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Effect of plant community composition on plant response to fire and herbicide treatments

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ABSTRACT

Vegetation management, using prescribed fire and herbicides, is used in forestry applications to reduce competition with desired species, improve wildlife habitat, and meet other silvicultural objectives. Although plant communities resulting from such treatments are generally known, it is unclear how pre-treatment plant community structure may influence specific plant community responses. Therefore, to examine how species dominance may impact response of plant communities to vegetation management, we compared the top contributors to plant biomass (kg ha^{-1}) among prescribed fire and herbicide (imazapyr) treatments within intensively managed pine stands in east-central Mississippi, USA. Ninety-two species of 390 collected comprised 95% of plant biomass and six species comprised 55% of total biomass. Dominant species may have restricted plant diversity. Prescribed fire with and without imazapyr improved species richness but did not control some highly competitive species. None of the treatments tested is necessarily an optimal solution to control well-established understory plant species. Although management prescriptions consider exotic and invasive plant species, control of well-established native species should also be considered to tailor vegetation management to meet forestry and wildlife habitat objectives. More research is needed concerning plant response to multiple herbicide tank mixtures with and without prescribed fire to optimize future vegetation management for multiple objectives.

1. Introduction

Prescribed fire and selective herbicides have been used for hardwood competition control and improving wildlife habitat in intensively managed pine (*Pinus* spp.) stands of the southeastern United States (Brockway and Outcalt, 2000; Edwards et al., 2004; McInnis et al., 2004). Fire is a natural process whereas selective herbicides, specifically those containing imazapyr, offer an alternative unimpeded by smoke management issues or limited burning degree days (Brennan et al., 1998; Wigley et al., 2002). Both fire and herbicides can reduce woody plant coverage and increase forbs, legumes, and grasses (Stransky and Harlow, 1981; Brockway and Outcalt, 2000; Miller and Miller, 2004) creating vegetative structure favorable to many declining wildlife species of the southeast (Burger, 2000; Hunter et al., 2001; Trani et al., 2001). They can also increase high quality forage for white-tailed deer (*Odocoileus virginianus*), an economically and socially important species of the United States (Demarais et al., 2000; Mixon et al., 2009; Iglay et al., 2010). However, neither independent nor combined applications of these treatments offer an optimal solution for controlling undesirable plants or well-established species and may inadvertently release some by impacting their competitors. When a few plant species dominate sites, species diversity can be restricted from reaching its full (seed bank) potential (Armesto and Pickett, 1985; Gibson, 1988).

Conservation of biodiversity has become an important goal of commercial forestry (Sustainable Forestry Initiative Inc., 2005). Although mid-rotation management is lacking in many short-rotation forests (Sladek et al., 2008), prescribed burning and selective herbicides applied at mid-rotation may accommodate wildlife management and timber management objectives (Tucker et al., 1998; Iglay et al., 2010). However, to maximize conservation values (e.g., species diversity, wildlife habitat quality), plant responses to prescribed fire and selective herbicides within mid-rotation, intensively managed pine stands must be understood.

Plant responses to vegetation management are assumed generally to follow a successional gradient beginning with post-disturbance conditions. The greater the disturbance intensity, the further succession is set-back (i.e., disking resulting in bare soil is more intense than woody plant removal resulting in herbaceous vegetation). However, pre-treatment plant communities may have a strong influence on vegetation response as well-established plant

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species, unhindered by a disturbance, may dominate the community post-disturbance (Egler, 1954). Information is lacking on efficacy of prescribed fire and imazapyr herbicide for vegetation management with respect to pre-treatment vegetation community composition.

Most past studies regarding responses of understory vegetative communities to prescribed fire and imazapyr herbicides in intensively managed pine have not investigated concomitantly independent and combined treatment effects or plant biomass dominance. Therefore, we examined understory plant biomass of well-established plant species and plant species richness from 1999 to 2008 in intensively managed pine plantations treated with factorial combinations of prescribed burning and imazapyr herbicide (Aresenal®, BASF Corporation, Research Triangle National Park, NC, USA). Our objective was to determine if prescribed fire and imazapyr herbicide (combined or independently applied) evenly affected most understory vegetation, consequently optimizing species richness and reducing a species' dominance post-treatment. If not, we expected only a few well-established understory plant species, unaffected by treatments, to dominate sites post-treatment, potentially minimizing species richness.

2. Methods and materials

2.1. Study sites and design

We selected six mid-rotation pine plantations (60–120 ha), owned and managed by Weyerhaeuser NR Company in east-central Mississippi, USA, from a 9700 ha area of short-rotation, intensively managed pine. During study establishment (1999), plantations were 18–22 years old, thinned 2–5 years prior, and had site indexes of 19.7–23.6 m 25 years^{-1}. Typical stand management consisted of 25–32 year rotations followed by clearcut harvest, site preparation, 1–2 commercial thinnings and fertilization (Siry, 2002). Forest types within the study area were pine plantations (70%), mature pine-hardwood (17%), mature hardwoods (10%), and non-forested areas (3%). Soil series were described as clay to sandy loam with poor to imperfect drainage, and local climate was subtropical with a mean annual temperature of 17.4 °C and mean annual precipitation of 149 cm (National Oceanic and Atmospheric Administration, 2009). At the time of treatment, common understory species (76% total biomass) included sawtooth blackberry (*Rubus argutus* Link, 13%), Japanese honeysuckle (*Lonicera japonica* Thunb., 11%), *Panicum* spp. (9%), *Vitis* spp. (8%), poison ivy [*Toxicodendron radicans* (L.) Kuntze, 7%], slender woodoats [*Chasmanthium laxum* (L.) Yates, 6%], *Smilax* spp. (5%), sweetgum (*Liquidambar styraciflua* L., 5%), and American beautyberry (*Callicarpa americana* L.), *Quercus* spp., blackgum (*Nyssa sylvatica* Marsh.), and *Scleria* spp. (3% each).

We divided stands into four, 10-ha (286 m × 350 m) experimental units (plots) ≥50 m apart (treatment buffers). We randomly assigned a treatment to each plot (burn, herbicide, burn + herbicide, control) creating a randomized complete block design. Herbicide was applied using a skidder in September 1999 with a tank mixture of 887 mL ha^{-1} (12.0 liquid oz. ac^{-1}) Aresenal® (255 mL imazapyr ha^{-1}; BASF, 2006), 0.5% volume to volume ratio of Timbursurf90 (Timberland Enterprises, Inc., Monticello, AR, USA), and water for dilution at a rate of 189 L ha^{-1}. Ground-applied, dormant season, prescribed burns in January 2000 and 2003 and February and March 2006 were set by drip torches in a strip fire pattern to all burned plots under 24–55% relative humidity, 7–22% fuel moisture, 0.0–6.9 km h^{-1} in-stand wind speeds, and 3.3–27.2 °C in-stand temperatures. As part of standard silviculture, all plots were fertilized immediately after commercial thinning at 16–19 years of age and again at ages 20–24 with diammonium phosphate (127–283.5 kg ha^{-1}, $\bar{x} = 153.4$ kg ha^{-1}) with or without urea (381–448 kg ha^{-1}, $\bar{x} = 222.8$ kg ha^{-1}), according to soil tests.

2.2. Plant biomass

We clipped all plants <1.3 cm diameter and ≤2 m tall in 20, 1 m^2 hoops systematically distributed along a diagonally oriented transect with a random origin across each plot, July 1999–2008. We used 10 hoops plot^{-1} initially (1999–2000) but increased number of subsamples plot^{-1} to 20 in subsequent years based on initial estimates of variability and desired precision. We dried each sample at 60 °C in a forced-air oven until constant weight (g) and weighed each to the nearest hundredth of a gram. We combined all clippings per species within a plot because hoops were subsamples. Total weight per species per plot was calculated as kg ha^{-1}.

2.3. Statistical analysis

We designated plant species contributing ≥0.1% of total biomass as top contributors. We justified this ranking by visual inspection of a graph of cumulative weight by species rank. We ranked species by total weight across all study years and plots in descending order with the greatest weight-contributing species ranked first. We then calculated cumulative weight as the corresponding summation of the ranked species weight and all higher ranked species. We graphed cumulative weight (*y*-axis) by species rank (*x*-axis) creating a horizontal asymptote with species on the asymptote contributing <0.09% each of total biomass. Our arbitrary cut-off point fell just prior to this asymptote and biomass of all top contributors accounted for >95% of total biomass.

We used repeated measures, mixed models analysis of covariance (SAS Proc Mixed; SAS Institute, Inc., Cary, NC, USA) to test main effects of treatment, year, and treatment × year interaction on mean biomass of top contributors with pre-treatment data as a baseline covariate. We used four levels of treatment main effects (burn, herbicide, burn + herbicide, control), random effects of stand, repeated measures of year, and subject of stand × treatment (plot; Littell et al., 2006) to test the null hypothesis of no difference in mean biomass of top contributors and species richness among treatments within years. We chose candidate covariance structures incorporating temporal variation (9-banded Toeplitz, heterogeneous compound symmetry, heterogeneous auto-regressive, and first order auto-regressive) because all variables followed a time series. We examined four models, one per covariance structure, under the restricted likelihood method (Method = REML) and determined appropriate covariance structures using Akaike's Information Criterion with second order correction due to low sample sizes (AICc; Gutzwiller and Riffell, 2007). We adjusted denominator degrees of freedom using the Kenward–Roger method (Littell et al., 2006; Gutzwiller and Riffell, 2007). After the best covariance structure was determined, we used a new analysis including LSMEANS SLICE and LSMEANS PDIFF options under the maximum likelihood method (METHOD = ML). We used the LSMEANS SLICE option in Proc Mixed (Littell et al., 2006) to identify significant treatment effects within years when the interaction term was significant, and LSMEANS PDIFF for pair-wise comparison among treatments (Littell et al., 2006). We conducted all tests using an *a priori* significance level of $\alpha = 0.05$. To reduce family-wise error rate, we limited statistical tests to species contributing ≥1% of the total biomass for all years. We designated year 0 as pre-treatment so all references in results and discussion are post-treatment.

3. Results and discussion

Prescribed fire and imazapyr herbicide applied at our rates unevenly affected well-established understory plant species in mid-rotation, intensively managed pine plantations of east-central Mississippi. Eighty-nine of 390 collected plant species were des-