THIRD-YEAR RESPONSES OF UNDERSTORY WOODY REGENERATION TO FUEL REDUCTION TREATMENTS IN THE SOUTHERN APPALACHIAN MOUNTAINS

Ross J. Phillips, Thomas A. Waldrop, and Dean M. Simon[1]

Abstract—The effects of fuel reduction treatments, fire and mechanical understory removal (alone and in combination), were examined to determine changes in abundance and composition of woody regeneration in the Southern Appalachian Mountains. While mechanical treatment alone (M) had little effect on seedling density, burning (B) and mechanical treatment + burning (MB) produced a significant increase. Sapling density was greatly reduced in MB immediately following treatment, but 2 years later abundant sprouting was observed. Regeneration of shade-tolerant species was encouraged in M and B, whereas MB favored shade-intolerant species. Reponses of dominant tree species varied by treatment based on species' reproductive strategies. Red maple (*Acer rubrum* L.) increased in B primarily through seed germination, whereas MB promoted sprouting. Yellow-poplar (*Liriodendron tulipifera* L.) showed rapid initial response to B and MB, but seedlings that germinated after fire in B did not persist. In contrast, seedlings germinating following treatment in MB thrived, quickly growing into the saplings. B and MB contained more than twice as many oak (*Quercus* spp.) seedlings recorded pretreatment, with the majority sprouting from remaining stems; however, a large acorn crop 1 year after burning contributed to seedling numbers observed the third year posttreatment. Shrub abundance was greatly reduced by M and MB, but sprouting in the understory layer was observed in all treatment units. Reducing fuel using techniques described here can affect woody species composition and potentially change development of mixed-oak forests in the Southern Appalachian Mountains.

INTRODUCTION

The selective use of fire by Native Americans for hunting, land clearing, pest control, and habitat improvement for wildlife (Carroll and others 2002) shaped vegetation composition throughout the Southern Appalachian Mountains (Delcourt and Delcourt 1997). Continued burning and logging by early European settlers promoted species adapted to frequent disturbances (Abrams 1992). However, fire suppression/exclusion practices in the early 1900s influenced stand structure and vegetation composition as late-successional, fire-intolerant species began to establish in these forests (Abrams and Nowacki 1992, Schuler and Gillespie 2000). At the same time, mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron* spp.) proliferated forming a dense shrub layer, subsequently affecting seedling recruitment (Waterman and others 1995) and increasing wildfire risk. To mediate these changes, prescribed burning and mechanical removal of fuel have been suggested to reduce fuel loading and encourage re-establishment of vegetation characteristic of forests that developed under frequent fire occurrence.

We examined changes in woody species composition following fuel reduction treatments in mixed-oak stands in the Southern Appalachian Mountains. Regeneration of dominant tree species and ericaceous shrubs was analyzed to identify shifts in species composition that may influence future development of mixed-oak forests in this region. Our work is part of a larger, multidisciplinary research project initiated to reduce fuels and help restore vegetation in forests across the United States that historically were sustained by frequent, low-intensity fires. By re-introducing fire and using other fuel reduction methods, researchers are studying the challenges of reducing fuels while restoring stand structure and ecosystem processes.

METHODS

The study is on the 5,800-ha Green River Game Land east of Hendersonville, NC. Stands are representative of second-growth mixed-oak forests in the Southern Appalachian Mountains with a dense ericaceous shrub layer. Oaks (*Quercus* spp.) represent 55 to 70 percent of overstory basal area; but other hardwoods, such as sourwood (*Oxydendrum arboreum* (L) DC.), red maple (*Acer rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), mockernut hickory (*Carya alba* (L.) Nutt. ex Ell.), and blackgum (*Nyssa sylvatica* Marsh.), also are common. Topography is highly dissected with elevations ranging from 366 to 793 m and slopes up to 84 percent. Soils are primarily mesic Typic Hapludults (Evard and Cliffield Series) with inclusions of mesic Typic Dystrudepts (Edneyville and Chestnut Series) (Keenan 1998). These soils are described as deep and well drained in mountain uplands. Small areas of mesic Fluvaquentic Dystrudepts (Arkaqua Series) and mesic aquic Hapludults (Dillard Series) are also present (Keenan 1998).

Four experimental units of at least 14 ha were established at three locations (blocks) for treatment application. Blocks were selected based on size (large enough to include four treatment units), forest age (80 to 120 years), cover type (mixed-oak forest), and management history (had not been thinned in at least 10 years or burned within 5 years). Within each block, one of four treatments (untreated control (C), mechanical-only treatment (M), burn-only treatment (B), or mechanical treatment + prescribed burning (MB)) was randomly assigned to experimental units. Pretreatment sampling occurred from May through August 2001. The mechanical treatment was installed in winter 2001-2002 using contract chainsaw crews who cut all sapling trees >1.4 m tall and <10 cm d.b.h., as well as all ericaceous shrubs. Cut material was left in place onsite. Burning was conducted 1 year after mechanical treatment (March 2003) to allow slash

[1]Ecologist and Supervisory Research Forester, respectively, U.S. Forest Service, Southern Research Station, Clemson, SC; and Wildlife Forester, North Carolina Wildlife Resources Commission, Division of Wildlife Management, Lawndale, NC.

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to cure. Our burn objectives were to topkill suppressed trees and reduce shrub cover using low- to medium-intensity fires. Ambient temperatures during burning were 17 to 27 °C, the minimum RH was 30 percent, and SW winds were light (3 to 5 km per hour). Fire intensity in MB was consistently greater than B, as mean maximum temperatures exceeded 370 °C as opposed to 180 °C for B.

Ten 0.1-ha plots (20 by 50 m) were randomly located within treatment units using a permanently marked, geo-referenced 50-m grid. Five subplots (10 by 10 m) within each 0.1-ha plot were used to record sapling density (trees >1.4 m tall and <10 cm d.b.h.) and to visually estimate cover of shrubs >1.4 m tall. Woody vegetation <1.4 m tall was measured in 1-m^2 quadrats located in opposing corners of each 10- by 10-m subplot (n=20 per 0.1 ha-plot). We tallied tree seedlings by species and noted origin status (germinant, established, sprout). We recorded ocular estimates of abundance for all woody species using cover classes: <1, 1 to 10, 11 to 25, 26 to 50, 51 to 75, >75 percent. All plants were identified to species level following USDA PLANTS database nomenclature (USDA, NRCS 2006). "Seedling" and "sapling" are used to refer to all stems within each respective category (i.e., "seedling" includes new germinants, established individuals, and sprouts) except where specified.

To analyze treatment effects on woody vegetation, we performed repeated measures ANOVA on sapling and seedling stem densities and shrub cover. Stem densities were summed across treatment unit and square-root transformed to improve normality. Cover class data were assigned the median value for each class, averaged across the treatment unit, and arcsine square-root transformed. Treatment and treatment x year interactions at $\alpha = 0.05$ were interpreted as significant effects from treatment and subjected to post-hoc comparisons using Tukey's multiple comparison procedure.

RESULTS

Fuel reduction treatments significantly affected seedling (P_{trt} <0.0001; P_{year} <0.0001; $P_{trtXyear}$ = 0.0001) and sapling (P_{trt} = 0.0004; P_{year} <0.0001; $P_{trtXyear}$ = 0.0016) density. Immediately following treatment, B and MB contained more seedlings than C and M, a trend which continued through the third-year sampling (fig. 1a). Sapling layer stem density was significantly reduced by all treatments after the first growing season. By year 3, M and B had yet to return to pretreatment levels, whereas MB contained three times more saplings per hectare than prior to treatment (fig. 1b).

Species composition changed dramatically as pretreatment shade-tolerant species, comprising 38 percent of the seedling layer and 68 percent of the sapling layer, increased seedling density in M from 6,367 to 13,967 stems/ha; in B from 15,517 to 78,583 stems per hectare; and in MB from 9,767 to 36,283 stems per hectare. Density of shade-tolerant saplings was little changed from pretreatment values in B (1,077 stems per hectare), whereas M declined from 933 to 740 stems per hectare and MB increased from 1,096 to 2,242 stems per hectare. Even though overall stem density for shade-tolerant species increased in MB, relative density dropped by 15 percent. For shade-intolerant species, treatments increased seedling density for all units (M: 7,067 to 11,400 stems per hectare; B: 6,600 to 26,833 stems per hectare; and MB: 7,117 to 33,650 stems per hectare); but only MB showed notable increases in relative density (+13 percent). Burning (B and MB) resulted in more shade-intolerant saplings (B increased from 146 to 236 stems per hectare; MB increased from 225 to 1,314 stems per hectare), whereas M reduced shade-intolerant sapling density from 240 to 142 stems per hectare.

Regeneration of dominant tree species differed among treatments based on reproductive strategies. Red maple showed significant effects from treatment as B encouraged seedling germination and MB promoted sprouting (fig. 2a,b). Although immediately following treatment, maple seedling density remained relatively unchanged from pretreatment values. After 3 years, B had more seedlings/ha than all other treatments, with new germinants comprising 83 percent of maple stems present. Following initial declines in maple sapling density, M and B showed few differences in number of stems per hectare from pretreatment levels, whereas sapling density doubled in MB. Medium-intensity burns in MB caused more maple overstory mortality (table 1), resulting in vigorous stump sprouting.

Burning (B and MB) elicited an immediate increase in yellow-poplar seedling density from < 450 to > 30,000 stems per hectare with new germinants accounting for 90 percent of stems in both treatments (fig. 2c). However, in B, the third-year inventory revealed 76 percent mortality of these stems. In contrast, seedlings in MB flourished and quickly grew into the sapling category, greatly increasing stem density (fig. 2d).

Oak seedlings responded positively to burning (B and MB), doubling in density over 3 years, whereas oak seedling density in unburned units (C and M) declined (fig. 2e). In the first growing season after treatment, sprouts comprised > 87 percent of oak seedlings for both B and MB. By the third posttreatment sampling, 50 percent of oak seedlings were new germinants. In the sapling layer, only MB had a positive effect on oak-regeneration density (fig. 2f). Both M and B resulted in declines in oak sapling density, which was unexpected, given oak's ability to sprout in response to disturbance.

Although shrub cover < 1.4 m tall showed no significant treatment effects (P = 0.1430), there was a treatment x year interaction (P = 0.0425). The first posttreatment sampling indicated shrub cover was reduced by all treatments; however, 2 years later abundance had recovered (table 2). Tall shrubs showed significant declines (P_{trt} = 0.0442; Pyear = 0.0071; $P_{trtXyear}$ = 0.0293) with large reductions in cover from mechanical treatment (M and MB). Mountain laurel and rhododendron dominated the shrub layer contributing the

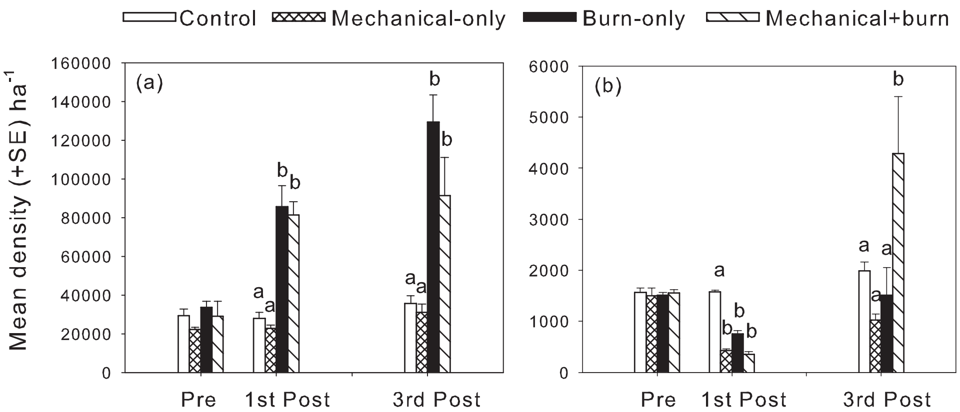

Figure 1—Mean density (+SE) for tree seedlings (a) and saplings (b) in mixed-oak stands treated for fuel reduction.

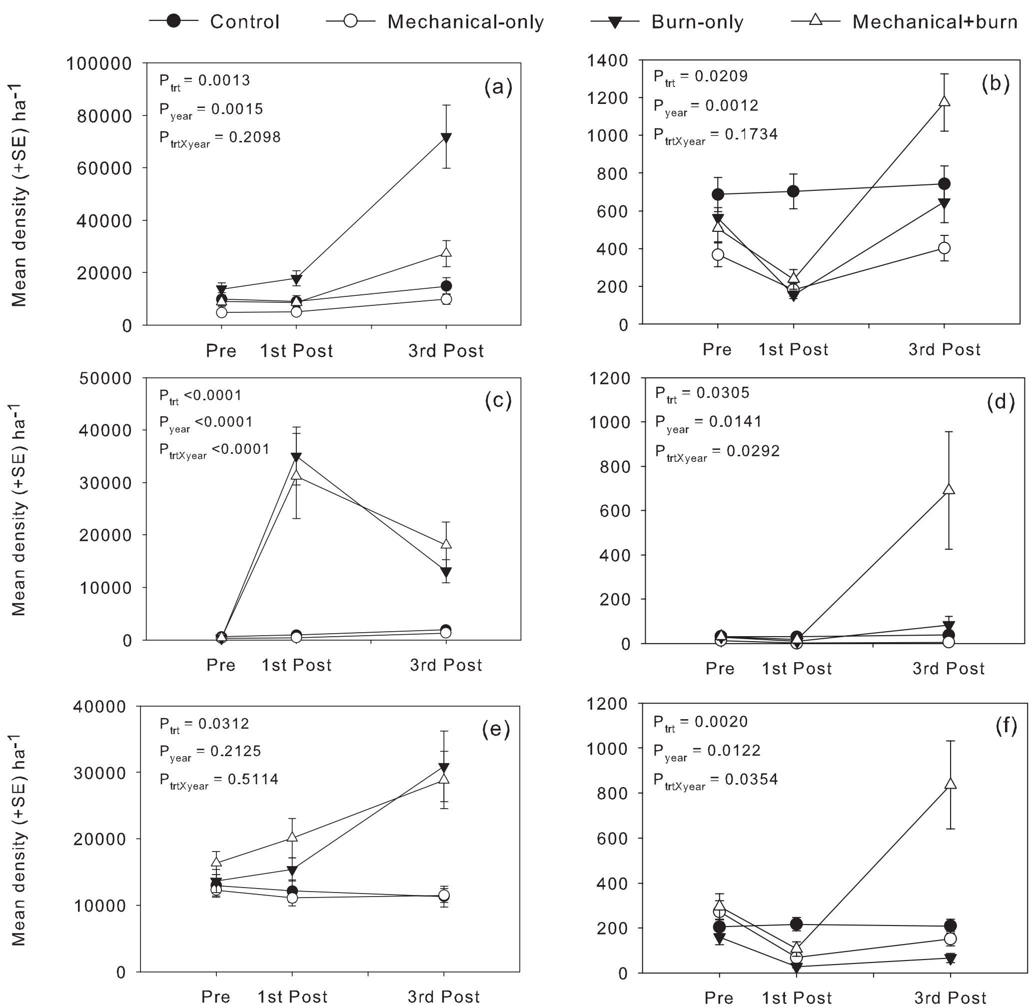

Figure 2—Changes in seedling (a, c, and e) and sapling (b, d, and f) densities for common tree species: red maple (a and b); yellow-poplar (c and d); and oak species (e and f).

Table 1—Overstory abundance of oak, red maple, and yellow-poplar in mixed-oak forests subjected to fuel reduction treatments on the Green River Game Lands in southwestern North Carolina

		Basal Area (m^2/ha)				Density (stems/ha)			
		Oak	Red Maple	Yellow-poplar	Total	Oak	Red Maple	Yellow-poplar	Total
Control	Pre	17.9	1.7	1.7	27.4	269	61	28	566
	1st Yr Post	18.0	1.6	1.7	27.0	261	55	26	551
	3rd Yr Post	18.5	1.8	1.8	28.1	265	57	26	560
Mechanical-only	Pre	19.1	1.0	1.1	27.4	324	55	18	603
	1st Yr Post	19.3	1.0	1.2	27.7	319	53	18	591
	3rd Yr Post	20.0	1.0	1.2	28.8	315	53	17	595
Burn-only	Pre	15.2	2.5	2.1	27.1	208	79	30	569
	1st Yr Post	15.1	2.4	2.1	26.4	199	76	29	541
	3rd Yr Post	15.1	2.3	2.2	26.2	184	71	27	508
Mechanical+burn	Pre	16.6	2.0	1.0	23.9	239	69	13	507
	1st Yr Post	14.7	1.7	1.0	21.0	177	44	11	380
	3rd Yr Post	12.9	1.5	1.0	18.3	141	30	9	277

Table 2—Changes in percent cover of ericaceous shrubs >1.4 m in height (tall shrubs) and understory woody stems <1.4-m tall (excluding tree seedlings) resulting from fuel reduction treatments.

	Control			Mechanical-only			Burn-only			Mechanical+burn		
	Pre	1st Yr Post	3rd Yr Post	Pre	1st Yr Post	3rd Yr Post	Pre	1st Yr Post	3rd Yr Post	Pre	1st Yr Post	3rd Yr Post
Tall Shrubs (>1.4m)												
Mt. laurel	9.7	10.4	11.4	5.3	0.4	1.0	1.9	0.8	0.5	6.2	0.0	0.0
Rhodo spp	2.4	4.3	2.9	7.9	0.4	0.6	4.7	3.5	3.4	1.3	0.0	0.0
Blueberry	0.7	2.1	3.4	0.9	0.4	0.7	0.3	0.0	0.0	1.0	0.0	0.1
Total	13.9	17.8	19.9	14.8	1.3	2.5	7.3	4.6	4.1	9.3	0.2	1.2
Woody Understory Stems(<1.4m)												
Mt. laurel	4.7	3.4	3.1	6.3	4.1	5.1	3.5	0.9	2.3	5.8	1.3	5.4
Rhodo spp	0.1	0.2	0.2	0.7	0.7	1.0	0.2	0.1	0.2	0.0	0.0	0.1
Blueberry	6.8	6.5	3.2	8.2	8.2	7.7	5.3	2.1	4.4	10.8	4.3	10.8
Total	12.6	11.3	7.2	16.2	14.7	15.6	10.3	3.8	8.6	18.2	6.6	18.9

The category "Rhodo spp." includes both *Rhododendron maximum* and *R. minus*.
"Total" is the mean cover for all shrubs species recorded within each treatment.

majority of cover in tall shrubs and blueberry (*Vaccinium* spp. L.) providing the greatest cover for shrubs < 1.4 m tall.

DISCUSSION

Fuel reduction treatments changed patterns of tree recruitment in these mixed-oak stands. Significantly more seedlings were present in burned areas; however, B favored shade-tolerant species, whereas MB caused overstory mortality, creating large canopy gaps and encouraging regeneration of shade-intolerant species. The increase in shade-tolerant species following the B treatment contradicts findings by Dolan and Parker (2004) and Hutchinson and others (2005). Greater stem densities of red maple in B largely contributed to the trend of increasing shade-tolerant species. Low-intensity fires produced patchy burn coverage and had little effect on overstory trees. This effect, coupled with the higher abundance of maple in B provided an ample seed source for tree regeneration in this treatment.

The combination of mechanical understory removal + prescribed burning promoted yellow-poplar and oak regeneration as seedlings (new germinants and sprouts) flourished and quickly grew into the sapling layer. While these species' responses were similar, their reproductive strategies differed. Yellow-poplar was uncommon in the understory prior to treatment probably because of the lack of large disturbances (Busing 1995) in these stands as they have not experienced fire or thinning in over 50 years. Burning removed leaf litter, improving habitat for seed germination and the proliferation of new seedlings (Beck 1965). The fires in MB caused sufficient overstory mortality, providing enough light to allow yellow-poplar seedlings to quickly increase in height. Although yellow-poplar regeneration was also abundant in B the first-growing season after treatment, sufficient light was not available to sustain growth similar to that observed in MB.

Significant increases in oak regeneration following application of mechanical + burn treatments primarily resulted from sprouting; however, 50 percent of oaks recorded in year three were new germinant seedlings. A 2004 mast survey by the North Carolina Wildlife Resources Commission found white oak subgenus (e.g., *Q. alba, Q. prinus*, etc.) mast was at the highest level recorded since surveys began in 1983 (Jones 2005). This large crop of acorns may have contributed to the large seedling increase observed between the first- and third-year posttreatment.

The M treatment had little effect on tree regeneration, although it did reduce total sapling density. Coverage and height of mountain laurel and rhododendron, which can reduce seedling densities through competition for resources (Clinton and others 1994), was reduced in this treatment. However, we observed little difference between units with an intact ericaceous shrub layer (C) and those in which the layer was removed (M). This may be because light levels at the forest floor were not substantially increased in M where the forest canopy remained intact, despite the reduced shrub cover. Additionally, competition with tree seedlings remained high, as shrubs < 1.4 m tall returned to pretreatment levels after 3 years.

Burning and mechanical understory removal are potential options for reducing fire hazard and managing succession in these forests, but other ecosystem components must be considered. Changes in herbaceous vegetation could affect species diversity and richness. Results presented here are short-term, and monitoring should continue in order to determine long-term effects on stand development.

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