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Vegetation dynamics after a prescribed fire in the southern Appalachians

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Abstract

In April 1995, the USDA Forest Service conducted a prescribed burn along with a south-facing slope of southern Appalachian watershed, Nantahala National Forest, western NC. Fire had been excluded for over 70 years and the purpose of the burn was to create a mosaic of fire intensities to restore a degraded pine/hardwood community and to stimulate forage production and promote oak regeneration along a hillslope gradient. Permanent plots were sampled at three locations along a gradient from 1500 to 1700 m. Plot locations corresponded to three community types: mesic, near-riparian cove (low slope); dry, mixed-oak (mid slope); and xeric, pine/hardwood (ridge). Before burning (1994–1995) and post-burn (summer, 1995 and summer, 1996) vegetation measurements were used to determine the effects of fire on the mortality and regeneration of overstory trees, understory shrubs, and herbaceous species. After the burn, mortality was highest (31%) at the ridge location, substantially reducing overstory (from 26.84 pre-burn to 19.05 $m^2 ha^{-1}$ post-burn) and understory shrub (from 6.52 pre-burn to 0.37 $m^2 ha^{-1}$ post-burn) basal area. At the mid-slope position, mortality was only 3%, and no mortality occurred at the low slope. Not surprisingly, percent mortality corresponded to the level of fire intensity. Basal area of *Kalmia latifolia*, *Gaylussacia baccata*, and *Vaccinium* spp. were substantially reduced after the fire, but density increased due to prolific sprouting. The prescribed fire had varying effects on species richness and diversity across the hillslope gradient. On the ridge, diversity was significantly increased in the understory and herb-layer, but decreased in the overstory. On the mid slope, no change was observed in the overstory, but diversity significantly decreased in the understory. On the low slope, no change was observed in the overstory or understory. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Historically, fire was an integral part of the disturbance regime of southern Appalachian forests and defined their natural structure and composition (Barden and Woods, 1976; Harmon, 1982; Buckner, 1989; van Lear and Waldrop, 1989; DeVivo, 1991; van Lear, 1991). The pre-colonial forests were disturbed by windstorms, floods, landslides, insect and disease epidemics, and American Indian- and lightning-caused fires. In particular, mixed pine/hardwood forest-types occupying dry ridge sites (primarily composed of *Pinus rigida* and *Quercus prinus* in the overstory and *Kalmia latifolia* in the understory) are

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thought to be highly dependent on high intensity fires for their maintenance (Barden and Woods, 1976). Fire suppression and the limited occurrence of intense natural fires in xeric pine/hardwood forests have promoted the dominance of hardwoods, and the pine component has been in a state of decline for about two decades (Smith, 1991; Vose et al., 1994). In addition, substantial drought-related insect infestations (primarily southern pine beetle (*Dendroctonus frontalis* Zimmermann)) (Hoffman and Anderson, 1945; Smith, 1991) and previous land practices, such as selective removal of high quality trees, have contributed to further degradation of these forests. The result is a significant increase in acreage of dense stands of *K. latifolia* on upper, drier slopes which provide competition to reproduction and growth of both woody and herbaceous vegetation.

The mixed-oak (*Quercus* spp.) stands that occupy mesic to dry-mesic forests at middle elevations are also undergoing considerable change. Oaks were a dominant feature of the southern Appalachians long before European settlement (Clark and Robinson, 1993), and throughout the entire region various species of oak remain major components of many forest-types (Nowacki and Abrams, 1992; Stephenson et al., 1993). These oak forests were established and historically maintained by a combination of natural and human-induced fires (Lorimer, 1984; Abrams and Nowacki, 1992). In the absence of fire, shade-tolerant species that were formerly confined to the understory, such as *Acer rubrum*, have become established and are recruiting into the overstory (Lorimer, 1985; Crow, 1988).

Fire has been prescribed as a silvicultural treatment in pine/hardwood forests in the southern Appalachians to restore diversity and productivity (Swift et al., 1993) and to promote regeneration of native pines (Vose et al., 1994; Vose et al., 1997). Fire reduces the abundance of *Kalmia latifolia* and delays its growth, encourages tree species such as oak to sprout (van Lear and Waldrop, 1989), and provides a seedbed for native pines to germinate and become established (Vose et al., 1994).

In April 1995, the USDA Forest Service conducted a prescribed burn along a south-facing slope in the Nantahala National Forest, western NC where fire had been excluded for over 70 years. The purpose of the burn was to create a mosaic of fire intensities to restore a degraded pine/hardwood community, to stimulate forage production, and to reduce the understory biomass of *Kalmia latifolia* and shade-tolerant hardwood tree species to promote pine and oak regeneration along the hillslope gradient. We hypothesized that (1) a high intensity burn along the ridge would simulate a wildfire that would produce seedbed conditions for pine seed germination and reduce *K. latifolia* to allow for seedling establishment (Vose et al., 1997); (2) a moderate intensity burn at mid slope would reduce *K. latifolia* density and promote forage production and oak regeneration; and (3) a low intensity, surface burn along the near-riparian low-slope position would promote regeneration of herb-layer species to increase diversity. The objectives of our research were to determine the effects of this fire on the mortality and regrowth of the overstory, understory, and herbaceous layer vegetation across a hillslope gradient from the mesic, near-riparian community to the xeric, ridge community.

2. Methods

2.1. Site description

The study area is located in the Nantahala National Forest of the southern Appalachian Mountains, western North Carolina (35°N latitude, 83°W longitude) and is part of the Wine Spring Creek Ecosystem Management Project (Swank et al., 1994). The wine Spring Creek watershed is within the Blue Ridge Mountain District of the Blue Ridge physiographic province. Three tributaries (Wine Spring Creek, Bearpen Creek, and Indian Camp Branch) converge to Wine Spring Creek which drains into Nantahala Lake at the western edge of the watershed boundary. The area has a southern aspect and elevations range from 1500 to 1700 m with slopes ranging from 35 to 60%. The soil-types along with the upper slope and ridge are fine-loamy, mixed, mesic Typic Hapludults (Edneyville Series) and loamy, mixed, mesic Lithic Dystrochrepts (Cleveland Series); and the soils along with the middle and lower slope positions are coarse–loamy to a loamy-skeletal, mixed, mesic Typic Haplumbrepts (Cullasaja Series) (Thomas, 1996). Mean annual temperature is 10.4°C and mean annual precipitation is 1900 mm (Swift, unpublished data).

The Wayah Ranger District, Nantahala National Forest, North Carolina prescribe burned the approximately 300 ha study area in April 1995. The fire was ignited by helicopter at the bottom of the south-facing slope near the stream and created a mosaic of fire intensities, ranging from lightly burned (<80°C) at the low slope to heavily burned (>800°C) along upper slopes and ridges (Vose et al., in review). On the ridge, the stand-replacing fire consumed understory vegetation and ignited the crowns in areas of highest fire intensity.

2.2. Experimental design

In July 1994, twelve 15 m×15 m plots were established along three parallel transects from the top of the ridge to the stream. Along each transect, three plots were located at about 80 m from the stream (low slope), three plots were located at about 140 m from the low-slope plots (mid slope), and six plots were located along the upper slope to ridge top at about 140 m from the mid-slope plots (ridge). Plot locations corresponded to three community-types: mesic, near-riparian cove (low slope); dry, mixed-oak (mid slope); and xeric, pine/hardwood (ridge). In March 1995, an additional twenty 10 m×10 m plots (six low slope, six mid slope, and eight ridge) were established along four parallel transects from the ridge to the stream. The 20 added plots and the 12 original plots were analyzed together as one population because plots were added to increase sample size and increase spatial coverage of the burned area.

2.3. Overstory and understory sampling

All plots were sampled at the time of plot establishment (i.e. July 1994 for the original plots and March 1995 for the additional plots) before the prescribed burn, and in July 1995 and July 1996 after the burn. Vegetation was measured by layer: the overstory layer included all trees ≥5.0 cm diameter at breast height (dbh, 1.37 m above ground); the understory layer included all woody stems <5.0 cm dbh and ≥1.0 cm basal diameter; the herb-layer included woody stems <1.0 cm basal diameter and all herbaceous species. Woody stems with <1.0 cm basal diameter were counted as seedlings regardless of the mode of reproduction (i.e. seedling or sprout origin).

Diameter of all overstory trees was measured to the nearest 0.1 cm and recorded by species in every plot. In the original plots, the understory layer was measured in the entire 15 m×15 m plot, with the exception of clonal shrubs (e.g. *Kalmia latifolia* and *Rhododendron calendulaceum*) which were measured in a 3.75 m×3.75 m subplot in the southwest corner of each 15 m×15 m plot. In the added plots, the understory layer (including *K. latifolia*, *Rhododendron maximum*, and *R. calendulaceum*) was measured in a 3.0 m×3.0 m subplot located in the southwest corner of each 10 m×10 m plot. In the understory layer, basal diameter of trees and shrubs was measured to the nearest 0.1 cm and recorded by species.

2.4. Herb-layer sampling

Only the original six ridge plots were used in the analyses to compare pre-burn 1994 to post-burn 1995 and 1996. Although all original plots were sampled for herb-layer species in pre-burn 1994 and resampled in 1995, only the six ridge plots were resampled in 1996. Since the herb-layer quadrats of the additional plots were only measured in 1995 and 1996, they were not used to compare pre-burn and post-burn herb-layer response. Percent cover of herb-layer species was estimated visually by cover classes in six 1.0 m^2 quadrats placed in the corners and at the midpoint of the eastern and western sides of each 15 m×15 m plot. The seven cover classes used were: R (0–0.5%), 1 (0.5–1%), 2 (1–3%), 3 (3–15%), 4 (15–33%), 5 (34–66%), and 6 (>66%). Midpoint values of each cover class were used in the analyses to compare pre-burn and post-burn effects.

Tree seedling abundance was estimated for all the original and additional plots. Tree seedlings were counted in each 1.0 m^2 quadrat of the original plots and in the 3.0 m×3.0 m subplots of the additional plots. All species nomenclature follows Radford et al. (1968).

2.5. Data analysis

We used several indices – species richness (S), Shannon–Weiner's index of diversity (H'), and Pielou (1966) evenness index (J') – to evaluate the change in vegetation diversity pre-burn 1994 to post-burn 1995 and 1996. Shannon–Weiner's index is a simple quantitative expression that incorporates both species richness and the evenness of species abundance. Since the calculated value of H' alone fails to show the degree that each factor contributes to diversity, we calculated a separate measure of species evenness (J'). Species diversity was calculated as: $H'=-\sum p_i \ln(p_i)$, where p_i=proportion of total abundance of species i, with abundance of woody species=stem density (stems ha^{-1}) or basal area ($m^2\ ha^{-1}$); and abundance of herbaceous species=percent cover. Species evenness was calculated as: $J' = H'/H'_{max}$, where H'_{max}=maximum level of diversity possible within a given population=ln(S). We used pairwise t-tests (Magurran, 1988) to examine the differences in H' between sampling years 1994–1996.

3. Results

3.1. Overstory

On the ridge, *Pinus rigida*, *Quercus prinus*, and *Quercus coccinea* were the most abundant species in the overstory, comprising 64% of the density and 74% of the basal area in 1994 (Table 1). After burning, these three species continued to dominate the overstory stratum with 70% of the density and 61% of the basal area. Mortality ranged between 18.5% and 30.6% (Table 2). High mortality significantly reduced overall overstory density and basal area after the fire. Species richness (S), density-based H', and basal area-based H' significantly decreased after the fire.

On the mid slope and low slope, no significant differences in overall average overstory density or basal area were found between pre- and post-burn sampling dates (Table 1). In addition, no differences in species richness (S), density-based H', or basal area-based H' were detected on the mid-slope or low-slope positions after burning. The fire had little effect on the mid-slope overstory with only 3% mortality and no overstory mortality occurred on the low slope in 1995. No additional mortality occurred on either slope or the ridge between 1995 and 1996.

3.2. Understory

The fire affected the understory layer on the ridge and mid slope much more than on the low slope. On the ridge, density and basal area significantly decreased after burning (Table 3). In post-burn 1996, density and basal area were significantly higher than post-burn 1995, but remained significantly lower than before burning. In contrast, density-based H' and basal area-based H' increased significantly every year.

Density and basal area of *Kalmia latifolia* were dramatically reduced after burning on the ridge and mid-slope positions. However, high clonal densities in 1995 and 1996 show that *K. latifolia* is sprouting prolifically (Table 4). By 1996, *Robinia pseudoacacia*, *Quercus prinus*, and *Quercus coccinea* density had increased on the ridge, while *Quercus rubra* and *Quercus velutina* had not returned to the understory.

On the mid slope, density and basal area were significantly reduced after burning (Table 3). In addition, species richness (S) and diversity were significantly lower. *Rhododendron maximum* was the dominant species before burning and had an even greater dominance after the burn because it occurred in plots that were not burned by the fire. *Quercus alba* and *Quercus rubra* were no longer present in the understory layer, and *Quercus prinus* had decreased in abundance.

3.3. Herb layer

On the ridge, S and H' increased, while percent cover decreased the first summer after the burn (Table 4). *Kalmia latifolia* percent cover in the herb layer decreased after burning in 1995 and although it increased in 1996, percent cover had not reached before burning levels. Deciduous shrubs, such as *Vaccinium* spp., *Gaylussacia baccata*, *Rhododendron calendulaceum*, and *Clethra acuminata*, increased after the burn. Grasses, *Andropogon scoparius* and *Panicum* spp., which were not present before the burn were relatively abundant after the burn.

The relative percent cover of growth forms changed after the burn. *Kalmia latifolia*, an evergreen shrub, was substantially reduced after burning, while deciduous shrubs and trees increased in relative percent cover (Fig. 1). Non-woody species (herbs, grasses, and vines) also increased. Before burning, non-woody species accounted for only 6% of the relative cover; by 1996, non-woody species accounted for 22% of the relative cover.

Table 1
Frequency (%), density (stems ha^{-1}), basal area ($m^2\ ha^{-1}$) and importance value (IV, (relative density+relative basal area)/2) of overstory trees for the three communities in the Wine Spring Creek prescribed burn area; pre-burn 1994 and post-burn 1995

Species	Ridge (*n*=14)							
	Frequency		Density		Basal area		IV	
	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995
Acer rubrum	50	21	108	41	2.14	1.21	7.48	6.28
Amelanchier arborea	43	21	109	70	0.97	0.67	5.33	5.55
Carya spp.	36	21	128	50	1.38	0.80	6.72	4.79
Castanea dentata	21	–	29	–	0.11	–	1.14	0
Halesia carolina	7	7	7	7	0.15	0.15	0.50	0.77
Nyssa sylvatica	14	–	29	–	0.17	–	1.25	0
Oxydendrum arboreum	50	50	96	77	1.60	1.40	6.09	7.82
Pinus rigida	93	78	637	441	12.45	9.67	43.81	49.27
Quercus alba	7	7	7	7	0.02	0.02	0.27	0.43
Quercus coccinea	57	36	121	60	2.26	1.55	8.14	7.35
Quercus prinus	93	64	239	146	5.22	3.33	17.45	16.70
Quercus rubra	21	14	17	14	0.07	0.07	0.70	0.95
Robinia pseudoacacia	7	–	7	–	0.01	–	0.26	0
Sassafras albidum	7	–	3	–	0.01	–	0.12	0
Tsuga canadensis	7	–	7	–	0.26	–	0.72	0
Total			1545a	913b	26.84a	18.86b		
(SE)			(137)	(163)	(1.99)	(3.00)		
H′			1.92a	1.73b	1.68a	1.55b		
J′			0.71	0.75	0.62	0.67		
S			15	10				
	Mid slope (*n*=9)							
Acer rubrum	200	100	626	606	9.01	9.02	37.32	38.07
Amelanchier arborea	33	33	38	38	0.27	0.27	1.79	1.88
Betula lenta	22	22	5	5	0.03	0.03	0.22	0.24
Carya spp.	67	67	173	178	2.84	2.89	10.92	11.60
Halesia carolina	11	11	44	33	0.26	0.23	1.99	1.63
Magnolia acuminata	11	11	5	5	0.04	0.04	0.24	0.26
Nyssa sylvatica	22	22	156	156	0.99	0.99	7.10	7.45
Oxydendrum arboreum	67	67	153	137	3.16	3.11	10.80	10.50
Quercus coccinea	22	22	38	27	4.00	3.91	8.30	7.88
Quercus prinus	56	44	99	94	6.47	6.44	14.68	14.78
Robinia pseudoacacia	56	44	89	64	0.66	0.53	4.22	3.28
Tsuga canadensis	22	22	22	22	0.94	0.94	2.41	2.47
Total			1448a	1365a	28.69a	28.42		
(SE)			(204)	(208)	(4.80)	(4.85)		
H′			1.85a	1.81a	1.86a	1.85a		
J′			0.74	0.73	0.75	0.74		
S			12	12				
	Low slope (*n*=9)							
Acer pensylvanicum	44	44	64	64	0.49	0.50	3.64	3.77
Acer rubrum	89	89	333	328	6.54	6.59	26.09	26.55
Acer saccharum	11	11	5	5	0.04	0.04	0.28	0.30
Amelanchier arborea	44	33	47	37	0.28	0.24	2.52	2.10
Carya spp.	78	78	186	167	6.64	6.62	19.97	19.35
Castanea dentata	11	11	11	11	0.001	0.001	0.48	0.50
Halesia carolina	22	11	44	15	0.13	0.05	2.14	0.76

Table 1 (*Continued*)

Species	Ridge (n=14)							
	Frequency		Density		Basal area		IV	
	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995
Hamamelis virginiana	11	11	11	11	0.02	0.02	0.52	0.54
Liriodendron tulipifera	22	22	15	15	0.48	0.51	1.49	1.58
Magnolia acuminata	11	11	30	39	0.16	0.18	1.57	2.09
Nyssa sylvatica	11	11	22	22	0.07	0.07	1.08	1.12
Oxydendrum arboreum	11	11	22	22	0.78	0.78	2.37	2.41
Quercus alba	22	22	36	36	2.88	2.90	6.73	6.82
Quercus coccinea	33	33	21	21	3.12	3.16	6.54	6.62
Quercus prinus	33	33	32	32	0.63	0.62	2.51	2.56
Quercus rubra	33	33	21	21	0.61	0.63	2.01	2.07
Robinia pseudoacacia	22	22	22	22	0.94	0.94	2.65	2.68
Sassafras albidum	11	11	5	5	0.07	0.07	0.34	0.35
Tsuga canadensis	89	89	238	243	3.80	3.87	17.08	17.85
Total			1167a	1117a	27.72a	27.82a		
(SE)			(104)	(113)	(4.25)	(4.24)		
H'			2.25a	2.26a	2.11a	2.13a		
J'			0.76	0.77	0.72	0.72		
S			19	19				

Values in rows followed by different letters are significantly different between years.
(SE)=standard error.
H'=Shannon's index of diversity.
J'=Pielou's evenness index.
S=species richness.

Table 2
Average percent mortality, standard error (SE), and coefficient of variation (CV) of overstory species for the ridge, pine/hardwood community in the Wine Spring Creek prescribed burn area; post-burn 1995

Species	n[a]	Mortality (%)	SE	CV (%)
Pinus rigida	12	18.5	8.6	161
Quercus prinus	12	30.6	13.3	150
Quercus coccinea	8	29.2	16.0	155
Amelanchier arborea	4	25.0	25.0	200
Carya spp.	5	57.5	17.5	68
Castanea dentata	3	100.0	0.0	0
Acer rubrum	7	42.8	20.2	125
Total	14	31.2	10.3	124

[a] n=number of plots; percent mortality of individual species was calculated based on number of plots where that species occurred before the burn.

3.4. Tree seedling regeneration

Total number of tree seedlings increased after the burn at all slope positions (Fig. 2). By summer 1996, the number of seedlings had declined from the previous year at all slope positions because new germinants died or fast-growing sprouts entered the understory stratum. The response of individual tree species to fire was variable. For example, on the ridge, *Quercus coccinea* was the only species to significantly increase (p=0.023) in number every year from pre-burn through post-burn 1995 and 1996. *Pinus rigida* seed-

Table 3
Frequency (%), density (stems ha^{-1}), and average basal area ($m^2 ha^{-1}$) of understory species (≥1.0 cm basal diameter, <5.0 cm dbh) for the three communities in the Wine Spring Creek prescribed burn area; pre-burn 1994 and post-burn 1995, 1996.

Species	Ridge (n=14)								
	Frequency			Density			Basal area		
	Pre-burn 1994	Post-burn 1995	Post-burn 1996	Pre-burn 1994	Post-burn 1995	Post-burn 1996	Pre-burn 1994	Post-burn 1995	Post-burn 1996
Acer rubrum	43	14	14	168	13	82	0.045	0.010	0.011
Amelanchier arborea	36	7	7	76a	6b	3b	0.027	0.008	0.001
Betula lenta	–	–	7	–	–	79	–	–	0.006
Carya spp.	14	–	14	82	–	161	0.022	–	0.025
Castanea dentata	21	–	21	952	–	413	0.536	–	0.184
Kalmia latifolia	100	21	14	8651a	248b	168b	4.974a	0.127b	0.403b
Oxydendrum arboreum	7	–	14	10	10	29	0.001	0.001	0.004
Pinus rigida	21	–	7	165	–	317	0.212	–	0.035
Quercus alba	28	–	–	397	–	–	0.096	–	–
Quercus coccinea	50	7	50	295b	6c	1997a	0.078b	0.008b	0.222a
Quercus prinus	50	14	21	505b	25c	720a	0.244	0.024	0.097
Quercus rubra	36	–	–	368a	19b	–	0.187	0.002	–
Quercus velutina	36	–	–	19	–	–	0.010	–	–
Rhododendron calendulaceum	7	–	7	159a	–	19b	0.038	–	0.002
Robinia pseudoacacia	14	–	28	10b	–	813a	0.002	–	0.119
Sassafras albidum	36	7	36	321b	82c	571a	0.050	0.191	0.102
Vaccinium stamineum	–	–	7	–	–	317	–	–	0.025
Total				12,178a	409c	5692b	6522a	0.371c	1.236b
(SE)				(3198)	(189)	(2205)	(2.20)	(0.199)	(0.482)
H'				1.24b	1.27b	2.03a	1.02c	1.19b	1.95a
J'				0.46	0.61	0.77	0.38	0.57	0.74
S				15	8	14			

Species	Mid slope (n=9)					
	Frequency		Density		Basal area	
	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995
Acer rubrum	56	22	326a	15b	0.494a	0.019b
Carya spp.	11	–	5	–	0.006	–
Castanea dentata	44	11	573a	20b	0.127a	0.002b
Halesia carolina	22	–	494	–	0.064	–
Kalmia latifolia	67	11	4691a	123b	4.497a	0.422b
Magnolia acuminata	11	–	123	–	0.019	–
Nyssa sylvatica	11	11	123a	10b	0.012a	0.012a
Oxydendrum arboreum	22	11	138a	25b	0.015a	0.002b
Pyrularia pubera	11	–	123	–	0.047	–
Quercus alba	22	–	247	–	0.020	–
Quercus prinus	11	11	25	5	0.012	<0.001
Quercus rubra	22	–	20	–	0.010	–
Rhododendron maximum	22	11	1605a	1358a	7.231a	7.789a
Robinia pseudoacacia	11	–	15	–	0.008	–
Tsuga canadensis	11	–	10	–	0.002	–
Total			851a	1556b	12.56a	8.25b
(SE)			(2929)	(1473)	(7.79)	(8.21)
H'			1.52a	0.54b	0.96a	0.23b
J'			0.56	0.39	0.35	0.17
S			15	7		

Table 3 (*Continued*)

Species	Ridge (n=14)								
	Frequency			Density			Basal area		
	Pre-burn 1994	Post-burn 1995	Post-burn 1996	Pre-burn 1994	Post-burn 1995	Post-burn 1996	Pre-burn 1994	Post-burn 1995	Post-burn 1996
	Low slope (n=9)								
	Frequency		Density		Basal area				
	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995	Pre-burn 1994	Post-burn 1995			
Acer pensylvanicum	22	22	133	153	0.018	0.026			
Acer rubrum	22	22	30	44	0.010	0.021			
Acer saccharum	33	33	138	158	0.026	0.032			
Amelanchier arborea	33	22	30	54	0.016	0.037			
Betula lenta	11	11	5	10	<0.001	<0.001			
Carya spp.	11	11	40	10	0.006	0.007			
Castanea dentata	33	44	138	592	0.044	0.115			
Crataegus spp.	–	11	–	123	–	0.014			
Fraxinus americana	11	22	15	79	0.005	0.017			
Halesia carolina	33	33	59	138	0.022	0.031			
Liriodendron tulipifera	22	33	69	118	0.011	0.020			
Magnolia acuminata	33	44	207	301	0.056	0.074			
Magnolia fraseri	11	–	5	–	<0.001	–			
Oxydendrum arboreum	11	11	5	10	0.002	<0.001			
Pyrularia pubera	11	33	123	370	0.051	0.135			
Quercus alba	22	11	10	34	0.001	0.003			
Quercus prinus	11	–	5	–	<0.001	–			
Quercus rubra	22	22	133	64	0.026	0.005			
Rhododendron calendulaceum	11	11	864	370	0.320	0.200			
Tsuga canadensis	22	22	143	20	0.400	0.019			
Total			2153a	2652a	1.015a	0.758a			
(SE)			(899)	(694)	(0.470)	(0.262)			
H'			2.15a	2.40a	1.76a	2.26a			
J'			0.73	0.83	0.60	0.78			
S			19	18					

Values in rows followed by different letters are significantly different ($p \leq 0.05$) between years.
(SE)=standard error.
H'=Shannon's index of diversity.
J'=Pielou's evenness index.
S=species richness.
In 1996, only six plots from the mid slope and six plots from the low-slope position were sampled, thus, diversity indices (H' and J') were not calculated for 1996.

ling numbers increased by 358% the first summer after the burn, then decreased to 35% of the pre-burn number by 1996. *Amelanchier arborea* seedling numbers decreased by 290% the first summer after the burn and an additional 350% the second summer (1996).

On the mid slope, only a small or temporary increase in *Quercus* seedlings was noted after burning (Fig. 2). *Acer rubrum*, *Halesia carolina* and *Robinia pseudoacacia* seedlings, not present before the burn, were abundant after the burn. On the low slope, *Quercus prinus*, *Acer rubrum*, and *Quercus rubra* seedlings, not present before the burn, were abundant, and *Acer saccharum* and *Magnolia acuminata* numbers increased (Fig. 2).

Table 4
Percent cover (%) and relative percent cover (%) of herb-layer species for the ridge, pine/hardwood community in the Wine Spring Creek prescribed burn area; pre-burn 1994 and post-burn 1995, 1996

Growth form	1994		1995		1996	
	Cover	Relative cover	Cover	Relative cover	Cover	Relative cover
Deciduous trees						
Acer rubrum	0.25	0.7	0.08	0.8	1.17	3.1
Quercus prinus	0.25	0.7	0.10	0.9	1.29	3.4
Sassafras albidum	0.10	0.3	0.25	2.4	2.88	7.6
Quercus coccinea	0.08	0.2	0.03	0.3	0.21	0.6
Quercus rubra	0.08	0.2	0.08	0.8	0.25	0.7
Amelanchier arborea	0.06	0.2	0.08	0.8	0.08	0.2
Quercus velutina	0.06	0.2	0.08	0.8	–	–
Quercus alba	0.03	0.2	–	–	–	–
Oxydendron arboreum	0.02	0.05	0.05	0.5	–	–
Robinia pseudoacacia	0.02	0.05	0.05	0.5	–	–
Castanea dentata	–	–	0.07	0.6	–	–
Evergreen trees						
Pinus rigida	0.10	0.3	0.08	0.8	–	–
Deciduous shrubs						
Vaccinium spp.	2.28	6.4	2.28	21.6	5.17	13.7
Gaylussacia baccata	1.03	2.9	1.88	17.8	0.96	2.5
Rubus spp.	–	–	–	–	0.12	0.3
Pyrularia pubera	0.18	0.5	0.08	0.8	0.67	1.8
Clethra acuminata	0.07	0.2	0.03	0.3	0.96	2.5
Rhododendron calendulaceum	0.02	0.05	0.25	2.4	1.46	3.9
Rhus glabra	–	–	0.03	0.3	–	–
Evergreen shrubs						
Kalmia latifolia (clonal density=#/ha)	28.0	78.7	3.67 (11,307)	34.6	11.4 (9,285)	30.4
Herbs						
Epigea repens	0.55	1.5	0.10	0.9	0.33	0.9
Galax aphylla	0.40	1.1	0.10	0.9	0.92	2.4
Melampyrum lineare	0.22	0.6	0.02	0.2	1.17	3.1
Medeola virginiana	0.02	0.05	–	–	0.12	0.3
Solidago spp.	0.02	0.05	–	–	–	–
Galium spp.	–	–	0.13	1.2	1.33	3.5
Pteridium aquilinum	–	–	0.10	0.9	0.42	1.1
Coreopsis major	–	–	0.05	0.5	–	–
Hypoxis hirta	–	–	0.05	0.5	–	–
Uvularia spp.	–	–	0.03	0.3	–	–
Saxifraga michauxii	–	–	0.02	0.2	0.29	0.8
Thelypteris noveboracensis	–	–	0.02	0.2	–	–
Froelichia floridana	–	–	–	–	0.12	0.3
Graminoids						
Carex spp.	1.08	3.0	0.10	0.1	–	–
Andropogon scoparius	–	–	0.23	2.2	0.54	1.4
Panicum spp.	–	–	–	–	2.75	7.3
Vines						
Smilax spp.	0.63	1.8	0.40	3.8	2.71	7.2
Total	35.6%a		10.6%b		37.7%a	
H'	1.01a		2.14b		2.50c	
J	0.32		0.61		0.77	
S	24		33		26	

Values in rows followed by different letters are significantly different ($p<0.05$) between years.

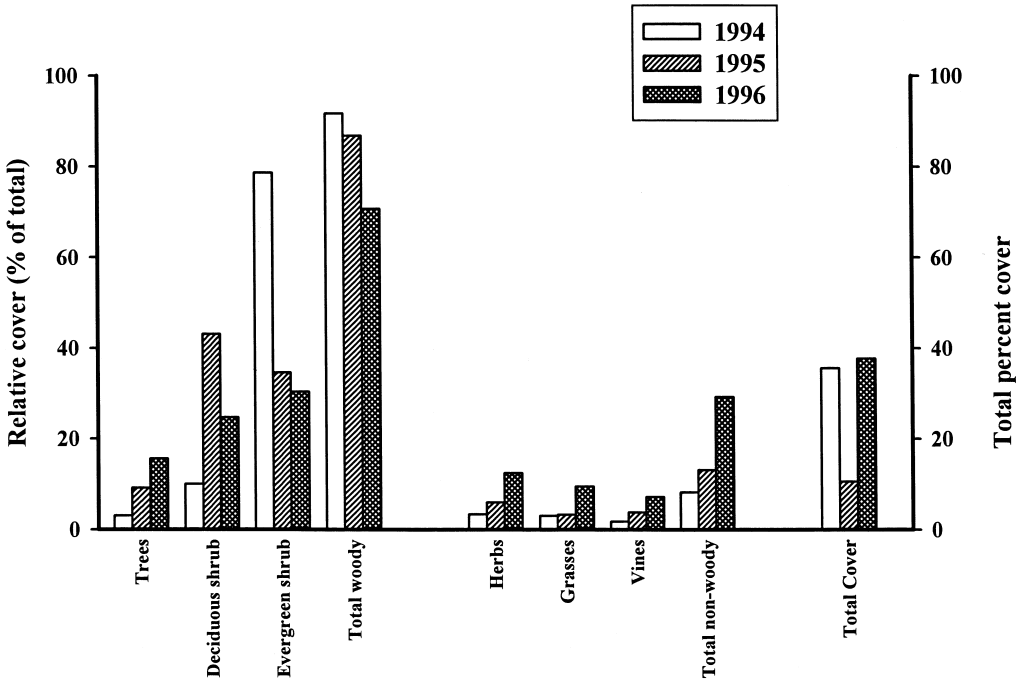

Fig. 1. Relative percent cover by growth form for the herb-layer vegetation on the ridge, pre-burn 1994 and post-burn 1995 and 1996. Trees=seedlings and saplings <1.0 m height; Deciduous shrubs=shrubs that produce fleshy berries (i.e. *Vaccinum* and *Gaylussacia*) or nuts (i.e *Pyrularia pubera*); Evergreen shrubs=*Kalmia latifolia*; Total woody=all woody species; Herbs=herbaceous species not including grasses and vines; Total non-woody=herbs+grasses+vines; Total Cover=right axis, average percent cover of all species.

4. Discussion

4.1. Overstory responses

Before the prescribed burn at Wine Spring Creek in 1995, the degraded condition of the pine/hardwood community was characteristic of other pine/hardwood forests in the southern Appalachians (van Lear and Johnson, 1983; Nicholas and White, 1984; Smith, 1991; Swift et al., 1993; Clinton et al., 1993). Overstory mortality was the heaviest on the ridge and was related to the fire intensity. We observed 31% mortality of trees the first summer after burning and no additional overstory mortality the second year after the fire. This observation is somewhat consistent with wildfire effects in a pine/hardwood forest in West Virginia where overstory mortality was 20% after the first year and 40% after the second year (Groeschl et al., 1992).

Other studies have reported understory dominance by shade-tolerant *Acer rubrum*, which in the absence of disturbance eventually replace *Quercus* species (Christensen, 1977). In the southern Appalachians, an increase in abundance of *A. rubrum* over the last two decades has been reported (Elliott et al., in review), and it has become a dominant species occurring across a wide range of elevation and environmental conditions. In our study, *A. rubrum*, a dominant species on the ridge before the burn, suffered heavier mortality than any other overstory species, and it was also substantially reduced in the understory layer. Conversely, *Quercus prinus* and *Quercus coccinea* had less overstory mortality, *Q. prinus* increased in importance value (IV=relative density+relative basal area/2), and both oak species increased in density in the understory and herb layer. The fire reduced the abundance of *A. rubrum*, while promoting the growth and recruitment of *Quercus* species.

On the ridge, overstory H' decreased after the burn due to the decline in species richness (S) rather than a change in evenness (J') of distribution of species. Four overstory species disappeared from the overstory after

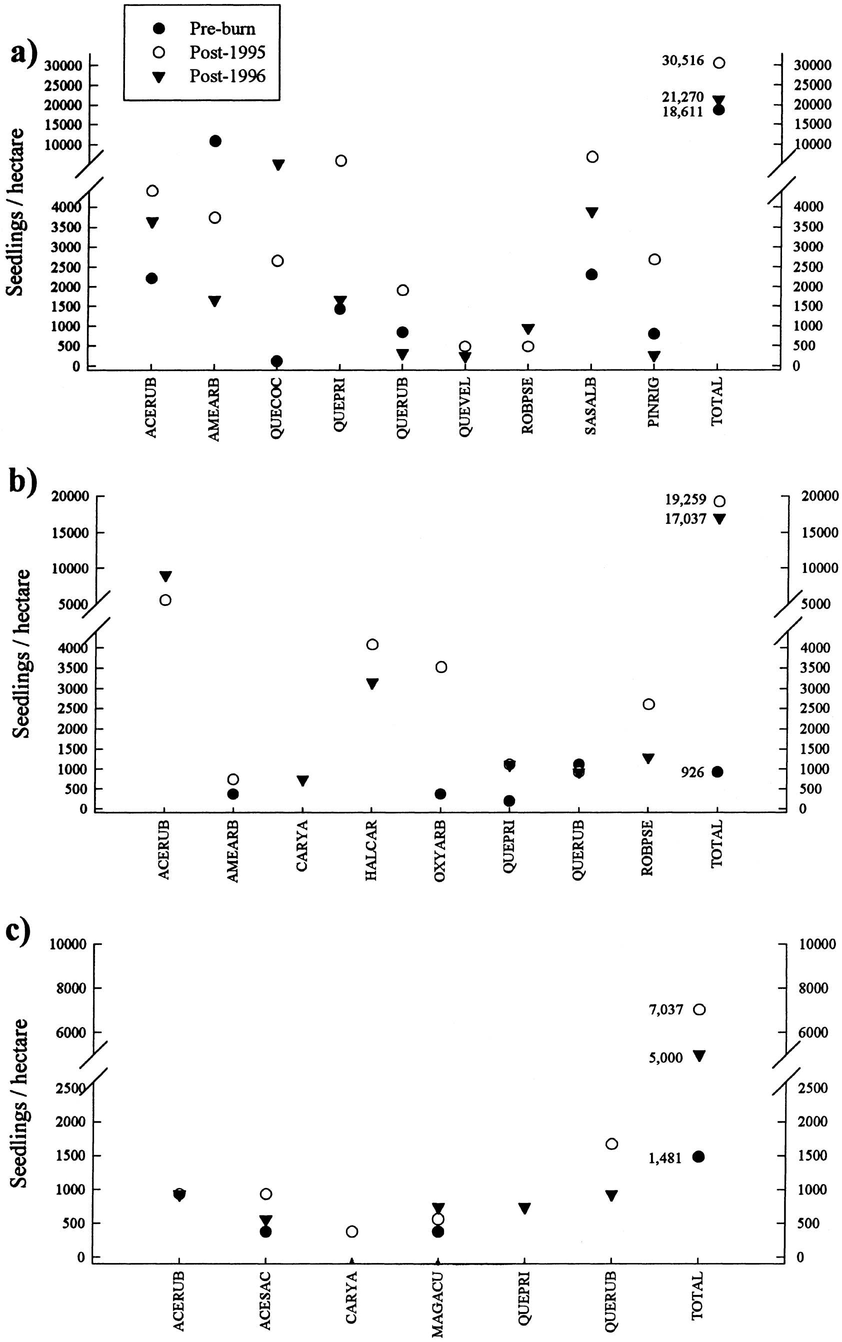

Fig. 2. Tree seedling densities pre-burn 1994, and post-burn 1995 and 1996. (a) ridge, pine/hardwood community; (b) mid slope, mixed-oak community; and (c) low slope, near-riparian cove-hardwood community. ACERUB=*Acer rubrum*; ACESAC=*Acer saccharum*; AMEARB=*Amelanchier arborea*; CARYA=*Carya* spp.; HALCAR=*Halesia carolina*; MAGACU=*Magnolia acuminata*; OXYARB=*Oxydendrum arboreum*; QUEPRI=*Quercus prinus*; QUERUB=*Quercus rubra*; QUECOC=*Quercus coccinia*; QUEVEL=*Quercus velutina*; ROBPSE=*Robinia pseudoacacia*; PINRIG=*Pinus rigida*; SASALB=*Sassafras albidum*.

the burn (*Castanea dentata*, *Nyssa sylvatica*, *Robinia pseudoacacia*, and *Tsuga canadensis*). All were minor components of the ridge community pre-burn; with the exception of *T. canadensis*, all are regenerating in the understory or herb layer. On the mid and low slope, where fire intensity was moderate to light, no change in overstory composition or diversity was observed.

4.2. Understory responses

On the ridge and mid slope, the increase in density and basal area of *Oxydendrum arboreum*, *Quercus coccinea*, *Robinia pseudoacacia*, and *Sassafrass albidum* saplings after the burn corresponded to the substantial decrease in *Kalmia latifolia*. Consequently, H' and J' were signficantly higher on the ridge because *K. latifolia* dominated this vegetation layer before the burn. The reduction of *K. latifolia* in the understory may be sufficient to allow regeneration of pine and oaks on the ridge and mid-slope communities. However, it is sprouting prolifically and may compete with other herb-layer species. *K. latifolia* is a vigorous sprouter that produces many stems (McGinty, 1972), but the growth of these stems is much slower than many woody seedlings (Hooper, 1969; McGee et al., 1995). The high number of *K. latifolia* clones that survived the fire suggests that it may regain its dominance in the understory stratum in a few years. Clinton et al. (1993) found that even after high intensity burning, *K. latifolia* reasserts its influence on microsite conditions at the forest floor within a few years and reduces the number of tree stems reaching the overstory. However, the early reduction in *K. latifolia* abundance allowed successful establishment of native pines (Clinton et al., 1993).

The mortality and regeneration of oak saplings were variable depending on species and intensity of the burn. For example, *Quercus alba*, *Quercus velutina*, *Quercus rubra* saplings suffered heavy mortality and have not reentered the understory-layer. While *Quercus coccinea* and *Quercus prinus* suffered heavy mortality in the overstory; saplings were more abundant in the understory and the number of *Q. coccinea* seedlings was significantly greater post-burn than pre-burn.

4.3. Herb-layer responses

On the ridge, *Kalmia latifolia* percent cover was substantially reduced and H' increased. Total percent cover decreased the first summer after the burn, then returned to pre-burn levels. However, the greater numbers of deciduous shrubs (e.g. *Vaccinium* spp. and *Gaylussacia baccata*) and grasses (e.g. *Panicum* spp. and *Andropogon scoparius*) after the fire provide soft mast and forage for wildlife. In general, nonwoody species increased in relative percent cover while woody species decreased after the fire. In addition, deciduous species increased while evergreen species (i.e. *K. latifolia*) decreased.

4.4. Tree regeneration

Regeneration of *Pinus rigida* may not occur at Wine Spring Creek without further disturbance. Although seedling numbers increased the first year after the burn, fewer seedlings were present in 1996 than were present before the burn. Fire is sometimes necessary to open the serotinous cones of *P. rigida* and most southern populations exhibit extensive stump sprouting after a fire (Ledig and Little, 1979). In our study, new germinants of *P. rigida* were abundant in the first summer after the burn. In a seed-bank study, viable *P. rigida* seeds were not present in pre-burn litter or mineral soil (Major, 1996), indicating that cones had opened and deposited viable seeds after the fire. However, most of these new germinants were not able to survive through the first year. After the burn, overstory basal area was reduced by only 30%; thus, the residual basal area (18.86 m^2 ha^{-1}) may have been too high for many of the shade intolerant *P. rigida* seedlings to become established. In addition, burning consumed little of the humus layer on the ridge (Vose et al., in review) and roots of many germinants probably did not penetrate to mineral soil. Seedling mortality was high during the late growing season of 1995 when precipitation totaled only 6.6 cm in September – well below the long-term average of 13.0 cm for this month (based on a 63-year record at Coweeta Hydrologic Laboratory; Swift, unpublished data).

For other species, the regeneration response to fire was also linked to individual tree species and fire intensity. On the ridge, *Quercus coccinea* was the only species to significantly increase in seedling numbers every year from 1994 to 1996. However, the regeneration success of other species was greater than that shown by total seedling numbers alone. Before the burn, *Amelanchier arborea*, a shade-tolerant understory tree (Brown and Kirkman, 1990), accounted for over one-half the total number of seedlings (Fig. 2). After the fire, *A. arborea* seedling numbers decreased dramatically, while total number of seedlings increased. *Quercus* species seedling numbers increased significantly (p=0.013) after the burn. With the exclusion of *A. arborea* from the data analysis, a significant increase (p=0.003) in total seedling numbers was observed (7778 for 1994; 26,786 for 1995; and 19,603 for 1996).

4.5. Restoration and recovery

Other studies have attributed community composition after a fire to the sprouting ability of dominant species, the failure of subordinate species to increase in numbers, and the failure of invasive species to persist (Abrahamson, 1984; Schmalzer and Hinkle, 1992; Matlack et al., 1993; McGee et al., 1995). In our study, all woody species sprouted, but increases in sprout densities among species varied. *Quercus* species, *Carya* spp., *Robinia pseudoacacia*, and *Sassafras albidum*, subordinate species in the understory before the burn, increased in numbers. *Kalmia latifolia*, the dominant species before the burn, decreased in density and basal area in the understory, but is sprouting prolifically in the herb layer. Invasive species such as *Andropogon scoparius*, *Panicum* spp., *Rubus* spp., and *Coreopsis major* that recruited into the herb layer are all early successional, shade-intolerant species which persist for only a few years after disturbance (Elliott et al., 1997).

A number of researchers have suggested that repeated burning may be necessary to promote successful oak regeneration (Johnson, 1985; van Lear and Waldrop, 1989; Lorimer, 1993; van Lear and Watt, 1993). van Lear and Waldrop (1989) reported that oaks resprouted more frequently than most other hardwood species after burning. Similar to other studies on the effects of fire on the understory (Langdon, 1981; Ducey et al., 1996; Keyser et al., 1996), we found that burning stimulated production of berries (*Gaylussacia baccata*, *Rubus* spp. and *Vaccinium* spp.) and grasses, both are important forage species for wildlife. The effect of intense fire on oak regeneration has received less attention and intense fires have produced the most dramatic results (Ward and Stephens, 1989; Nowacki et al., 1990).

5. Summary and conclusions

The effects of the prescribed fire varied along the hillslope gradient in this southern Appalachian watershed. Overstory mortality was the highest along with the ridge which decreased overstory diversity. Although mortality was also significant in the understory, the reduction of *Kalmia latifolia* abundance increased diversity in the understory and herb layer.

The first summer after the burn, *Pinus rigida* germinated prolifically. However, by summer of 1996 most of these new germinants had died and seedling numbers were less than before burning. *Quercus* spp. and *Carya* spp. seedlings were much more abundant after the burn in both 1995 and 1996. Prescribed fire may be successful in restoring the oak component of these ridge and mid-slope communities, but in this study it has not successfully restored the pine component of the xeric, ridge community.

The prescribed burn had varying effects on species richness and diversity across the hillslope gradient. On the ridge, where the fire was the most intense, S and H' significantly increased in the understory and herb layer but decreased in the overstory. Percent cover of *Kalmia latifolia* was substantially reduced, allowing for an increase in other species such as *Vaccinium* spp. and *Gaylussacia baccata* and the invasion of new species not formerly found on this site.

At the mid slope, where very little overstory mortality occurred, no significant change in S or H' was noted in the overstory, but S and H' significantly decreased in the understory. In the understory, many of the infrequent species disappeared. The decline in H' was attributed to both the loss of species and a change in evenness of distribution; J' was also significant lower after the burn. At the low slope, no change in overstory or understory diversity was observed after the burn.

Without future fires, the regeneration of the pine/hardwood community will probably be transient. High intensity prescribed fires may help to regenerate declining pine stands, but they need to occur when the mature pines have sufficient cone crops to provide viable seeds. The fires must be intense enough to open the serotinous cones, remove the litter layer to provide favorable seedbed conditions, and reduce competing vegetation, especially *Kalmia latifolia*. Based on this study, the use of prescribed fire to restore degraded pine/hardwood communities shows promise. However, residual basal area of overstory trees and the humus layer were not reduced sufficiently to allow for successful establishment of *Pinus rigida* seedlings. Further studies should evaluate the timing of the first fire, season of burn, stand age, and stage of stand development, and the frequency and intensity of fire needed to maintain these communities. Restoring and maintaining pine/hardwood communities and promoting oak regeneration in mixed-oak communities in the southern Appalachians may require more aggressive silviculture treatments. For example, an initial high intensity fire followed by low intensity burning at 5–10 year intervals may maintain *K. latifolia* at low densities while promoting successful establishment of *P. rigida* and *Quercus* species. Clearly, we need more research on the long-term effects of stand-replacement prescribed fire.

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