cobertura de hierbas y arbustos. Mayores densidades de plántulas de *Quercus* L., *Liriodendron tulipifera* L., y *Acer rubrum* L. en las áreas quemadas sólo ocurrieron en la segunda temporada después del fuego. Los rebrotes totales, especialmente de *Acer rubrum* L. y *Cornus florida* L. fue mayor en dos temporadas después del fuego. El fuego promovió la regeneración de especies tolerante e intolerantes al fuego de igual manera. El uso de fuego recetado para mantener la densidad de especies de árboles tolerantes al fuego y reducir la proliferación de especies intolerantes probablemente requerirá más fuegos frecuentes, mayor intensidad de fuego o ambos.

Index terms: oak-pine forest, oak regeneration, prescribed burning, species richness, understory vegetation

INTRODUCTION

Many factors have affected species composition in southern Appalachian forests since their development approximately 9000 years BP, including the changes in climate following glacial retreat and activities by both prehistoric and Euro-American humans (Delcourt and Delcourt 1993). Fire played an important role in Native American daily life as a tool for hunting, farming, land clearing, and cooking (Pyne et al. 1996). Approximately 200 years ago, European settlers began clearing land for agriculture (Pyne et al. 1996). Heavy logging was prevalent between 1880 and 1930 (Clark 1984), and fire regimes were altered (Van Lear and Waldrop 1989). Disturbance by Euro-Americans, especially the use of fire, initially maintained forests dominated by fire-tolerant and fire-adapted species (Martin 1989). In the 1930s, chestnut blight (*Endothia parasitica* Murr.) was introduced, decimating American chestnut (*Castanea dentata* [Marshall] Borkh.), which comprised up to 40% of the forest overstory (Keever 1953). Also in the early 1930s, the U.S. Forest Service adopted and implemented a program of total fire exclusion; as a result, species composition began to shift to more fire-sensitive species (Martin 1989, Delcourt and Delcourt 1998) and species such as red maple (*Acer rubrum* L.), sassafras (*Sassafras albidum* [Nutt.] Nees), basswood (*Tilia americana* L.), and beech (*Fagus grandifolia* Ehrh.) became established in the forest midstory (Delcourt and Delcourt 1998), while oak (*Quercus* L.) regeneration declined (Lorimer 1992).

It has been suggested that fire may play an important role in maintaining oak forests because the decline of fire-tolerant oak species apparently coincides with effective fire exclusion (Lorimer 1992). Oaks have several characteristics that increase survival following fire, such as thick bark, resistance to rot after scarring, and the ability of seedlings and saplings to resprout repeatedly after burning (Abrams 1992, Watt et al. 1993). When fire is excluded, a dense understory of fire-intolerant species develops, which can "outcompete" oaks and may lead to increased acorn and seedling predation (Lorimer 1992, Van Lear 1992, Watt et al. 1993). Because oaks are generally shade intolerant and are notably poor competitors, oak species experience low survival in closed understory conditions (Abrams 1992, Lorimer 1992).

Changes in ridgetop forest species composition in the Cumberland Plateau in eastern Kentucky, USA, have occurred after many years of active fire exclusion by the U.S. Forest Service. Fire-sensitive species are increasingly prevalent, and fire-tolerant species are not regenerating (Martin 1989, Wehner 1991, Arthur et al. 1998). In Daniel Boone National Forest (DBNF), the regeneration of fire-sensitive species, most notably red maple and blackgum (*Nyssa sylvatica* Marshall), has been favored over regeneration of the oaks (white oak, *Quercus alba* L.; scarlet oak, *Q. coccinea* Muenchh.; chestnut oak, *Q. prinus* L.; and black oak, *Q. velutina* Lam.) and the hard pines (shortleaf pine, *Pinus echinata* Miller; pitch pine, *P. rigida* Miller; and Virginia pine, *P. virginiana* Miller) (Martin 1989). Eastern white pine (*P. strobus* L.), a species historically important on lower south-facing and upper north-facing slopes, has become common on upland sites as well (Wehner 1991).

In the Stanton Ranger District of DBNF in eastern Kentucky, the primary objective of the U.S. Forest Service fire prescription program is to restore fire to the ridgetop ecosystem to maintain native, fire-tolerant species (Richardson 1995). Mortality of eastern white pine and eastern hemlock (*Tsuga canadensis* [L.] Carriere) seedlings and saplings < 3 m tall was the initial measure used by the Forest Service to determine if fire prescription objectives were being met, which they were (Blankenship and Arthur 1999). Understanding the more subtle effects of fire on the herbaceous and shrub communities and on tree regeneration, particularly of oaks, is the current focus of research and management.

The objective of this study was to examine the four-year understory vegetation response to a single, late-winter, low-intensity fire by documenting (1) changes in understory species richness, composition, and coverage, and (2) the regeneration of tree seedlings, especially the effects of fire on oak versus red maple regeneration.

METHODS

Site Description

This study was conducted in the Red River Gorge Geological Area of DBNF in eastern Kentucky, an area Braun (1950) in-

Table 1. Basal area (m^2 ha^{-1}) and percent total density (stems ha^{-1}) of tree species that comprise the 0 – <2 cm dbh, ≥2 – <10 cm dbh, and ≥10 cm dbh size classes on all sites in Daniel Boone National Forest, Kentucky, before burning in 1995. "Other" category contains species that make up less than 5% of the total density when added together.

	0 – < 2 cm dbh	≥ 2 – < 10 cm dbh		≥ 10 cm dbh	
Species	Density (%)	Density (%)	Basal Area (m^2/ ha)	Density (%)	Basal Area (m^2/ ha)
Acer rubrum L.	22	42	1.59	17	1.86
Cornus florida L.	17	10	0.36	0	0
Nyssa sylvatica Marshall	10	9	0.17	1	0.76
Oxydendrum arboreum (L.) DC	1	6	0.30	5	0.37
Pinus L. spp.	2[a]	2[b]	0.06	10[a]	3.64
Pinus strobus L.	7	23	0.71	6	1.44
Quercus alba L.	1	1	0.07	6	2.16
Quercus coccinea Muenchh.	3	1	0.01	19	10.26
Quercus prinus L.	6	3	0.16	30	6.00
Quercus velutina Lam.	0	0	0	2	1.21
Sassafras albidum (Nutt.) Nees	28	1	0.03	1	0.04
Other	3[c]	2[d]	0.08	3[e]	0.51
Total stems/ha	**16,200**	**3060**		**1201**	
Total basal area			**3.54**		**28.25**

[a] Includes *Pinus echinata* Miller, *P. rigida* Miller, and *P. virginiana* Miller
[b] Includes *Pinus rigida* and *P. virginiana*
[c] Includes *Carya glabra* (Miller) Sweet, *Fagus grandifolia* Ehrh., *Ilex opaca* Aiton, *Juniperus virginiana* L., *Magnolia acuminata* (L.) L., *M. macrophylla* Michx., and *Tsuga canadensis* (L.) Carriere
[d] Includes *Carya glabra, C. tomentosa* (Poiret) Nutt., *Magnolia macrophylla,* and *Tsuga canadensis*
[e] Includes *Carya glabra, C. tomentosa,* and *Tsuga canadensis*

cluded in the Cliff Section of the Cumberland Plateau. Mean annual precipitation is approximately 113 cm and mean annual temperature is 12°C , with average daily maximum and minimum temperatures in January of 6°C and -6°C , and in July of 30°C and 17°C (Hill 1976). In late 1994, permanent study plots were located on three noncontiguous ridgetops selected for prescribed burning by the Stanton Ranger District of the U.S. Forest Service: Whittleton Ridge in Powell County, Pinch-Em-Tight Ridge in Wolfe County, and Klaber Ridge in Menifee County. The geologic substrate of the ridgetops consists of siltstones and shales of the Upper and Lower members of the Breathitt Formation, and the Corbin Sandstone (Weir and Richards 1974). Soils on Klaber and Whittleton Ridges are very similar, classified as Latham-Shelocta and Gilpin silt loams of the subgroups Typic and Aquic Hapludults (Avers et al. 1974, Hayes 1993). Soils at Pinch-Em-Tight Ridge are of Alticrest-Ramsey-Rock outcrop, in the subgroups Typic and Lithic Dystrochrepts (Hayes 1993). These soils encompass a range of drainage classes from deep and well drained to excessively drained.

The three ridgetops were similar in size and forest structure (Blankenship and Arthur 1999). Size ranged from 32 to 40 ha, including burned and reference areas. Stems ≥10 cm diameter (dbh) were dominated by scarlet and chestnut oak (Table 1). Red maple, hard pines, and eastern white pine (33% of stem density and 25% of basal area) were minor components of the overstory. In the 2–10 cm dbh stratum, red maple was the dominant species, along with eastern white pine. Scarlet and chestnut oak were minor components of this stratum (Table 1). In the understory (<2 cm dbh), red maple comprised 22%, sassafras 28%, flowering dogwood (*Cornus florida* L.) 17%, blackgum 10%, and oaks 10% of the stem density (Table 1). Ericaceous shrubs, including blueberry (*Vaccinium* L. spp.) and mountain laurel (*Kalmia latifolia* L.) were common in the forest understory (Blankenship and Arthur 1999).

In the past 20 years, neither management nor unplanned fire have taken place on the study sites (Jorge Hersel, U.S. Forest Service, Stanton, Ky., pers. com.). Natural disturbances in this region during that same period included ice storm and wind damage in the late 1990s. However, none of our study plots were affected by recent storm damage.

Fire Prescription

Prescribed fires were conducted by personnel of the Stanton Ranger District. All fires were started with a drip torch, firing the highest point on the ridgetops first, and lit in strips downslope into the wind from the ridgetops. Point-source and strip firing were used to increase intensity to acceptable levels if banking and flanking fires were not of sufficient intensity, defined as flame length < 0.3 m (Richardson 1995). The prescribed fires on each ridgetop were within prescription parameters.

Pinch-Em-Tight Ridge was burned 15 March 1995, with air temperature of 20°C, relative humidity of 29%, and winds from the northeast at 0–1.6 km h^{-1}. Whittleton Ridge was burned 15 March 1995, with air temperature of 22°C, relative humidity of 29%, and winds from the north to northeast at 1.6–3.2 km h^{-1}. Klaber Ridge was burned 17 March 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^{-1}. The prescribed fires were considered moderate-intensity burns with surface temperatures between 316°C and 398°C (Blankenship and Arthur 1999) and flame lengths between 0.3 and 1.2 m (Richardson 1995).

Vegetation Sampling

We conducted initial vegetation sampling on all sites in February 1995 prior to burning. To characterize the species composition of the sites, we identified all stems ≥2 cm dbh and recorded dbh within 0.01-ha circular plots. Understory vegetation was defined as all vegetation < 2 cm dbh; all stems < 2 cm dbh were identified within permanent 25 m^2 circular plots. Individual tree stems were counted in all plots. We visually estimated herbaceous and shrub species percent cover using the following cover classes: 0–1%, 1–2%, 2–5%, 5–10%, 10–15%, 15–25%, 25–50%, 50–75%, and 75–100%. The initial vegetation sampling was completed in February, before leaf-out of woody species and emergence of herbaceous species; therefore, no preburn cover data exist for herbaceous species.

We conducted postburn sampling in May and August of 1995 and 1996 for all sites. However, since species composition did not change from May to August, due to lack of early summer ephemerals, subsequent sampling was conducted in August of 1997 and 1998. The origin (sprout or seedling) of each stem (< 2 cm dbh) was noted starting in August 1995 and recorded on all subsequent sampling dates. We classified stems as sprouts only if they were obviously associated with a "parent" tree; this method results in inclusion of root sprouts in the seedling category. We estimated cover of tree species (<2 cm dbh) on the August 1997 and August 1998 sampling dates. Plant nomenclature follows Gleason and Cronquist (1991).

Statistical Analysis

Each ridgetop was divided into an area to be burned and an unburned reference area. Within each treatment area on each ridgetop, plot centers were located at random and permanently marked with rebar. On Klaber and Whittleton Ridges, eight permanent plots were located in each treatment area. Due to the narrowness of Pinch-Em-Tight Ridge, we were only able to place six permanent plots in each treatment area.

Species richness data were analyzed by repeated measures ANOVA using the MIXED procedure of SAS (SAS Institute 1995) with ridgetop (n=3) as the experimental unit. Midpoint values of each cover class were used in the analyses to compare treatment effects. All other data were analyzed as a randomized complete block design by repeated measures and subsampling using the MIXED procedure of SAS with ridgetop (n=3) as the experimental unit. This analysis allowed us to compare burned plots versus reference plots over time. When treatment-by-time interactions were significant, the LSMEANS statement in the MIXED procedure in SAS was used to test for significant main effects of treatment. To test for a significant interaction effect between ridgetop and treatment factors, the Tukey Test for Additivity was performed for each sample period on the average plot measurement (IML procedure of SAS). Since ridgetop-by-treatment interactions did occur for many of the species, we analyzed the data for each ridgetop separately using the MIXED procedure of SAS. In these analyses, we used plots within ridgetop (n=8 for Klaber and Whittleton Ridges, and n=6 for Pinch-Em-Tight Ridge) as the experimental unit, resulting in a pseudoreplicated analytical design (Hurlburt 1984). As suggested by van Mantgem et al. (2001) for improving statistical analysis in fire research, we incorporated time-series, before/after and impact/reference approaches in this study. Significance of statistical tests was evaluated at $P \leq 0.05$.

RESULTS

Species Composition and Richness

Species composition in the understory (<2 cm dbh) was similar for burned and reference areas (Table 2). However, there were a few species that, although uncommon, occurred on burned sites only: Virginia pine, pitch pine, winged sumac (*Rhus copallina* L.), strawberry-bush (*Euonymus americanus* L.), *Carex* L. spp., pink lady-slipper orchid (*Cypripedium acaule* Aiton), wild yam (*Dioscorea quaternata* [Walter] J. F. Gmelin), clovers (*Trifolium* L. spp.), Canada goldenrod (*Solidago canadensis* L.), and bracken fern (*Pteridium aquilinum* [L.] Kuhn).

Species composition fluctuated on burned and reference sites on all ridgetops over the course of the study. However, most tree species in the understory (stems < 2 cm dbh) that were present at a site before fire but absent in August 1995 had returned by August 1996, the second growing season after fire. Eastern hemlock stems < 2 cm dbh declined on burned sites on all three ridgetops and on the reference site on Pinch-Em-Tight Ridge for the duration of the study.

There was a trend toward higher species richness on burned than on reference sites,

Table 2. Vascular plant presence (all sampling dates combined) on burned (B95) and reference (R) sites on Klaber, Pinch-Em-Tight, and Whittleton Ridges in Daniel Boone National Forest, Kentucky. Prescribed burns were conducted in mid-March 1995.

	Klaber		Pinch-Em-Tight		Whittleton	
	R	B95	R	B95	R	B95
Trees						
Acer rubrum L.	X	X	X	X	X	X
Carya glabra (Miller)	X	X	X	X	X	X
C. tomentosa (Poiret) Nutt.	X	X		X	X	X
Castanea dentata (Marshall) Borkh					X	X
Cornus florida L.	X	X	X	X	X	X
Diospyros virginiana L.				X		
Fagus grandifolia Ehrh.		X	X		X	
Ilex opaca Aiton	X			X	X	X
Juniperus virginiana L.					X	
Liriodendron tulipifera L.	X	X	X	X	X	X
Magnolia acuminata (L.) L.					X	
M. macrophylla Michx.	X	X	X	X	X	X
Nyssa sylvatica Marshall	X	X	X	X	X	X
Oxydendrum arboreum (L.) DC	X	X		X	X	X
Pinus echinata Miller		X			X	X
P. rigida Miller				X		X
P. strobus L.	X	X	X	X	X	X
P. virginiana Miller		X		X		X
Quercus alba L.	X	X		X	X	X
Q. coccinea Muenchh.	X	X	X	X	X	X
Q. prinus L.	X	X	X	X	X	X
Q. velutina Lam.	X	X	X	X	X	X
Rhus copallina[a] L.		X				X
Sassafras albidum (Nutt.) Nees	X	X	X	X	X	X
Tsuga canadensis (L.) Carriere			X	X		X
Shrubs and Vines						
Amelanchier arborea[b] (Michx. F.) Fern.	X	X	X	X	X	X
Epigaea repens L.	X	X		X		
Euonymus americanus L.		X				X
Gaultheria procumbens L.	X	X	X	X	X	X
Gaylussacia baccata (Wangenh.) K. Koch	X	X	X			
Kalmia latifolia L.	X		X	X	X	X
Pyrularia pubera Michx.					X	
Rubus L., spp.	X	X		X		X
Smilax glauca Walter	X	X	X	X	X	X
S. rotundifolia L.	X	X	X	X	X	X
Vaccinium L. spp.	X	X	X	X	X	X
Viburnum acerifolium L.	X	X		X	X	X
Vitis vulpina L.	X	X		X		
Herbs						
Carex L. spp.				X		
Chimaphila maculata (L.) Pursh	X	X	X	X	X	X
Coreopsis major Walter	X			X		
Cypripedium acaule Aiton						X
Desmodium Desv. nom. conserv.	X	X		X	X	X

continued

Table 2, *continued*

	Klaber		Pinch-Em-Tight		Whittleton	
	R	B95	R	B95	R	B95
Dioscorea quaternata (Walter) J.F. Gmelin		X				
Euphorbia corollata L.			X	X		
Goodyera pubescens (Willd.) R. Br.	X					X
Iris verna L.				X		
Isotria verticillata (Willd.) Raf.					X	X
Lysimachia quadrifolia L.	X	X		X	X	X
Medeola virginiana L.	X					X
Mitchella repens L.		X	X			
Potentilla simplex Michx.	X	X		X		X
Panax quinquefolius L.	X					
Panicum L. spp.	X	X		X	X	X
Polygonatum biflorum (Walter) Elliott	X					X
Prenanthes altissima L.	X	X				
Pteridium aquilinum (L.) Kuhn		X		X		X
Scutellaria elliptica Muhl.	X					
Smilacina racemosa (L.) Desf.	X					X
Solidago canadensis L.		X		X		X
Thelypteris noveboracensis (L.) Nieuwl.		X				
Trifolium L. spp.		X		X		X
Vicia L. sp.		X				
Viola L. spp.	X	X		X	X	X
Uvularia perfoliata L.		X				

[a] Data were collected on *Rhus copallina* as if it were a tree, due to its single-stemmed growth form on these sites.

[b] Data were collected on *Amelanchier arborea* as if it were a shrub, due to its multi-stemmed growth form.

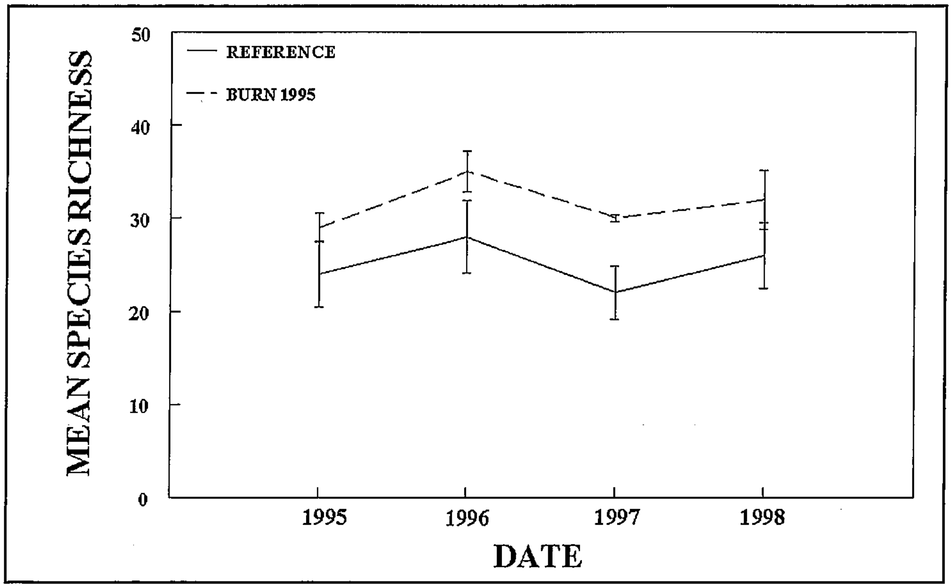

Figure 1. Mean (± SE) species richness for all three ridgetops in Daniel Boone National Forest, Kentucky, combined (n=3), for each of the postburn sampling dates. Sampling was conducted in August of each year. Preburn data are not included because the initial vegetation sampling was completed in February 1995, before the emergence of the herbaceous species.

but this trend was not significant (F=5.22, df=1, *P*=0.15 for 1995; F=14.30, df=1, *P*=0.063 for 1996; F=8.67, df=1, *P*=0.099 for 1997; and F=3.96, df=1, *P*=0.185 for 1998; Figure 1). For Pinch-Em-Tight and Whittleton Ridges, higher species richness on the burned sites was due predominantly to a greater number of herbaceous species, while for Klaber Ridge, it was due to an increase in tree species (Table 3). Changes in species richness for trees, shrubs, and vines occurred after the first growing season (August 1995) (Table 3).

Species Cover

Herbaceous species cover in both burned and reference areas on all three ridgetops was very low, ranging from <1% to 6%. There was a trend of higher herbaceous cover in the burned plots than in the reference plots, but these differences were not statistically significant (Table 4). We also analyzed each species separately. Only clovers, which had cover < 1%, showed a significant treatment effect with greater cover on burned sites than on reference sites (F=4.37, df=1, *P*=0.043).

No general trend in mean percent cover of shrub and vine species after fire was observed; cover on each ridgetop responded differently (Table 4), so the data were analyzed separately for each ridgetop. There were no significant differences in shrub and vine cover between burned and reference sites on Klaber and Whittleton Ridges (Table 4). On Pinch-Em-Tight Ridge, there was a significant treatment-by-time interaction (F=4.53, df=3, *P*=0.01) for the sum of shrub and vine species cover. In August 1996, the burned cover of shrub and vine species was 33.4%, significantly higher (F=9.96, df=1, *P*=0.007) than the shrub and vine cover on the reference site on Pinch-Em-Tight Ridge (7.8%; Table 4). Only one species showed a significant treatment effect across all ridges. Serviceberry (*Amelanchier arborea* [Michx. f.] Fern.) had a significantly higher cover in burned than in reference areas (F=6.29, df=1, *P*=0.016).

Cover data for tree seedlings was collected only in August 1997 and 1998. There was no significant treatment effect of fire on

Table 3. Species richness in the understory of the burned (B95) and reference sites (R) on each sampling date for Klaber, Pinch-Em-Tight, and Whittleton Ridges, Daniel Boone National Forest, Kentucky. Prescribed burns were conducted in mid-March 1995. Preburn data for trees and shrubs were collected in February 1995. All postburn sampling was conducted in August of each year.

	Preburn		1995		1996		1997		1998	
	R	B95	R	B95	R	B95	R	B95	R	B95
Klaber Ridge										
Trees	13	14	14	14	16	18	12	15	12	18
Shrubs and Vines	5	6	4	6	4	8	6	7	6	7
Herbs	—[a]	—	11	10	10	12	9	8	12	13
Total	**18**	**20**	**29**	**30**	**30**	**38**	**27**	**30**	**30**	**38**
Pinch-Em-Tight Ridge										
Trees	9	14	7	13	12	13	8	11	10	12
Shrubs and Vines	7	7	8	7	7	7	6	8	6	5
Herbs	—	—	2	6	1	11	3	10	3	11
Total	**16**	**21**	**17**	**26**	**20**	**31**	**17**	**29**	**19**	**28**
Whittleton Ridge										
Trees	16	12	15	13	20	18	12	15	16	13
Shrubs	6	8	6	8	7	9	6	8	7	8
Herbs	—	—	4	10	6	10	4	7	6	8
Total	**22**	**20**	**25**	**31**	**33**	**37**	**22**	**30**	**29**	**29**

[a] There are no preburn data for herbaceous species.

overall seedling cover. Seedlings of eastern white pine showed no significant treatment effects, but did show a significant treatment-by-time interaction for August 1997 (F=6.26, df=1, P=0.031). On this sampling date, eastern white pine seedling cover was higher in the reference (7%) than in the burned areas (0.1%).

Due to significant ridgetop-by-treatment interaction, analysis of sprout cover by ridgetop was warranted. Total cover of sprouts was significantly higher in burned than in reference areas on Klaber (F=4.94, df=1, P=0.043) and Whittleton Ridges (F=6.78, df=1, P=0.021). Although marginally nonsignificant, there was a trend of higher cover of sprouts on Pinch-Em-Tight Ridge as well (F=4.79, df=1, P=0.053). Sprout data were also analyzed by individual species. On Whittleton Ridge only, red maple showed a significant treatment effect (F=5.83, df=1, P=0.03), with higher cover in burned than in reference areas. No other individual species responses were found.

Tree Regeneration

There were no significant trends in the response of total tree seedling density to fire (Figure 2A). Tree seedling density increased in both burned and reference areas from August 1995 to August 1996, then declined from August 1996 to August 1997.

Oak seedlings had a similar response to fire on all ridgetops (there were no ridgetop-by-treatment interactions). Seedlings of all oak species were pooled and analyzed as a group because of low density. The completely randomized block analysis showed a significant treatment-by-time interaction for oaks (F=6.96, df=4, P=0.01) in August 1996, with higher mean density of oak seedlings in the burn than in the reference areas (F=28.82, df=1, P=0.0005) (Figure 2B).

Significant interactions between ridgetop and treatment for all other tree species required additional analysis by ridgetop for individual species. Only two species had significant treatment effects for seedling density. On Pinch-Em-Tight Ridge, red maple seedling density was significantly lower in the burned than in the reference areas (F=10.67, df=1, P=0.009). On Whittleton Ridge, yellow-poplar (*Liriodendron tulipifera* L.) seedling density was significantly higher in the burned than in the reference areas (F=5.72, df=1, P=0.031). Several species, while not having an overall treatment effect, showed a treatment-by-time interaction. On Klaber Ridge, sourwood (*Oxydendrum arboreum* [L.] DC; F=2.66, df=4, P=0.042) and yellow-poplar (F=3.50, df=4, P=0.013) had significant treatment-by-time interactions. Lower seedling density (300 stems ha^{-1}) of sourwood in the burned than in the reference areas (4800 stems ha^{-1}) was found in August 1996 on Klaber Ridge. Higher seedling density of yellow-poplar in the burned than in the reference areas was found in August 1995 (46,400 vs. 1,900 stems ha^{-1}) and 1996 (54,800 vs. 9,500 stems ha^{-1}). On Whittleton Ridge, red maple had a significant treatment-by-time interaction (F=4.12, df=4, P=0.005), with higher seedling density in the burned than in the reference areas in August 1997 (78,700 vs. 34,100 stems ha^{-1}) and 1998 (80,700 vs. 35,800 stems ha^{-1}). Differences in burn treatment effects on red maple seedling density between Whittleton and Pinch-Em-Tight Ridges reflect the very xeric nature of the Pinch-Em-Tight burn site and the lack of red maple seed trees in close proximity to this site.

There was significantly higher sprout density in the burned plots than in the reference plots using the randomized complete block analysis (F=75.82, df=1, P=0.001) (Figure 3). There was a marginally significant treatment-by-time interaction (F=3.62, df=3, P=0.045), with higher sprout density in the burned than in the reference areas in August 1995 (24,317 vs. 6000 stems ha^{-1}) and 1996 (54,028 vs. 13,298 stems ha^{-1}), but not in 1997 or 1998.

Sprout density of most species had signif-

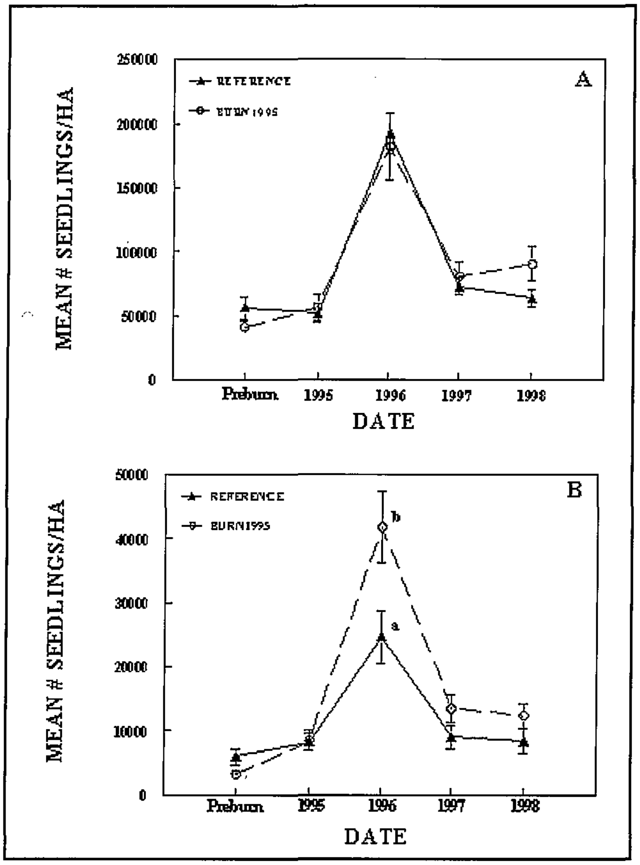

Figure 2. Mean density (± SE) of all tree seedlings (A) and oak seedlings (B) for all three ridgetops in Daniel Boone National Forest, Kentucky, combined (n=3). Preburn sampling was completed in February 1995; sampling in all other years was completed in August.

icant ridgetop-by-treatment interactions, warranting further analysis by ridgetop. Higher sprout densities of red maple were found on burned than on reference areas on Klaber (F=10.88, DF=1, P=0.0053) and Whittleton Ridges (F=10.5, df=1, *P*=0.006), but not on Pinch-Em-Tight Ridge (F=0.33, df=1, *P*=0.58). Flowering dogwood (F=2.84, DF=3, *P*=0.049) and sassafras (F=2.89, df=3, *P*=0.047) had marginally significant treatment-by-time interactions on Whittleton Ridge. In August 1996, there was higher flowering dogwood sprout density in the burned than the reference areas (F=9.82, df=1, *P*=0.003). In August 1998, there was lower sassafras sprout density in the burned than in the reference areas (F=10.82, df=1, *P*=0.002). No other differences in sprout density between burned and reference sites were found.

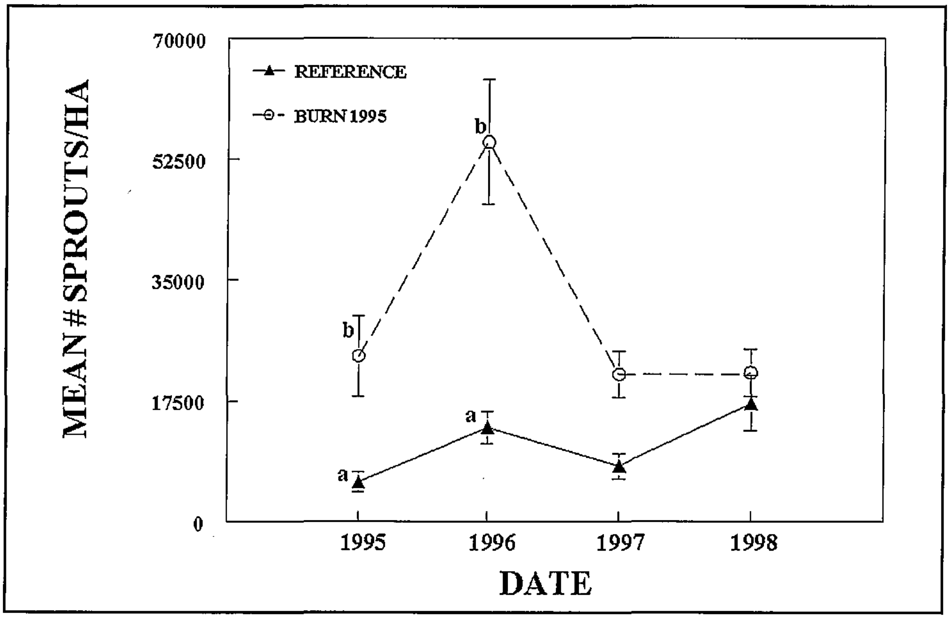

Figure 3. Mean density (± SE) of tree sprouts for all three ridgetops in Daniel Boone National Forest, Kentucky, combined (n=3). No preburn sampling was conducted for sprouts. Sampling in all years was completed in August.

DISCUSSION

Tree regeneration in both the herbaceous and shrub layers is an important component of the understory in these ridgetop communities. The herbaceous layer was also composed of various shrubs, most notably blueberry, and forbs. The shrub layer consisted of mostly tree regeneration, but blueberry, mountain laurel, and briar (*Smilax* L. spp.) were also present. Species richness of the ridgetop communities in this study was comparable to that of other studies in southern Appalachian forests (Arthur et al. 1998, Elliott et al. 1999), but diversity was lower in comparison to other forest ecosystems, such as mixed mesophytic (Hedman and Van Lear 1995, Huang 1995), Illinois oak-hickory (Wilhelm 1991), longleaf pine (Jacqmain et al. 1999), New York transition oak (McGee et al. 1995), and southeastern coastal plain forests (White et al. 1990).

Single fires often increase species richness, primarily of herbaceous species, with little or no change in shrub and vine species (Gilliam and Christensen 1986, McGee et al. 1995, Brockway and Lewis 1997). The lack of preburn data for the herbaceous species prevented us from comparing herbaceous species richness before and after burning. However, there was a trend of higher herbaceous species richness in burned sites compared to reference sites after the fire, whereas there was little or no change in shrub and vine species richness before and after fire. These results differ from those of Arthur et al. (1998) in this same region, where species richness was similar in burned and reference areas for herbaceous, vine, and shrub species two and four years after fire. Although a few species were absent in burned areas at the end of the study, fluctuations in the presence and absence of these species during the course of the study suggest that these species have not been permanently lost.

Overall, there was little change in species

Table 4. Mean total percent cover for trees, shrubs and vines, and herbs in the burned (B95) and reference (R) areas after the spring 1995 prescribed burn for Klaber, Pinch-Em-Tight, and Whittleton Ridges in Daniel Boone National Forest, Kentucky. Sampling was conducted in August 1995, 1996, 1997, and 1998 for shrub, vine, and herb species. Sampling for tree species was conducted only in August 1997 and 1998. n=8 for Klaber and Whittleton Ridges and n=6 for Pinch-Em-Tight Ridge.

	August 1995		August 1996		August 1997		August 1998	
	R	B95	R	B95	R	B95	R	B95
Klaber Ridge								
Seedlings					8.4	4.3	9.7	5.5
Sprouts					3.9	14.6	1.3	11.0
Total Trees					**12.3**	**18.9**	**11.0**	**16.5**
Shrubs and vines	6.3	3.3	13.6	10.3	5.3	7.3	3.1	5.3
Herbs	1.3	2.3	1.7	5.8	1.3	3.4	1.2	4.0
Total	**7.6**	**5.6**	**15.3**	**16.1**	**18.9**	**29.6**	**15.3**	**25.8**
Pinch-Em Tight Ridge								
Seedlings					10.3	6.2	2.5	9.9
Sprouts					1.8	9.3	2.3	9.1
Total Trees					**12.2**	**15.5**	**4.8**	**19.0**
Shrubs and vines	6.9	12.7	7.8	33.4	8.1	16.9	3.9	15.3
Herbs	0.2	1.7	0.1	6.0	0.2	3.1	0.2	3.0
Total	**7.1**	**14.1**	**7.9**	**39.4**	**20.5**	**35.5**	**8.9**	**37.3**
Whittleton Ridge								
Seedlings					20.5	8.9	5.1	5.0
Sprouts					0.4	21.4	3.1	34.2
Total Trees					**20.9**	**30.3**	**8.2**	**39.2**
Shrubs and vines	7.5	6.4	22.1	10.3	9.7	11.2	3.0	5.5
Herbs	0.4	0.9	1.6	2.1	0.4	0.9	0.4	1.1
Total	**7.9**	**7.3**	**23.7**	**12.4**	**31.0**	**42.4**	**11.6**	**45.8**

composition over the course of the study. This agrees with other studies conducted in areas where the understory is composed primarily of woody species (Van Lear and Waldrop 1989, Wade et al. 1989, Matlack et al. 1993, Ducey et al. 1996). Species composition in a forest dominated by woody species may change little following fire due to rapid sprouting, which can prevent colonization by other species. In particular, low-intensity fires similar to the fires in our study often have little effect on plant community composition (Van Lear and Waldrop 1989, McGee et al. 1995, Ducey et al. 1996). As fire frequency and intensity increase, composition shifts from shrubs and woody vegetation to herbs and grasses (Little and Moore 1949, Buell and Cantlon 1953, Hodgkins 1958, McGee et al. 1995). Thus, monitoring species composition on these sites as fire treatments are repeated will be an important aspect of ongoing monitoring activities.

Single fires may increase cover of herbaceous, shrub, and vine species (Waldrop and Lloyd 1990, Arthur et al. 1998). Although not statistically significant, there was a trend of higher herbaceous species cover in burned than in reference areas. Contrary to our expectations, shrub and vine species cover was not higher in burned compared to reference areas, except on Pinch-Em-Tight Ridge, where shrub cover, composed mainly of blueberry, was higher in burned areas. Shrub and vine cover fluctuated similarly on burned and reference areas on Klaber and Whittleton ridgetops during the four-year study, primarily due to fluctuations in blueberry cover in those areas.

Density of seedlings of most tree species increased in August 1996 in the burned and reference areas, indicating a good seed year. The high number of seedlings in 1996 on both burned and reference areas masked any effects of fire on total seedling density. Density of oak seedlings was higher on burned areas on all ridgetops in 1996, as were yellow-poplar seedling densities on Klaber and Whittleton Ridges for 1995 and 1996, and red maple seedling density on Whittleton Ridge for 1997 and 1998.

Failure of oaks to regenerate has been documented as a problem coincident with fire exclusion (Lorimer 1992), leading to speculation that fire may be an effective tool for promoting oak regeneration (Van Lear and Waldrop 1989, Watt et al. 1993, Abrams 1998). In our study, oak seedling densities were higher on burned sites in 1996, but there was a failure of seedlings to survive through 1997 on both burned and reference sites. The failure of shade-intolerant oak seedlings to survive on burned sites may be caused by minimal change in light conditions on the forest floor due to prolific sprouting and high sprout cover of shade-tolerant species, as well as the absence of any change in the canopy cover.

Total sprout density increased significantly in burned areas by August 1996 and then declined. In general, sprouting by red maple, flowering dogwood, hickories (*Carya* Nutt. spp.), blackgum, and sourwood was higher in burned than in reference areas in August 1996. While a single fire may increase oak regeneration (Van Lear 1992, Lorimer et al. 1994, Arthur et al. 1998, Brose and Van Lear 1998), fire may also increase regeneration of competing species, such as red maple (Van Lear 1992, Abrams 1998, Arthur et al. 1998) and yellow-poplar (Barnes and Van Lear 1998). Our data show a transient increase in oak regeneration after a single prescribed fire, but also regeneration of fast-growing oak competitors such as red maple and yellow-poplar.

Management Implications and Future Research

We found minor changes in species richness and composition in the four years following a single prescribed fire, and little or no changes in herb, vine, and shrub species cover. There were changes in the density of seedlings and tree sprouts, but these were found for both oak and fire-sensitive oak competitors. It has been postulated that a single fire may not be adequate to promote long-term survival of oak regeneration, due to poor competitive ability of oaks under shaded conditions and the increase of oak competitors in the regeneration pool (Abrams 1992, Lorimer et al. 1994, Moser et al. 1996). Our study supports this conclusion.

Fire frequency, intensity, and seasonal timing can have various impacts on tree sprouting ability and on stand structure and composition. Sprouting is generally increased by fire, but as fire frequency or intensity increases, the number of sprouts declines (Hodgkins 1958, Van Lear and Waldrop 1989, Waldrop and Lloyd 1990). If fires are frequent enough, they can arrest the hardwood understory by preventing sprouts from growing into larger size classes (Waldrop and Lloyd 1990, Van Lear 1992), creating structural change in the stand. Multiple burns (Watt et al. 1993, Arthur et al. 1998, Barnes and Van Lear 1998) and/or higher-intensity, growing-season burns (Van Lear 1992, Waldrop and Lloyd 1990, Brose et al. 1999) have been suggested as a means of promoting long-term regeneration of fire-tolerant species over fire-intolerant species. Conversely, sprouting may be more vigorous following periodic winter burns conducted every four to seven years when carbohydrate reserves have sufficient time to recover (Van Lear 1992).

A single burn creates temporary openings for oak regeneration, but if these openings are not maintained, seedlings fail to grow or they die. This is suggested by Figure 2, in which the 1996 increase in oak regeneration was followed by an almost equivalent decrease one year later. Multiple dormant-season burns, or burning in conjunction with periodic thinning, will undoubtedly be necessary to provide and maintain openings for shade-intolerant oaks to regenerate on these sites. Multiple burns may be the best management strategy to restore fire-adapted species on sites in DBNF where strict fire prescriptions and restrictions on climatic conditions limit the practicality of higher intensity fires and forest cutting has been curtailed.

As the use of prescribed fire by land managers increases, further studies will be necessary to determine the most effective return frequency of fire for the regeneration of fire-tolerant oaks, and for maintenance of those stands. Our study helps to establish that burning, at least a single burn, does not result in a loss of species; rather, burning appears to promote species richness.

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