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Changes in vegetation structure and composition in response to fuel reduction treatments in the South Carolina Piedmont

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Abstract

Fuel reduction treatments are helpful to restore ecosystem structure and function to forests that historically sustained frequent, low-intensity fires. But the impacts of these treatments on Piedmont forests are not well understood. We examined the effects of prescribed burning, thinning, and a combination of burning and thinning on community composition of *Pinus taeda*/*Pinus echinata* forests in the South Carolina Piedmont to identify changes in community structure and species composition. Overstory basal area was reduced across all treatments. The combination of thinning and burning resulted in a substantial increase in sapling density, whereas the burn-only decreased slightly after 3 years. Seedling density for all tree species increased across all treatment units during the same time span. In addition, cover of grasses and forbs increased in the burn-only and thin + burn treatments. Treatments appeared to affect understory life forms differently with the burn-only treatment encouraging forb cover while the thin + burn treatment promoted shrub and graminoid abundance. Non-metric multidimensional scaling (NMS) indicated rapid changes in understory composition for the burn-only and thin + burn treatments, whereas the thin-only treatment showed a more gradual shift over time.
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Keywords: Prescribed fire; Thinning; *Pinus taeda*; South Carolina Piedmont; Species richness; Non-metric multidimensional scaling

1. Introduction

The southeastern Piedmont is a unique transitional region between the pine forests of the Coastal Plain and the hardwood forests of the Appalachian Mountains. In the past, fire functioned as an integral part of ecosystem development in the southern United States as Native Americans used burning to hunt, maintain prairies and grasslands, improve wildlife habitat, and clear land for agriculture (Van Lear and Waldrop, 1989; Williams, 1989; Silver, 1990; DeVivo, 1991; Carroll et al., 2002). The forests were characterized by an open, herbaceous understory with widely spaced trees and fire was observed throughout the landscape (Silver, 1990). Fire continued to be used as a tool for land management up until the 1900s when the federal government enacted the Clarke–McNary Act, which encouraged fire suppression by providing funding for such activities (Williams, 1989; Wade et al., 2000). Although prescribed fire was touted as a method to help reduce fuels in southern forests following major wildfires in the 1930s and 1950s (Stanturf et al., 2002), most forest land in the southeastern Piedmont is owned by non-industrial private landowners (Bechtold and Ruark, 1988) and remains unmanaged. Relatively little information is available on the effects of prescribed fire and fuel reduction treatments on vegetation in the southeastern Piedmont region.

Disruption of the fire cycle as well as other factors (e.g., farming and subsequent land abandonment, timber harvesting) has led to forests with less spatial heterogeneity, greater stem densities, and therefore, increased fuel loads. In South Carolina approximately 5000–6000 fires occur each year burning an average of 12,000 ha (South Carolina Forestry Commission, http://www.state.sc.us/forest/fire.htm). Since 1970, catastrophic wildfires (those over 400 ha) have occurred at the rate of one per year in South Carolina. Because of the high degree of urban/wildland interface in the region, fires of this size usually destroy homes, businesses, or other private property.

Fire-sensitive, shade-tolerant species are becoming established changing community composition (Halls and Homesley, 1966; Cowell, 1998) and altering nutrient cycling and decomposition rates in addition to other ecosystem functions (Lockaby et al., 1995). Fuel reduction techniques have been

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proposed to help restore stand structure and function to forests that traditionally experienced low-intensity fires with short return intervals (Mutch, 1994; Covington, 1995; Moore et al., 1999). Previous studies have documented the effects of silvicultural treatments on different vegetative components of *Pinus taeda* and *Pinus echinata* communities, but none have examined the effects of several different fuel reduction treatments on the entire vegetation community over time.

This work is a part of the National Fire and Fire Surrogate (FFS) study (http://www.fs.fed.us/ffs), which is evaluating the long-term effects of fuel reduction treatments (prescribed burning, mechanical treatment, prescribed burning + mechanical) on ecosystem structure and function at 13 sites across the U.S. (Weatherspoon, 2000). The study sites represent a variety of forest types that historically sustained frequent low-intensity surface fires which currently have greater stem densities and increased fuel loading as a result of long-term fire suppression. At the Southeastern Piedmont site the primary goals were to re-establish stand structure and composition characteristic of fire-adapted communities. We compared the effectiveness of dormant-season prescribed burns, thinning from below, and the combination of thinning and prescribed burning to achieve these goals while supporting stand management for timber production, wildlife habitat, and recreation.

We hypothesized that the combination of thinning and burning would have the greatest impact on stand structure and composition by reducing basal area and density for the overstory and midstory, and thus elicit the greatest increase in understory abundance. Intermediate levels of stand change and understory response were expected for the burn-only and thin-only treatments.

2. Methods

2.1. Study site

The study site is located on the Clemson Experimental Forest in Anderson, Oconee, and Pickens Counties, South Carolina. The forest, essentially reclaimed farm land, supported subsistence agriculture until the 1930s, which greatly reduced the land's productivity, as most of the topsoil was removed. Reforestation programs begun during the Great Depression and harvesting since that time have resulted in second- or third-growth timber on most of the forest. The dominant forest type is *P. taeda* and *P. echinata* with a mixture of oaks (*Quercus*), hickories (*Carya*), and other hardwoods.

Elevation ranges from 200 to 300 m. Topography is a factor of past erosion, ranging from rolling hills to moderately steep slopes. Most soils on the Clemson Experimental Forest are Ultisols, predominantly of the Cecil–Lloyd–Madison association (fine, kaolinitic, thermic Typic Kanhapludult), with moderate to extremely severe erosion (Herren, 1975). Entisols and Inceptisols are present but not abundant.

Average annual temperature and precipitation are 15.3 °C and 138 cm, respectively. Growing season (May–September) temperatures average 23 °C and precipitation during those months totals 54 cm. Drought conditions were prevalent in the southeast from 1999–2001, where deficits in annual precipitation greater than 43 cm for 2000 and 37 cm for 2001 were recorded (NCDC: Annual Climatological Summary, http://cdo.ncdc.noaa.gov).

2.2. Treatments

Thinning and burning levels were prescribed that would reduce fuels and follow standard silvicultural practices for managed stands in the Piedmont. Our prescription for thinning was to reduce basal area to 18 m^2/ha by removing small, merchantable-sized trees and diseased or insect-infested trees first, and cutting other trees as necessary to provide the target residual basal area. Residual tree spacing following treatment was approximately 6 m. Thinning treatments occurred in the winter of 2000–2001. Non-merchantable material was left on-site.

Prescriptions for the burn-only treatment were moderate-intensity fires resulting in some mortality of large overstory trees, whereas low-intensity fires were prescribed for the thin + burn treatment to kill saplings and small diameter overstory trees. Prescribed burns were conducted on three consecutive days for the burn-only treatment units in April 2001; ambient temperatures ranged from 22 to 30 °C, relative humidity (RH) was between 42% and 56%, and wind speeds varied from 4 to 10 km/h. The thin + burn treatment units were burned 1 year later (March 2002) to allow the slash to fully cure; ambient temperatures were 18–20 °C, RH 22–56%, and winds from 4 to 7 km/h. For all burns we used strip head fires spaced approximately 10 m apart. Observed flame lengths for both the burn-only and thin + burn units were 0.5–2.0 m. Maximum fire temperature was measured using heat-sensitive paint applied to ceramic tiles hung 0.8 m above the ground along the center-line of the vegetation plots (n = 5/plot). We recorded maximum temperatures of 253–399 °C in the burn-only plots and 177–253 °C in the thin + burn plots.

2.3. Field sampling

Twelve treatment units were selected on the basis of stand size, tree size distribution, and management history. Stands at least 14 ha in size were selected in order to allow for a 10-ha sampling area plus a buffer (approximately 20 m) to reduce edge effects. Tree size was used as a blocking factor to reduce variability, with blocks defined as: block 1—pulpwood-sized trees (dbh 15–25 cm); block 2—a mixture of pulpwood- and sawtimber-sized trees (dbh >25 cm); and block 3—sawtimber-sized trees. None of these areas had been thinned during the past 10 years and none had been burned (wild or prescribed) in at least 5 years.

Ten 0.1 ha vegetation plots (20 m × 50 m) were systematically placed every 200 m within each treatment unit using permanently marked, geo-referenced locations that had previously been established on a 50 m × 50 m grid. The direction of the long axis of each plot was randomly assigned one of the four cardinal directions (N, S, E, W). Each vegetation plot was subdivided into ten 10 m × 10 m subplots, five of

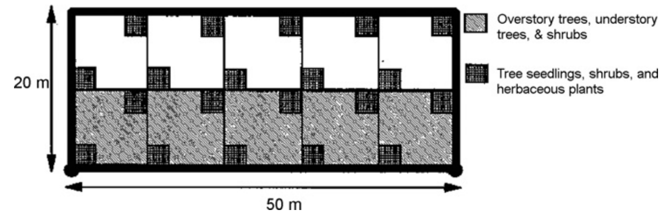

Fig. 1. Schematic of plots used to sample vegetation. Overstory trees, saplings, and shrubs greater than 1.4 m in height were measured on five 10 m × 10 m subplots within each 0.1-ha plot. Understory species (<1.4 m in height) were measured in 1 m^2 quadrats (20 total for each plot) located in opposite corners of each 10 m × 10 m subplot.

which were used to measure overstory trees (10 cm dbh or larger), saplings (tree species taller than 1.4 m and dbh <10 cm), and shrubs >1.4 m tall (Fig. 1). We recorded species, dbh, status (live or dead), and incidence of disease and/or beetles for each overstory tree. Diseases were identified by causal species and beetles were identified as southern pine beetle (*Dendroctonus frontalis*) or *Ips* species. Saplings were identified by species and status (live or dead) and assigned to one of three dbh classes: <3 cm, 3–6 cm, >6 cm. For shrubs greater than 1.4 m in height, we visually estimated the percentage of ground covered by each species within the subplots.

Twenty 1 m^2 quadrats were established in each 0.1-ha plot for measurement of understory vegetation (woody stems <1.4 m tall and all herbaceous species) (Fig. 1). Ocular estimates of each species were recorded using cover classes: <1%, 1–10%, 11–25%, 26–50%, 51–75%, and >75%. Additionally, tree seedlings/sprouts <1.4 m tall were tallied by height classes (<10 cm, 10–50 cm, and >50 cm). All plants were identified to species level following USDA PLANTS database nomenclature (USDA, NRCS, 2006). In situations where species were too similar to distinguish in the field, we grouped them by genus which resulted in slight under-estimations of species richness. Pre-treatment sampling was conducted from May to August in 2000 with subsequent measurements during the growing season immediately following treatment, and 3 years after treatment.

2.4. Data analysis

Densities (stems/ha) for overstory trees, saplings, and seedlings were computed for each 0.1-ha vegetation plot ($n = 30$ plots/treatment). Pre-treatment values were subtracted from both 1st year and 3rd year post-treatment measurements to account for pre-treatment differences. These change variables were subjected to repeated measures ANOVA with treatment and year modeled as fixed effects and block as a random effect. To account for differences among years, we interpreted significant treatment and (or) treatment × year interactions ($\alpha = 0.05$), as evidence of treatment effect differences and made post hoc comparisons using Tukey's multiple comparison procedure.

All species in the understory vegetation were classified into general life form categories (tree, shrub, vine, graminoid, and forb) for analysis. Actual cover values were derived from cover classes by assigning the mid-point of each cover class and summing all 20 quadrats across each 0.1-ha plot. Pre-treatment cover values for tree seedlings were not recorded; therefore, cover values presented represent shrubs, vines, graminoids, and forbs. Analyses of understory changes were conducted using the same methods as described for stem densities.

Non-metric multidimensional scaling (NMS) (McCune and Mefford, 1999) was used to examine differences in understory composition due to treatment effects. To test compositional change across all treatment units over time, we analyzed presence/absence data for the understory layer (since cover values were not available for tree seedlings prior to treatment) so that we could include all species for pre-treatment, year 1, and year 3. Rare species, defined as those occurring in less than two percent of sampled quadrats, were removed from the data set. Ordinations were performed using the following settings: Sorensen distance measure; 400 maximum iterations; 6 axes; 0.00001 instability criterion; 40 real runs; 50 randomized runs. The three-dimensional solution was identified as sufficiently reducing stress and used as the final ordination.

3. Results

3.1. Overstory

Overstory basal area (all *P*-values <0.0010) and stem densities (all *P*-values <0.0001) decreased across all treatments with the largest reductions occurring in thin + burn (Fig. 2). The thin-only treatment was not as intense as anticipated as harvesting only reduced basal area to 21.3 m^2/ha (1st year post-treatment), whereas the burn-only and thin + burn treatments achieved our target residual basal area with 18.6 and 16.7 m^2/ha (as measured immediately following treatment), respectively. Large reductions in pine basal area and stem densities in the control, thin-only and burn-only treatments from year 1 to year 3 were primarily caused by the southern pine beetle. The control and the burn-only treatment sustained the greatest losses from beetle infestation with declines of more than 30%.

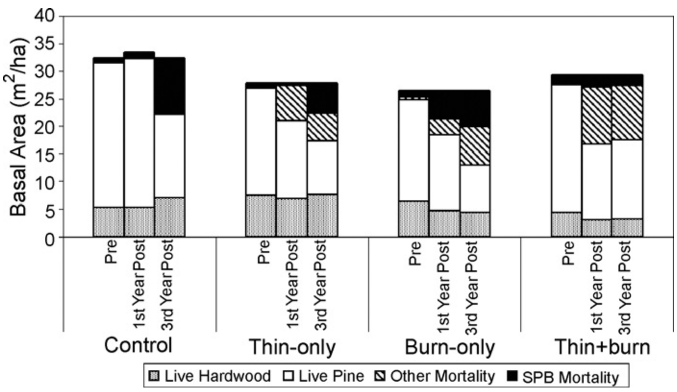

Fig. 2. Total basal area and mortality due to southern pine beetle (SPB) of overstory trees (dbh ≥10 cm) for pine and hardwood species for pre-treatment, 1st year, and 3rd year post-treatment measurements. "Other Mortality" includes death resulting from natural causes as well as treatment effects (e.g., harvesting, top-killed by fire).

Table 1
Basal area and density for common overstory trees of the Southeastern Piedmont Fire and Fire Surrogate study site

	Control			Thin-only			Burn-only			Thin + burn		
	Pre	1st year post	3rd year post	Pre	1st year post	3rd year post	Pre	1st year post	3rd year post	Pre	1st year post	3rd year post
Basal area (m^2/ha)												
Pinus taeda	21.5	22.2	12.1	15.1	10.8	6.5	12.2	9.2	6.7	15.8	9.3	10.2
Pinus echinata	2.3	2.2	1.5	2.5	2.1	1.7	4.0	3.1	1.4	4.7	3.4	3.1
Pinus virginiana	2.5	2.6	1.7	2.6	1.6	1.6	2.3	1.6	0.4	2.2	1.1	1.1
Liriodendron tulipifera	0.7	0.7	0.6	2.1	2.1	2.3	0.4	0.4	0.4	0.8	0.7	0.8
Quercus alba	0.3	0.4	0.5	1.3	1.1	1.2	1.0	0.7	0.6	0.3	0.2	0.2
Liquidambar styraciflua	0.9	0.9	1.0	0.9	0.8	0.9	0.3	0.3	0.3	0.9	0.3	0.4
Oxydendrum arboreum	0.4	0.4	0.7	0.8	0.7	0.8	0.8	0.5	0.4	0.3	0.2	0.2
Prunus serotina	0.3	0.4	0.5	0.2	0.1	0.2	0.4	0.2	0.2	0.6	0.4	0.3
Total	31.8	32.9	22.3	24.6	21.3	17.3	24.9	18.6	13.0	27.2	16.7	17.4
Density (stems/ha)												
Pinus taeda	493	492	165	440	273	150	311	225	151	462	213	207
Pinus echinata	63	59	37	59	44	37	141	106	41	130	67	61
Pinus virginiana	71	70	35	91	47	49	74	41	15	93	39	39
Liquidambar styraciflua	41	44	46	39	33	45	10	9	9	47	21	21
Oxydendrum arboretum	15	15	30	39	36	41	43	28	21	14	9	9
Quercus alba	9	9	13	48	42	43	33	16	12	13	8	7
Prunus serotina	20	21	24	16	12	19	26	13	11	33	14	11
Liriodendron tulipifera	20	19	22	36	31	38	11	9	9	27	21	23
Total	844	835	525	845	576	489	785	532	343	902	439	433

Sampling occurred prior to treatment (pre), immediately following treatment (1st year post), and 3 years after treatment (3rd year post).

Relative importance of common hardwood species (*Liquidambar styraciflua*, *Oxydendrum arboreum*, *Liriodendron tulipifera*, *Quercus alba*, *Prunus serotina*) increased by 10.78%, 16.39%, 7.65%, and 1.03% from pre-treatment to year 3 for the control, thin-only, burn-only, and thin + burn, respectively (Table 1).

3.2. Midstory

Sapling density decreased across all treatment units immediately following treatment; however, treatment effects differed among species (Table 2). Moderate increases in overall sapling density were observed in the thin-only treatment largely resulting from sprouting of *L. tulipifera* and *L. styraciflua*, but changes in densities for these species were not significantly different from the burn-only and thin + burn treatments. Burning alone significantly reduced overall sapling density compared to other treatments, causing high rates of mortality for *Pinus* and *Quercus* saplings (>70%) immediately following treatment. After 3 years, *Pinus* saplings showed little recovery, whereas *Quercus* saplings had returned to higher than pre-treatment levels. The combination of thinning plus burning resulted in the largest increase in sapling density, practically doubling the number of stems/ha present before treatment. *P. serotina* and *L. styraciflua* were significantly greater in the thin + burn treatment than other treatments. *Quercus* saplings also increased in response to the thin + burn treatment resulting in more stems/ha than all other treatments (but did not differ statistically from the burn-only treatment).

Tall shrubs (greater than 1.4 m tall) were not significant components in these forest stands with pre-treatment cover of 1.6%, 1.7%, 3.2%, and 5.9% for the control, thin-only, burn-only, and thin + burn treatments, respectively. Treatment resulted in an overall increase of tall shrub cover for the control (+2.5%) and thin-only treatment (+2.3%), whereas the burn-only (−1.9%) and thin + burn (−4.7%) treatments decreased; however, none of the differences were significant ($P_{trt} = 0.0645$; $P_{trt \times time} = 0.0796$).

3.3. Understory layer

3.3.1. Tree seedlings

Total tree seedling density increased across all treatments over 3 years with immediate responses evident for the burn-only and thin + burn treatments (Table 2). The thin-only treatment showed a delayed response with moderate gains in stems/ha for the 1st post-treatment sampling; yet by year 3, total seedling density was similar to the burn-only and thin + burn treatments. We also observed increases in seedling numbers within the controls after 3 years as overstory basal area declined following pine beetle infestation.

Thinning appeared to favor *Pinus* and *L. tulipifera* seedlings, whereas thinning plus burning resulted in a significant positive response for *Quercus* seedlings. Burning alone caused an increase in *Quercus* seedlings immediately following treatment, but after 3 years there were fewer stems/ha than present prior to treatment. Burning also negatively affected *P. serotina* as seedling regeneration continued to decline over 3 years.

Table 2
Means changes[a] between pre-treatment and each post-treatment sampling for sapling and seedling densities (±S.E.) of common tree species

	Time[b]	Control		Thin-only		Burn-only		Thin + burn		*P* values		Treatment effects[c]
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	P_{trt}	$P_{trt \times time}$	
Saplings (stems/ha)												
Pinus species	1	−66	24	−48.0	18	−285	172.0	−137	37.7	<0.0001	0.4676	$\mathrm{TB^{a}B^{a}T^{b}C^{b}}$
	2	3	20.9	−65	20.2	−313	162.4	−148	47.3			
Quercus species	1	−27	21.7	−229	70.7	−525	74.2	−693	110.4	0.0002	<0.0001	$\mathrm{C^{a}T^{ab}B^{bc}TB^{c}}$
	2	24	20.1	99	56.3	159	116.9	379	114.2			
P. serotina	1	−53	18.4	−101	28.8	−3	36.4	178	42.0	<0.0001	0.0001	$\mathrm{C^{a}T^{ab}B^{b}TB^{c}}$
	2	−20	14.9	77	22.5	177	35.8	345	52.2			
L. styraciflua	1	−2	7.3	−129	52.0	−83	51.9	−1	82.7	<0.0001	0.0003	$\mathrm{B^{a}C^{a}T^{a}TB^{b}}$
	2	20	8.8	217	51.5	25	21.4	1233	436.2			
L. tulipifera	1	−7	5.2	−74	28.0	−45	23.5	−98	73.8	0.0250	<0.0001	$\mathrm{B^{a}C^{ab}T^{ab}TB^{b}}$
	2	−14	9.5	55	26.4	−31	15.2	116	63.7			
O. arboreum	1	4	5.4	−39	20.9	−21	42.9	−65	34.2	0.7999	<0.0001	
	2	71	58.8	69	27.4	221	64.6	145	46.5			
All species	1	−146	70.0	−841	170.1	−1861	271.9	−1298	255.8	<0.0001	<0.0001	$\mathrm{B^{a}C^{b}T^{b}TB^{b}}$
	2	243	127.9	515	125.5	−175	280.1	2188	616.8			
Seedlings (stems/ha)												
Pinus species	1	−294	101.9	1050	231.9	−394	121.3	44	69.6	<0.0001	<0.0001	$\mathrm{C^{a}B^{ab}TB^{b}T^{c}}$
	2	367	103.7	2244	661.9	1094	294.7	967	186.1			
Quercus species	1	−417	135.3	−106	230.3	622	420.0	2561	469.2	<0.0001	<0.0001	$\mathrm{C^{a}B^{a}T^{a}TB^{b}}$
	2	−42	176.0	422	162.0	−433	320.4	1272	300.9			
P. serotina	1	306	262.1	594	255.4	−1200	422.2	−428	313.4	<0.0001	0.1048	$\mathrm{B^{a}TB^{ab}C^{bc}T^{c}}$
	2	342	268.6	889	357.4	−794	497.3	−761	227.7			
L. styraciflua	1	61	73.0	−156	192.3	417	206.8	1378	563.2	0.0111	0.0014	$\mathrm{C^{a}T^{ab}B^{ab}TB^{b}}$
	2	292	139.4	439	156.5	400	132.2	544	182.4			
L. tulipifera	1	22	17.4	822	326.1	756	253.3	606	194.8	0.0011	<0.0001	$\mathrm{C^{a}B^{ab}TB^{ab}T^{b}}$
	2	258	67.8	1239	220.4	461	171.1	389	109.1			
O. arboreum	1	6	12.6	6	35.3	533	227.8	367	184.7	0.0582	0.0956	
	2	58	38.8	122	71.0	144	63.8	217	93.9			
All species	1	−3433	1376.1	6017	2216.9	12083	2954.9	24250	5685.5	<0.0001	0.0008	$\mathrm{C^{a}T^{b}B^{b}TB^{b}}$
	2	8550	2284.7	19400	2249.3	17850	6504.4	18717	4871.8			

"Saplings" were defined as stems taller than 1.4 m with dbh < 10 cm. "Seedlings" were stems <1.4 m in height.

[a] Actual means for changes between pre-treatment and post-treatment measurements are presented in table. ANOVA was performed using square root transformed data.

[b] Time codes represent difference between pre- and post-treatment measurements: 1 = pre-treatment density subtracted from 1st year post-treatment; 2 = pre-treatment density subtracted from 3rd year post-treatment. Different letters denote significant differences between sampling intervals.

[c] Significant differences in treatment effects are indicated by different letters. Treatments are ordered from lowest to highest.

3.3.2. Treatment effects on species

The total number of species identified in the understory layer was 348 of which 54 species were tree seedlings, 37 shrubs, 16 vines, 35 graminoids, and 206 forbs. By year 3, understory (<1.4 m in height) shrub cover remained relatively unchanged from pre-treatment values for the control, thin-only, and burn-only treatments (Table 3). However, shrub cover in the thin + burn treatment increased immediately following treatment with more than twice as much cover as pre-treatment by the 3rd year post-treatment sampling. *Lespedeza bicolor*, *Vaccinium arboreum*, and *Vaccinium stamineum* showed significant treatment effects as the thin + burn significantly increased *L. bicolor* ($P_{trt} = 0.007$; $P_{trt \times time} = 0.0664$); the burn-only resulted in greater abundance of *V. arboreum* ($P_{trt} = 0.0015$; $P_{trt \times time} = 0.0409$); and thinning increased *V. stamineum* ($P_{trt} = 0.0016$; $P_{trt \times time} = 0.0264$).

Woody vine cover increased slightly for the thin-only and thin + burn treatments but did not differ statistically from the control, whereas the burn-only treatment showed significantly greater abundance of vines. For the common vine species, *Lonicera japonica* ($P_{trt} = 0.0201$; $P_{trt \times time} = 0.0016$), *Toxicodendron radicans* ($P_{trt} = 0.0217$; $P_{trt \times time} = 0.1010$), and *Gelsemium sempervirens* ($P_{trt} = 0.0001$; $P_{trt \times time} = 0.0769$) showed statistically significant responses to treatment: *L. japonica* responded positively to thinning (thin-only and thin + burn); *T. radicans* increased in the thin-only and burn-only treatments, but consecutive disturbances (thinning followed by burning) resulted in a decline in abundance for this species; and *G. sempervirens* showed a negative response to the thin-only treatment.

Graminoid cover increased in the burn-only and thin + burn treatments with the combination of thinning and burning producing the greatest response. Although *Danthonia sericea*, *Schizachyrium scoparium*, *Andropogon virginicus*, and *Carex* species increased cover in response to the burn-only and thin + burn treatments, only *Panicum* showed statistically significant differences ($P_{trt} = 0.0178$; $P_{trt \times time} = 0.00084$).

Forb cover increased immediately following burning (burn-only and thin + burn), but after 3 years only stands that were subjected to prescribed fire alone differed statistically from all

Table 3
Mean changes[a] from pre-treatment to each post-treatment sampling in understory abundance (±S.E.) of life forms

	Time[b]	Control		Thin-only		Burn-only		Thin + burn		*P* values		Treatment effects[c]
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	P_{trt}	$P_{trt \times time}$	
Shrubs	1	−0.46	0.21	−0.75	0.23	−2.61	0.71	0.65	0.57	<0.0001	0.0095	B[a]C[a]T[a]TB[b]
	2	−0.41	0.32	0.27	0.45	−0.03	0.66	4.51	1.00			
Vines	1	−1.15	0.50	−1.28	0.49	−0.33	0.64	0.11	0.55	0.0072	0.3120	C[a]T[ab]TB[ab]B[b]
	2	−2.73	1.54	0.09	0.70	3.23	1.38	0.94	0.70			
Graminoids	1	−0.38	0.16	−0.51	0.26	−0.11	0.41	4.51	0.76	<0.0001	0.0043	C[a]T[ab]B[b]TB[c]
	2	−0.48	0.22	0.52	0.41	3.26	0.73	6.16	1.03			
Forbs	1	−0.26	0.09	−0.36	0.12	2.63	0.83	5.10	1.27	<0.0001	<0.0001	C[a]T[a]TB[a]B[b]
	2	−0.22	0.10	0.29	0.44	2.63	0.53	0.62	0.90			

[a] Actual mean changes from pre-treatment to post-treatment measurements are presented in table. ANOVA was performed using arcsine square root transformed data.
[b] Time codes represent difference between pre- and post-treatment measurements: 1 = pre-treatment density subtracted from 1st year post-treatment; 2 = pre-treatment density subtracted from 3rd year post-treatment. Different letters denote significant differences between sampling intervals.
[c] Significant differences are indicated by different letters. Treatments are ordered from lowest to highest.

other treatment units. *Erechtites hieraciifolia* and *Conyza canadensis* (all *P*-values <0.0001) significantly increased in the burn-only treatment although *C. canadensis* was not recorded until the 3rd year post-treatment sampling. *Eupatorium capillifolium* was not recorded on any plot prior to treatment, but showed significant increase in abundance in response to the thin + burn treatment ($P_{trt} = 0.0001$; $P_{trt \times time} = 0.0593$).

Species richness at the plot level (0.1 ha) increased across all treated units with significantly more species in all treatments than the control ($P_{trt} = 0.0014$, $P_{trt \times time} < 0.0001$) (Table 4). The thin + burn treatment significantly increased species richness in both year 1 and year 3 and resulted in the greatest number of species. The burn-only and thin-only treatments showed only slight increases immediately following treatment yet by year 3 had similar species richness as the thin + burn.

3.3.3. Community composition

Ordination revealed similar trajectories of species compositional change within treatments over time (Fig. 3). The final stress for three axes (13.7%) fell on the low end of the expected range of 10–20% and was considered acceptable (i.e., a good representation of the original distance matrix) (McCune and Grace, 2002). The proportion of variance explained for each ordination axis was 10.4% for Axis 1, 48.5% for Axis 2, and 23.8% for Axis 3 (cumulative $r^2 = 0.826$). Understory species showing high negative correlations with Axis 1 were *Calycanthus floridus*, *Trillium* species, *Hepatica acutiloba*, and *Sanguinaria canadensis* (Table 5), whereas *Hieracium gronovii* and *Potentilla canadensis* exhibited strong positive associations with this axis. Axis 2 indicated separation between species typically found in mesic conditions versus species characteristic of xeric habitats. Axis 3 showed strong positive association with early-seral species (e.g., *E. capillifolium*, *Phytolacca americana*, *Acalypha gracilens*, and *E. hieraciifolia*).

Table 4
Mean plot level (0.1 ha) species richness (±S.E.)

Year	Control	Thin-only	Burn-only	Thin + burn
Pre	30.5 ± 1.8	26.3 ± 1.3	27.4 ± 1.6	29.8 ± 1.3
1st year post	28.4 ± 1.9a	28.0 ± 1.3a	29.0 ± 1.2a	37.1 ± 1.5b
3rd year post	31.7 ± 2.0a	39.5 ± 1.7b	41.3 ± 1.5b	45.1 ± 1.7b

Means within rows followed by the same letter are not significantly different ($\alpha = 0.05$).

In NMS axis order does not necessarily correspond to relative importance; therefore, we chose to display axes 2 and 3 since they accounted for the majority of variation in the ordination. Treatment units showed similar trends across ordination axes from pre-treatment to the 1st post-treatment sampling, increasing along Axis 2 (left to right) and Axis 3 (bottom to top) (Fig. 3). From the 1st year to 3rd post-treatment sampling, the thin-only treatment units changed little with respect to Axis 2, but continued to increase along Axis 3. Compositional changes between years 1 and 3 were larger than those from pre-treatment to year 1. For the burn-only and thin + burn treatments, species composition demonstrated rapid initial responses to treatment with substantial changes in community composition; however from year 1 to year 3, these changes were less extreme. The burn-only treatment units continued to show influence of early-seral species between the 1st and 3rd year post-treatment sampling.

4. Discussion

Fuel reduction techniques used in this study significantly changed stand structure and composition across all treatments. The thin-only treatment reduced overstory density and basal area, but stimulated hardwood sprouting, resulting in a greater number of saplings. Changes in the understory were evident as seedling regeneration was greater and abundance of shrubs, graminoids, and forbs increased, but these results were delayed until the 3rd year after treatment. Incidence of southern pine beetle provided a confounding factor in trying to identify treatments effects. Although Boyle et al. (2004) found no significant differences in beetle-caused mortality among treatments, increased light in the control units encouraged sapling growth as well as seedling establishment making

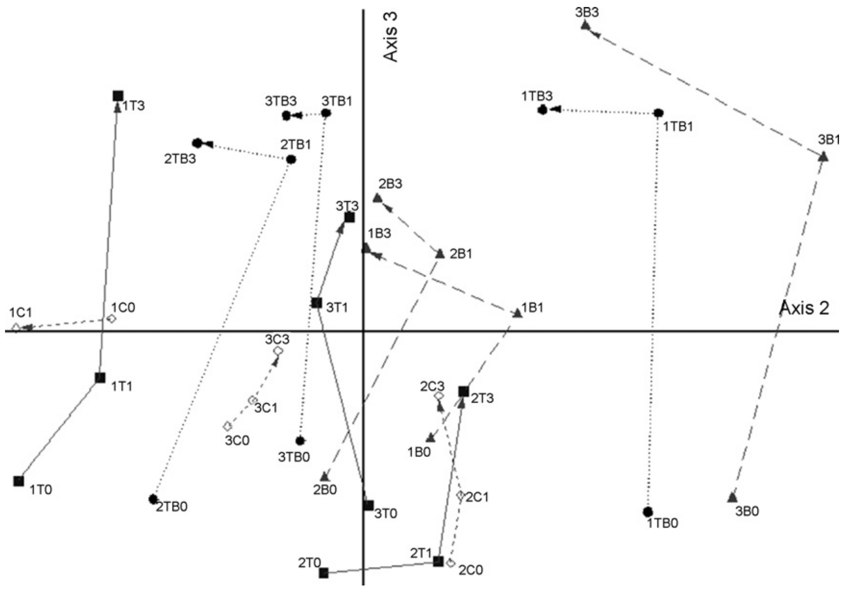

Fig. 3. NMS ordination for effects of fuel reduction treatments on species composition of the understory layer. Vectors connect plots for consecutive sample years, with vector length corresponding to compositional change. Plots are labeled by block: 1, 2, 3; treatment: C = control (◇); T = thin-only (■); B = burn-only (▲); TB = thin + burn (●); and sample year: 0 = pre-treatment; 1 = 1st year post-treatment; 3 = 3rd year post-treatment.

significant differences between the control and thin-only treatment difficult to detect. We expected the thin-only plots to respond in a manner similar to those of the burn-only treatment with increases in cover of early-seral, herbaceous species as more light was available in the understory and disturbance of the forest floor provided a suitable habitat for seed germination. However, the higher basal area initially following thinning (as compared to the other treatments), the small increase in sapling density, and the patchy nature of forest floor disturbance (i.e., compaction, no disturbance, increased litter and fuel depth, exposed mineral soil) may explain the delayed response. Thomas et al. (1999) and Zenner et al. (2006) identified significant increases in herbaceous cover in response to different levels of harvesting and indicated that different life forms were affected by certain harvest intensities—graminoids and forbs required more intense harvesting to significantly increase abundance. Our thinning treatment reduced basal area by 22% and may not have been of sufficient intensity to elicit a rapid response similar to Zenner et al. (2006). Physical changes as a result of this treatment (e.g., soil compaction and residual slash) could present physical barriers to plant growth and seed germination, requiring more time for responses to be observed. The proportion of hardwood basal area may have also been a factor in the response of the understory layer to the thin-only treatment. Shelton and Murphy (1997) and Miller et al. (1999) demonstrated that decreasing basal area of hardwoods resulted in a higher abundance of herbaceous species in southern pine-oak forests. The thin-only treatment retained the greatest proportion of hardwoods of all treatments which may have moderated the understory response.

The burn-only treatment significantly decreased densities of overstory trees and saplings and changed species compositions of these stands. Dormant-season burning favors the development of a hardwood midstory (Hodgkins, 1958; Langdon, 1981; Waldrop et al., 1992; Clendenin and Ross, 2001) and increases the abundance of herbaceous vegetation (Jones, 1989; Wade et al., 1989; Cain et al., 1998; Sparks et al., 1998). Results from this study support those findings. We observed substantial reduction of *Pinus* saplings in response to burning, contrasted by increasing stem densities of *Quercus* species, *P. serotina*, and *O. arboreum* via prolific stump sprouting. Overall reduction in overstory and midstory densities allowed more light to reach the forest floor promoting large increases in herb (graminoid and forb) abundance, most likely attributed to a germination response as litter and duff were reduced and available light increased. Sparks et al. (1998) found late growing-season burns reduced the abundance of *Panicum* species 1 year after burning in *P. echinata* grassland communities of Arkansas, whereas late dormant-season burns increased *Panicum* abundance and distribution and favored legumes. Although we also observed a large positive response in *Panicum*, this did not occur until the third growing season after burning. Small increases in the abundance of several legumes (*Chamaecrista nictitans*, *Desmodium* species, *Lespedeza* species, and *Stylosanthes biflora*) were also detected, but these species did not show any statistical difference from the control or other treatments. Forbs showed an immediate response to burning as early-seral, seed-banking species (e.g., *E. hieraciifolia*, *P. americana*) became established. However, increases in herb and graminoid abundance may be short-lived if fire does not recur at frequent enough intervals (Wade et al., 1989; Waldrop et al., 1992).

Significant reductions in overstory basal area and density in the thin + burn treatment encouraged sapling growth and increased abundance of understory vegetation. All life forms exhibited immediate responses to treatment with herbaceous vegetation showing the greatest gains. However, from year 1 to year 3, forb cover had decreased approximately 50% while

Table 5
Understory species highly correlated with the first 3 non-metric multidimensional scaling (NMS) ordination axes for stands treated for fuel reduction

Species	Axis 1		Axis 2		Axis 3	
	r[a]	τ[a]	r	τ	r	τ
Acalypha gracilens	−0.124	−0.064	0.056	0.074	0.680	0.558
Aralia spinosa	−0.043	−0.071	0.350	0.272	0.714	0.560
Asplenium platynueron	−0.181	−0.129	−0.718	−0.579	−0.211	−0.161
Botrychium dissectum	−0.165	−0.136	−0.577	−0.560	0.113	0.106
Calycanthus floridus	−0.685	−0.541	0.234	0.245	−0.248	−0.206
Campsis radicans	0.242	0.172	−0.750	−0.689	0.142	0.124
Conyza canadensis	0.247	0.218	−0.039	−0.011	0.667	0.530
Croptilon divaricatum	0.076	0.078	−0.020	0.010	0.641	0.513
Diospyros virginiana	0.002	0.053	0.320	0.249	0.570	0.469
Erechtites hieraciifolia	−0.166	−0.112	0.123	0.112	0.680	0.572
Eupatorium capillifolium	0.099	0.073	0.223	0.165	0.857	0.684
Gelsemium sempervirens	−0.083	−0.059	−0.634	−0.469	−0.128	−0.076
Hepatica acutiloba	−0.533	−0.323	−0.041	−0.040	0.111	0.111
Hieracium gronovii	0.673	0.563	−0.135	−0.109	−0.169	−0.143
Hypoxis hirsuta	0.140	0.076	0.424	0.328	0.645	0.504
Ligustrum sinese	−0.005	0.014	−0.736	−0.636	0.107	0.110
Liquidambar styraciflua	−0.263	−0.221	−0.690	−0.495	−0.138	−0.094
Lonicera japonica	−0.247	−0.211	−0.730	−0.541	−0.274	−0.193
Parthenocissus quinquefolia	−0.065	−0.023	−0.656	−0.504	0.092	0.082
Paspalum dilatatum	0.219	0.194	0.069	0.054	0.591	0.462
Passiflora incarnata	−0.022	0.010	0.249	0.217	0.575	0.479
Passiflora lutea	−0.625	−0.482	−0.033	−0.054	0.314	0.257
Phytolacca americana	−0.051	−0.042	0.064	0.052	0.818	0.675
Piptochaetium avenaceum	−0.140	−0.183	0.583	0.518	0.318	0.242
Potentilla canadensis	0.519	0.324	−0.376	−0.228	0.076	0.074
Pteridium aquilinum	0.144	0.056	0.753	0.684	−0.128	−0.112
Rhus copallinum	0.195	0.118	0.391	0.345	0.681	0.553
Sanguinaria canadensis	−0.533	−0.323	−0.041	−0.040	0.111	0.111
Toxicodendron pubescens	0.222	0.186	0.651	0.510	0.141	0.093
Trillium species	−0.602	−0.333	−0.028	−0.020	−0.112	−0.091
Ulmus alata	0.332	0.227	−0.669	−0.558	−0.063	−0.030
Vaccinium pallidum	−0.281	−0.218	0.697	0.591	−0.035	−0.047

[a] Pearson's parametric (r) and Kendall's non-parametric (τ) correlations for all treatments (control, thin-only, burn-only, and thin + burn) prior to treatment, 1 year post-treatment, and 3 years post-treatment.

graminoid abundance continued to increase, similar to results obtained by Brockway et al. (1998) for *P. taeda* and *P. echinata* forests in the Gulf Coastal Plain following site preparation treatments.

Ordination suggested large changes in species composition in relation to moisture and light. Following burning, treatment units showed higher incidence of species associated with xeric sites as well high light, open environments. Changes in species composition for the thin-only units appear to be related to germination of early-seral species. Halpern (1988) discussed the resilience of *Pseudotsuga* forests in Oregon to logging and (or) burning over 21 years. He demonstrated that significant changes in understory composition occurred immediately following disturbance, although over time these sites gradually returned to pre-disturbance composition. He stated that unburned, logged sites would exhibit successional patterns intermediate to sites that were burned but not logged. Our results show similar trends—a rapid floristic change from initial composition was observed for plots that were burned (burn-only and thin + burn), while thin-only treatment areas showed a more gradual shift over time. While these results indicated significant changes, initially, in community composition due to fuel reduction treatments, distinct communities as a result of these treatments were not evident in our ordination. It should be emphasized that these results are short-term and continued monitoring over time will be necessary to identify possible changes to community composition.

Annual climate differences could have affected species composition and abundance, particularly in the understory vegetation. Larger than normal deficits in precipitation resulting from drought conditions in 2000–2001 correspond to pre-treatment and the 1st post-treatment sampling for the control, thin-only and burn-only treatments and may have resulted in lower estimates of species cover and richness. Pre-treatment measurements for the thin + burn treatment also occurred under drought conditions, but the 1st post-treatment sampling was conducted during a year of average rainfall, which could have resulted in slightly higher values of abundance and richness.

Fuel reduction techniques used in this study significantly effected stand structure and species composition in *P. taeda*/*P. echinata* forests of the southeastern Piedmont. Reduction of overstory basal area from the thin-only treatment promoted sapling growth and encouraged regeneration of shade-intolerant trees. Medium-intensity burning (the burn-only treatment) created open stands with high mortality of overstory and saplings, which translated into greater understory abundance, particularly with respect to forbs. The combination of thinning and low-intensity burning (thin + burn) caused significant increases in sapling densities in addition to promoting growth of understory shrubs and graminoids. By changing stand structure through mechanical thinning and (or) re-introducing fire, land managers can encourage growth of different understory components.

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