OCCURRENCE AND SPREAD OF NONNATIVE INVASIVE PLANTS IN STANDS TREATED WITH FIRE AND/OR MECHANICAL TREATMENTS IN THE UPPER PIEDMONT OF SOUTH CAROLINA

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Abstract—Increasing numbers of nonnative invasive plant species and the expansion of existing nonnative plant populations provide challenges for land managers trying to achieve commercial and restoration goals. Some methods used to achieve these goals, e.g., prescribed fire and mechanical treatments, may result in disturbances that promote the establishment and spread of invasive species. Natural disturbances, e.g., insect infestations, can also provide opportunities for nonnative plant expansion. We examined the effects of fuel-reduction treatments on the occurrence and abundance of nonnative invasive plants for mixed *Pinus taeda*/*P. echinata* stands that had sustained southern pine beetle (*Dendroctonus frontalis*) infestations and those that had not. Invasive plant abundance appeared to be greatest 3 to 5 years after disturbance. For stands not affected by southern pine beetles, the combination of mechanical treatment plus burning resulted in the largest increases for invasive species. Stands suffering pine beetle damage and subjected to mechanical treatment showed higher invasive abundance as compared to other treatments. Some invasive species responded differently to treatments. This information can help direct land management decisions.

INTRODUCTION

Invasions of nonnative plant species have received considerable attention over the last few decades as land managers are faced with increasing issues of exotic plant control, which can affect biodiversity, forest productivity, and disturbance regimes (Gordon 1998, Levine and others 2003, Vitousek 1990). Fuel-reduction treatments intended to reduce fuel loading and restore community composition and structure may be contributing to nonnative plant invasion and expansion (e.g., Metlen and Fiedler 2006); therefore, managers need information on the changes to community structure, environmental variables, and invasive plant dynamics in response to these treatments.

Natural disturbances can also provide opportunities for nonnative plant expansion. Outbreaks of southern pine beetle (*Dendroctonus frontalis* Zimm.) occur periodically in the Southern United States with severe outbreaks causing extensive damage to large areas of pine forests. In South Carolina, southern pine beetle infestations from 2000 until the winter of 2002 affected over 2.2 million ha (U.S. Department of Agriculture Forest Service 2003a) and caused losses over $250 million for 2002 alone (U.S. Department of Agriculture Forest Service 2002). For existing nonnative plant populations in the understory of these affected areas, overstory mortality can lead to expansion of these plant populations as limiting resources become more available.

It has been estimated that economic impacts of invasive species exceed more than $4 billion a year (U.S. Department of Agriculture Forest Service 2003b). With invasive species comprising up to 48 percent of the total flora for some States and the expected increase of nonnative species as globalization continues and climate conditions change (Dukes and Mooney 1999), dealing with these species will continue to be a major issue for land managers.

We examined the effect fuel-reduction treatments had on nonnative invasive plant abundance and how this was influenced by additional natural disturbances, i.e., southern pine beetle infestation. We also looked at the changes in understory species composition over time as it related to differences in stand structure with particular emphasis on nonnative invasive species.

STUDY SITE

The study site is in the South Carolina Piedmont on the Clemson Experimental Forest (34°40' N, 82°49' W) in Anderson, Oconee, and Pickens Counties. The dominant forest type is *Pinus taeda* L. and *P. echinata* Mill. growing over highly degraded soils. Most of the forest is second- or third-growth timber resulting from reforestation programs of abandoned agricultural fields in the early 1900s. The area also had a history of intentional introductions of nonnative plants for erosion control, wildlife forage, and/or horticultural purposes (Sorrells 1984). The climate of the region is characterized by mean monthly temperatures between 5 °C and 26 °C, and mean annual precipitation of 1372 mm distributed evenly throughout the year (National Oceanic and Atmospheric Administration 2002).

METHODS

We used a randomized complete block design with each treatment replicated three times. The treatments for intact pine stands, i.e., no presence of pine beetles at study initiation, included: (1) mechanical treatment by means of a single entry thinning from below (conducted in the winter of 2000 to 2001) with a target basal area of 18 m^2/ha,

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(2) prescribed burning during the spring every 3 years, (3) the combination of mechanical treatment plus burning, and (4) an untreated control. The first prescribed burns were performed in 2001 for the burn-only treatment, whereas the burns for the mechanical+burn treatment occurred the following year. A second round of burns was conducted in 2004 and 2005 for the burn treatment and mechanical+burn treatment, respectively. Pine beetle damage was so extensive in the original burn treatment that a second set of burn treatments was established (designated as “burn1” for the original and “burn2” for the replacements). For the initial burns, we recorded maximum temperatures of 253 °C to 399 °C in the “burn1” treatment; 177 °C to 253 °C for the “burn2” treatment, and 177 °C to 253 °C in the mechanical+burn treatment. Maximum temperatures for the second burn in the mechanical+burn treatment ranged from 204 °C to 816 °C. Details on fire behavior and weather are reported by Phillips and Waldrop (2008). Additional treatment units were selected from stands that sustained southern pine beetle damage, where all overstory pines had been killed over an area of at least 15 ha and that had active pine beetles within 2 years prior to plot establishment. To reduce fuel loading for these stands, we used: (1) a mastication treatment, which removed all dead overstory trees and turned large woody fuel into mulch, (2) low-intensity site prep burns conducted in the late spring of 2006, and (3) high-intensity site prep burns, also in the spring of 2006. An untreated control was established for comparison. Maximum temperatures measured at 1 m above the forest floor for the beetle-killed prescribed burns ranged from 181 °C to 216 °C for the low-intensity burn treatment and from 291 °C to 320 °C for the high-intensity burn treatment.

Understory vegetation (<1.4 m tall) was measured on twenty 1-m^2 subplots nested within 0.1-ha modified Whittaker plots prior to treatment (year 0), immediately following treatment (year 1), and every year thereafter (year 2, year 3, etc.) for up to 7 years. For the intact pine stands we measured ten 0.1-ha plots per treatment area, whereas the size of the beetle-killed stands permitted only two 0.1-ha plots. All understory vegetation was recorded by cover class: 1 = <1 percent; 2 = 1 to 10 percent; 3 = 11 to 25 percent; 4 = 26 to 50 percent; 5 = 51 to 75 percent; and 6 = >75 percent. Each cover class was assigned the value of the class midpoint and averaged across plots for data analysis. We selected a subset of nonnative invasive species to analyze based on maximum abundance, number of occurrences, and threat classification. All species selected are classified as “severe threat” for South Carolina, defined by the SC Exotic Pest Plant Council (2008) as posing significant risk to composition, structure, or function of natural areas. These species included: *Lonicera japonica* Thunb., *Lespedeza bicolor* Turcz., *Microstegium vimineum* (Trin.) A. Camus, *Ligustrum sinense* Lour., *Albizia julibrissin* Durazz., *Ailanthus altissima* (Mill.) Swingle, and *Pueraria montana* (Lour.) Merr. Diameter at breast height (d.b.h.) for all live overstory trees on one-half of the 0.1-ha plot was measured and converted to basal area for each treatment area.

We applied repeated measures analysis of variance to test differences in percent cover of selected nonnative invasive plants and their responses to each fuel-reduction treatment. To account for pretreatment differences, we subtracted pretreatment values from each posttreatment measurement. We made post-hoc comparisons using linear contrasts to test differences between each treatment and interpreted significant treatment and/or treatment by year interactions at $\alpha = 0.05$ as evidence of treatment effects. Data from stands unaffected by pine beetles were analyzed separately from beetle-killed stands.

Nonmetric multidimensional scaling (NMS) was used to examine changes in total understory vegetation composition over time due to treatment effects with particular emphasis on nonnative species. After removing rare species (occurring in <2 percent of sampled plots) from the dataset, we conducted ordinations using the Sørensen distance measure with 250 runs of real data and 250 runs of randomized data in 6 dimensions (McCune and Mefford 2006).

RESULTS AND DISCUSSION

Prior to fuel-reduction treatments, total cover of nonnative invasive species was considerably less in stands not impacted by pine beetles (0.8 percent) as compared to those that had sustained southern pine beetle damage (3.9 percent). Pine beetle infestations caused extremely high mortality for all overstory pines resulting in basal areas of ≤1 m^2/ha, whereas intact stands were characterized by basal areas of 25 m^2/ha or greater (Phillips and Waldrop 2008).

Time since disturbance appeared to be the most important factor affecting species abundance with species responding differently to the treatments (table 1). The greatest increases in nonnative invasive species cover were observed 3 to 5 years after treatment, primarily in the mechanical+burn treatment, as species were able to take advantage of more available resources quickly recovering from treatment disturbances or becoming established following treatment. *L. japonica* was significantly greater in the mechanical+burn treatment than all other treatments (*P*-values ≤ 0.0313) 3 years after treatment but significantly less than the mechanical treatment (*P*-value ≤ 0.0001) and control (*P*-value = 0.0008) 5 years after treatment. *L. sinense* also showed significant increases in the mechanical+burn treatment as compared to the “burn1” treatment (*P*-value = 0.0084), mechanical treatment (*P*-value = 0.0065), and control (*P*-value = 0.0087) after 3 years, but not the “burn2” treatment (*P*-value = 0.0823). *M. vimineum* was only recorded in the mechanical+burn treatment and the control with significant differences observed for the sampling period 3 years after treatment (*P*-value = 0.0074). Burning appeared to encourage growth and/or establishment for *L. bicolor*, *L. sinense*, and *A. julibrissin*, whereas *L. japonica* demonstrated a decrease in cover in the burn treatments but showed a slight increase in abundance after initial mechanical+burn treatment. However, successive burns for this treatment reduced cover to below pretreatment values. In contrast, the mechanical treatment resulted in continued growth of *L. japonica* as it was able to take advantage of more available light.

Table 1—Mean invasive plant cover (and standard error) for intact pine stands treated with fuel-reduction techniques in the upper Piedmont of South Carolina

Years since treatment[a]	Treatment	LONIJAP	LESPBIC	MICRVIM	LIGUSIN	ALBIJUL	AILAALT	PUERMON
0	Control	0.47 (0.16)	0.00 (0.00)	0.01 (0.01)	0.09 (0.05)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mechanical	0.65 (0.22)	0.00 (0.00)	0.00 (0.00)	0.05 (0.03)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Burn 1	0.16 (0.11)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)
	Burn 2	1.18 (0.43)	0.00 (0.00)	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mechanical+burn	0.72 (0.24)	0.00 (0.00)	0.19 (0.19)	0.41 (0.30)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1	Control	0.62 (0.20) a[b]	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00) b	0.00 (0.00) c	0.00 (0.00)
	Mechanical	0.37 (0.10) ab	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00) b	0.00 (0.00) c	0.00 (0.00)
	Burn 1	0.04 (0.02) ab	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00) b	0.22 (0.06) a	0.00 (0.00)
	Burn 2	0.36 (0.14) b	0.10 (0.10)	0.00 (0.00)	0.16 (0.10)	0.15 (0.09) ab	0.00 (0.00) c	0.00 (0.00)
	Mechanical+burn	0.38 (0.15) ab	0.53 (0.29)	0.31 (0.31)	0.24 (0.17)	0.35 (0.21) a	0.14 (0.07) b	0.00 (0.00)
3	Control	0.66 (0.16) b	0.00 (0.00) b	0.00 (0.00) b	0.03 (0.01) b	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mechanical	0.84 (0.28) b	0.00 (0.00) b	0.00 (0.00) b	0.02 (0.01) b	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)
	Burn 1	0.13 (0.04) b	0.00 (0.00) b	0.00 (0.00) b	0.00 (0.00) b	0.01 (0.01)	0.05 (0.04)	0.00 (0.00)
	Burn 2	0.44 (0.15) b	0.07 (0.06) b	0.00 (0.00) b	0.26 (0.18) ab	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mechanical+burn	1.77 (0.67) a	1.16 (0.84) a	1.84 (1.84) a	1.13 (0.78) a	0.26 (0.22)	0.00 (0.00)	0.00 (0.00)
5	Control	2.43 (0.56) a	0.00 (0.00) b	0.13 (0.13)	0.08 (0.05) b	0.00 (0.00) b	0.00 (0.00)	0.00 (0.00)
	Mechanical	2.99 (0.94) a	0.00 (0.00) b	0.00 (0.00)	0.08 (0.05) b	0.00 (0.00) b	0.00 (0.00)	0.00 (0.00)
	Burn 1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Burn 2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Mechanical+burn	1.12 (0.30) b	5.73 (2.91) a	0.97 (0.97)	1.48 (0.84) a	0.51 (0.31) a	0.01 (0.00)	0.00 (0.00)
7	Control	0.45 (0.10)	0.00 (0.00)	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mechanical	1.13 (0.39)	0.00 (0.00)	0.00 (0.00)	0.05 (0.03)	0.00 (0.00)	0.03 (0.03)	0.00 (0.00)
	Burn 1	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Burn 2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Mechanical+burn	0.59 (0.14)	0.02 (0.01)	0.10 (0.10)	0.50 (0.30)	0.25 (0.15)	0.00 (0.00)	0.00 (0.00)

Species codes: LONIJAP = *Lonicera japonica*; LESPBIC = *Lespedeza bicolor*; MICRVIM = *Microstegium vimineum*, LIGUSIN = *Ligustrum sinense*; ALBIJUL = *Albizia julibrissin*; AILAALT = *Ailanthus altissima*; PUERMON = *Pueraria Montana*.

n/a = data not available.

[a] Corresponds to pretreatment sampling (0); first year immediately after initial treatment (1); 3 years after initial treatment (3), etc.

[b] Within sample year, values followed by different letters indicate significant change in percent cover from pretreatment level at $\alpha = 0.05$.

Our results are consistent with other studies showing greater abundance of nonnative invasive plants in areas subjected to mechanical treatment combined with prescribed burning (Dodson and Fiedler 2006, Griffis and others 2001). Large reductions in overstory basal area and disturbance to the forest floor provided suitable seedbed habitat for nonnative species to germinate and expand. Implications from these findings suggest fuel-reduction treatments could potentially have effects opposite from intended purposes, e.g., ecosystem restoration, by negatively impacting natural species regeneration (Oswalt and others 2007) and altering disturbance regimes (Brooks and others 2004).

Results from the fuel-reduction treatments in beetle-killed stands (table 2) cover only the first 2 years since disturbance; therefore, conclusions are preliminary. Initial reductions in invasive cover did not persist over time as relatively few significant differences between pretreatment and 2-year

Table 2—Mean invasive plant cover (and standard error) in southern pine beetle-killed pine stands treated with fuel-reduction techniques in the upper Piedmont of South Carolina

Years since treatment[a]	Treatment	LONIJAP	LESPBIC	MICRVIM	LIGUSIN	ALBIJUL	AILAALT	PUERMON
0	Control	4.74 (1.66)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mastication	8.07 (4.36)	0.00 (0.00)	0.00 (0.00)	0.15 (0.15)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Low burn	2.32 (1.60)	0.00 (0.00)	0.00 (0.00)	0.16 (0.16)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	High burn	0.20 (0.14)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1	Control	7.36 (2.54) a[b]	0.00 (0.00)	0.00 (0.00)	0.06 (0.03)	0.13 (0.10)	0.00 (0.00)	0.00 (0.00) b
	Mastication	1.35 (0.74) b	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00) b
	Low burn	1.53 (1.26) a	0.00 (0.00)	0.00 (0.00)	0.15 (0.10)	0.00 (0.00)	0.00 (0.00)	0.11 (0.11) a
	High burn	0.25 (0.12) a	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00) b
2	Control	4.48 (1.48)	0.00 (0.00)	0.00 (0.00)	0.10 (0.06) a	0.05 (0.05)	0.00 (0.00)	0.00 (0.00)
	Mastication	7.57 (3.68)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00) b	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Low burn	1.63 (1.02)	0.00 (0.00)	0.00 (0.00)	0.06 (0.05) ab	0.05 (0.05)	0.00 (0.00)	0.00 (0.00)
	High burn	0.22 (0.15)	0.05 (0.05)	0.00 (0.00)	0.00 (0.00) ab	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Species codes: LONIJAP = *Lonicera japonica*; LESPBIC = *Lespedeza bicolor*; MICRVIM = *Microstegium vimineum*, LIGUSIN = *Ligustrum sinense*; ALBIJUL = *Albizia julibrissin*; AILAALT = *Ailanthus altissima*; PUERMON = *Pueraria montana*.

[a] Corresponds to pretreatment sampling (0); first year immediately after initial treatment (1); 3 years after initial treatment (3), etc.

[b] Within sample year, values followed by different letters indicate significant change in percent cover from pretreatment level at $\alpha = 0.05$.

posttreatment values were evident. *L. japonica* was the most abundant species with other species periodically recorded during the study period. Surrette and Brewer (2008) demonstrated that high cover of *L. japonica* was associated with areas of high disturbance, low fire frequency, and high soil compaction, which are characteristics of both the mechanical and mastication treatments. For these stands, *L. japonica* is likely to out-compete other species preventing stand development unless fire, or another means for limiting its growth (herbicides or manual removal), is incorporated. Burning successfully reduced *L. sinense*; however, *P. montana* and *L. bicolor* became established following treatment. Continued burning will likely increase the abundance of *L. bicolor* (Tesky 1992) as well as *P. montana* (Munger 2002) unless accompanied by herbicide application (Miller 2003).

Distinct differences in community composition between intact pine stands and beetle-killed pine stands were evident prior to treatment, but these differences appeared to diminish over time, except for the control and mastication treatments for the beetle-killed stands (fig. 1). The final NMS ordination converged on three axes with a final stress of 7.4. The amount of variance explained by each axis was 36.3 percent for axis 1, 29.0 percent for axis 2, and 28.9 percent for axis 3 (cumulative R^2 = 94.2 percent). Over time plots generally moved from left to right across axis 1, which may be an increasing gradient of soil moisture. Data on soil moisture were not available, but we speculate there were differences between stands that were not affected by beetles and those which had beetle infestations. These changes in stand structure and disturbance to the forest floor may have affected soil moisture thus influencing species composition. Axis 3 appeared to be associated with light availability as demonstrated by the positive correlation to basal area (r = 0.829) and the movement of plots down this axis for intact pine stands (increased light reaching the forest floor) contrasted by the progression of beetle-killed plots up this axis.

With respect to invasive species, *A. julibrissin* and *L. sinense* were positively associated with axis 1, whereas *M. vimineum* showed positive correlation with axis 3 (table 3). *L. japonica* was correlated with both axis 1 (r = 0.829) and axis 3 (r = –0.535). Even though *L. japonica* can persist under low-light conditions, it is more prolific in high-light environments as demonstrated by a strong negative correlation with axis 3. In contrast, *M. vimineum*, which is well adapted to low-light conditions and prefers disturbed sites that are shaded and more mesic (Barden 1987), had a positive association with this axis.

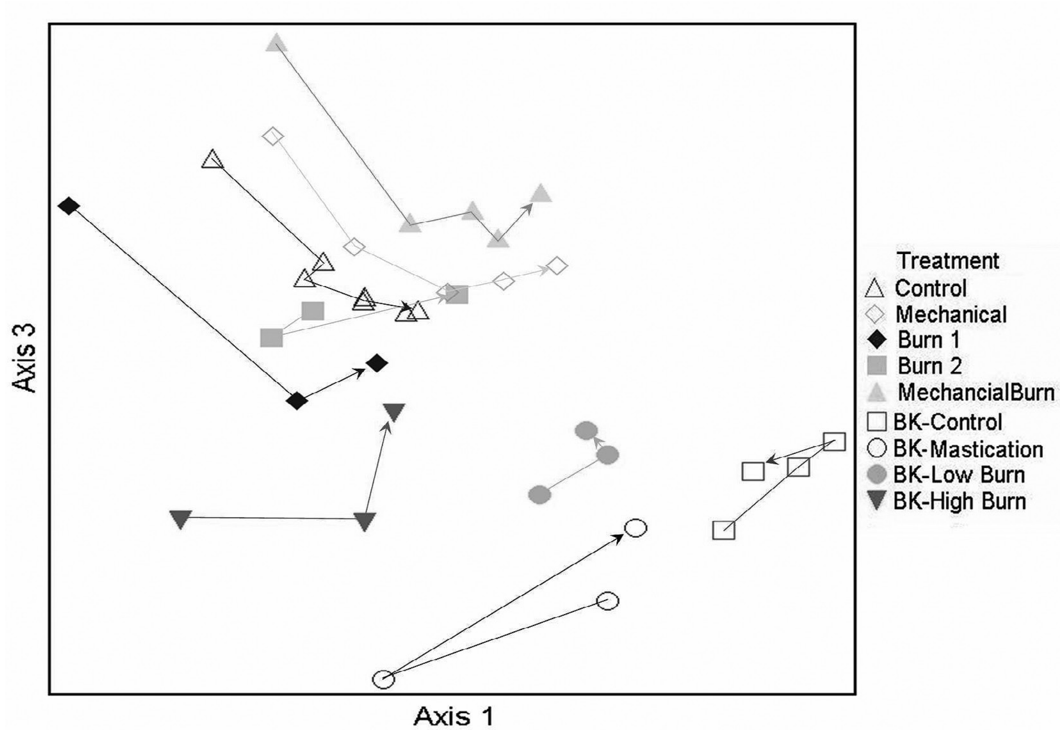

Figure 1—Nonmetric multidimensional scaling (NMS) ordination of plots in species space depicting change over time for pine stands treated with fuel-reduction treatments in the upper Piedmont of South Carolina. Axis 1 appeared to be related to soil moisture (decreasing from left to right) and axis 3 was associated with light availability (increasing from top to bottom).

Table 3—Parametric (Pearson's *r*) and nonparametric (Kendall's tau) correlations of invasive species with NMS axes for pine stands in the upper Piedmont of South Carolina

	Axis 1		Axis 2		Axis 3	
Species	*r*	tau	*r*	tau	*r*	tau
AILAALT	–0.190	–0.129	0.020	0.097	0.119	0.209
ALBIJUL	0.430	0.340	–0.406	–0.413	0.069	–0.038
LESPBIC	0.035	0.048	–0.317	–0.389	0.232	0.240
LIGUSIN	0.423	0.304	–0.210	–0.178	0.276	0.175
LONIJAP	0.829	0.613	–0.080	–0.060	–0.535	–0.263
MICRVIM	0.030	–0.096	–0.181	0.029	0.353	0.435
PUERMON	0.187	0.216	–0.356	–0.293	–0.148	–0.149

Species codes: LONIJAP = *Lonicera japonica*; LESPBIC = *Lespedeza bicolor*; MICRVIM = *Microstegium vimineum*, LIGUSIN = *Ligustrum sinense*; ALBIJUL = *Albizia julibrissin*; AILAALT = *Ailanthus altissima*; PUERMON = *Pueraria montana*.

NMS = nonmetric multidimensional scaling.

Abundances of some of these nonnative species are relatively small and statistically significant differences may not represent biological differences, but their presence and responses to these treatments indicate that land managers need to consider these species when planning hazard-reduction or restoration treatments. The establishment of nonnative species following treatment, even at low levels, needs to be addressed in a timely manner as cost for eradication increases over time (Rejmánek and Pitcairn 2002). Invasion by nonnative species can cause a variety of changes in the ecosystem, from altered disturbance regimes (Mack and D'Antonio 1998) to changes in soil nutrient cycling and decomposition (Ehrenfeld 2003).

CONCLUSIONS

Based on understory vegetation composition, it appears that pine stands treated with prescribed fire and mechanical fuel-reduction techniques and those sustaining southern pine beetle damage are more or less converging over time; however, the effects of these treatments on nonnative invasive species differed. Burning decreased *L. japonica* cover; mechanical+burning stimulated growth and/or establishment for *L. bicolor*, *L. sinense*, and *A. julibrissin*; whereas the mechanical treatments, both thinning and mastication, resulted in the greatest abundance of *L. japonica*. Depending on the presence of invasive species prior to fuel-reduction treatment, land managers can decide which treatment is best suited for preventing invasive expansion while accomplishing the goal of hazard fuel reduction.

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LITERATURE CITED

Barden, L.S. 1987. Invasion of *Microstegium vimineum* (Poaceae), an exotic, annual, shade-tolerant C4 grass, into a North Carolina floodplain. American Midland Naturalist. 118: 40–45.

Brooks, M.L.; D'Antonio, C.M.; Richardson, D.M. [and others]. 2004. Effects of invasive alien plants on fire regimes. BioScience. 54: 677–688.

Dodson, E.K.; Fiedler, C.E. 2006. Impacts of restoration treatments on alien plant invasion in *Pinus ponderosa* forests, Montana, USA. Journal of Applied Ecology. 43: 887–897.

Dukes, J.S.; Mooney, H.A. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution. 14: 135–139.

Ehrenfeld, J.G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems. 6: 503–523.

Gordon, D.R. 1998. Effects of invasive, non-indigenous plant species on ecosystem processes: lessons from Florida. Ecological Applications. 8: 975–989.

Griffis, K.L.; Crawford, J.A.; Wagner, M.R.; Moir, W.H. 2001. Understory response to management treatments in northern Arizona ponderosa pine forests. Forest Ecology and Management. 146: 239–245.

Levine, J.M.; Vilà, M.; D'Antonio, C.M [and others]. 2003. Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society of London Series B. 270: 775–781.

Mack, M.C.; D'Antonio, C.M. 1998. Impacts of biological invasions on disturbance regimes. Trends in Ecology and Evolution. 13: 195–198.

McCune, B.; Mefford, M.J. 2006. PC-ORD. Multivariate analysis of ecological data. Version 5.14. Gleneden Beach, OR: MjM Software.

Metlen, K.L.; Fiedler, C.E. 2006. Restoration treatment effects on the understory of ponderosa pine/Douglas-fir forests in western Montana, USA. Forest Ecology and Management. 222: 355–369.

Miller, J.H. 2003. Nonnative invasive plants of southern forests: a field guide for identification and control. Gen. Tech. Rep. SRS-62. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 93 p.

Munger, G.T. 2002. *Pueraria montana* var. *lobata*. Fire effects information system [online]. [Fort Collins, CO]: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. [Date accessed: January 8, 2009].

National Oceanic and Atmospheric Administration. 2002. Climatography of the United States series no. 81: monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971–2000 (South Carolina–38). Asheville, NC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center. 23 p.

Oswalt, C.M.; Oswalt, S.J.; Clatterbuck, W.K. Effect of Migrostregium vimineum (Trin.) A Camus on native woody species density and diversity in a productive mixed-hardwood forest in Tennessee. Forest Ecology and Management. 242: 727–732.

Phillips, R.J.; Waldrop, T.A. 2008. Changes in vegetation structure and composition to fuel reduction treatments in the South Carolina Piedmont. Forest Ecology and Management. 255: 3107–3116.

Rejmánek, M.; Pitcairn, M.J. 2002. When is eradication of exotic pest plants a realistic goal? In: Veitch, C.R.; Clout, M.N., eds. Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. Gland, Switzerland and Cambridge, UK: IUCN: 249–253.

SC Exotic Pest Plant Council. 2008. Invasive plant pest species of South Carolina. http://www.se-eppc.org/southcarolina/scinvasives.pdf. [Date accessed: October 10, 2008].

Sorrells, R.T. 1984. The Clemson Experimental Forest: its first fifty years. Clemson, SC: Clemson University, College of Forest and Recreation Resources. 52 p.

Surrette, S.B.; Brewer, J.S. 2008. Inferring relationships between native plant diversity and *Lonicera japonica* in upland forests in north Mississippi, USA. Applied Vegetation Science. 11: 205–214.

Tesky, J.L. 1992. *Lespedeza bicolor*. In: Fire effects information system [online]. [Fort Collins, CO]: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. [Date accessed: January 08, 2009].

U.S. Department of Agriculture Forest Service. 2002. 2002 forest insect and disease conditions for the Southern Region. Washington, DC. http://www.fs.fed.us/r8/foresthealth/2002conditions/index.html. [Date accessed: October 10, 2008].

U.S. Department of Agriculture Forest Service. 2003a. Forest insects and disease conditions in the United States 2002. Washington, DC. 124 p.

U.S. Department of Agriculture Forest Service. 2003b. USDA Forest Service strategic plan for fiscal years 2004–08. FS-810. Washington, DC. 32 p.

Vitousek, P.M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos. 57: 7–13.