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Forest herbicide influences on floristic diversity seven years after broadcast pine release treatments in central Georgia, USA

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Application. Broadcast herbicide release treatments for minimizing hardwood competition in loblolly pine plantations did not greatly affect herbaceous or woody plant composition of treated areas seven-years post-treatment. On sites with similar vegetation, use of such treatments should not have significant adverse effects on plant community diversity or species richness.

Abstract. Maintenance of biodiversity is becoming a goal of forest management. This study determined effects of broadcast pine release herbicide treatments on plant species richness, diversity, and structural proportions seven years after treatment. Three study blocks were established in central Georgia. Plots 0.6–0.8 ha in size were planted to loblolly pine (*Pinus taeda* L.) in the Winter of 1982-83 and then treated with imazapyr (Arsenal), glyphosate (Roundup), and hexazinone (Velpar L. and Pronone 10G) in 1985. In 1992, overstory and understory (cl.5 m height) layers were examined utilizing stem and rootstock counts and basal area of overstory species and cover of understory species. ANOVA's were used to test for significance using a randomized complete block model. We found no effect of treatments on species richness. Diversity, measured separately for overstory and understory layers by Shannon-Wiener and Simpson indices, also was not influenced significantly by treatments. Arsenal significantly decreased *Diospyros virginiana* L. and increased *Rubus argutus* Link and legumes. Hexazinone treatments generally decreased *Quercus nigra* L., and Roundup significantly reduced *Vaccinium* spp. compared to the Check. We concluded that herbicide release treatments did not decrease overstory or understoryplant species richness and diversity seven years post-treatment.

Introduction

There is widespread concern for the maintenance of biodiversity on our planet. Human activities are causing extinction of species at an alarming rate (Wilson 1989). It is becoming clear that maintenance of biodiversity cannot depend solely on establishment of protected areas and preserves.

Other areas with commercial values (e.g., forests managed for timber) must be integrated into the biodiversity picture (Hansen et al. 1991; Probst and Crow 1991). Burton et al. (1992) argue that biodiversity is an important long-term objective of forest management and has practical economic benefits. The forestry industry is recognizing the importance of responding appropriately to the public's environmental concerns (Norse et al. 1986; Miles 1990; Lyons and Tuchmann 1993).

In the United States, the National Forest Management Act requires that diversity in National Forests be monitored and maintained. Harvesting and regenerating timber involves choices at each step, including choices of harvest method, site preparation method, and post-planting management techniques. Recent studies have focussed on plant species diversity as affected by timber harvesting methods (Lu and Buongiomo 1993; Vora 1993; Wang and Nyland 1993), site preparation methods (Lewis et al. 1984; Stransky et al. 1986; Locasio et al. 1991; Blake et al. 1987), and herbaceous control treatments (Blake et al. 1987; Zutter et al, 1987). Studies that examine post-planting herbicide release techniques are more scarce. A common post-planting practice in the southeastern United States is to apply herbicide release treatments to young (one- to seven-year-old) pine plantations. Such release treatments have been shown to boost early pine growth by suppressing or controlling naturally regenerating woody and herbaceous species that compete for moisture and nutrients (Bacon and Zedaker 1987; Alm and Whorton 1988; Zutter et al. 1988a, 1988b; Glover et al. 1991; Long and Flinchum 1992).

Herbicides are widely used release treatments with a relatively low cost-per-hectare (Belli et al. 1993; Busby et al. 1993). By their nature, successful herbicide treatments initially decrease plant species richness in treated areas. However, the duration of their effect appears limited (Lewis et al. 1984, Blake et al. 1987; Zutter and Zedaker 1987). We know of no studies that examine the effects of herbicide treatments longer than six years after the last herbicide application.

This project examined diversity of herbaceous and woody species on three diverse sites in Georgia, USA. Our primary goal was to determine whether richness and diversity were significantly altered by these commonly-used forest management procedures seven years after treatment. If differences were found, we also wished to determine which species were affected by the treatments. A secondary objective was to assess whether significant shifts in community dominants or structural proportions of herbaceous and subcanopy species had occurred due to treatments, recognizing that the post-treatment abundance of species reflected both the influence of treatment effects and any differences in pre-treatment abundances. This research is thought to be vital at this time to see if intensive broadcast herbicide applications to forest tracts cause major reductions in species richness in the period immediately prior to pine canopy closure.

Method

Study sites

This project examined diversity of herbaceous and woody species on three sites in Georgia. These sites were part of a pre-existing study comparing release treatments initiated by the USDA Forest Service in cooperation with the Georgia Forestry Commission (Edwards and Miller 1991; Miller and Edwards 1991). Each of the three sites is found in a different area of two physiographic provinces in central Georgia. The Robinson site is located in the Piedmont physiographic province. The other two sites are located in the Coastal Plain physiographic province: the Patton site is in the sand hills portion of the Hilly Coastal Plain, and the Duggins site is in the Middle Coastal Plain.

Plot preparation and release treatments

Tracts had been completely harvested of all standing woody plants for fuelwood biomass in 1982 and prescribed burned. One-year-old loblolly pine seedlings were planted in the winter of 1982-83. Sites were selected for study based on the severe woody competition present in 1985. They thus initially had been worst-case situations for application of herbicide release treatments.

At each location, four herbicide release treatments were applied randomly to plots that were 0.6–0.8 ha in size, and an untreated check plot was included. Plots were upland portions of larger tracts and encompassed ephemeral stream channels. Commonly used release herbicides were applied at labeled rates and at recommended timings: imazapyr [2-[4,5-dihydro-4-methyl-4-(1 -methyl+ 1 -methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid], glyphosate [N-(phosphonomethyl)glycine], and hexazinone [3-cyclohexyl-6-(dimethylamino)-1 -methyl- 1,3,5-triazine-2,4(1H,3H)-dione]. Imazapyr (Arsenal Applicators Concentrate@ (AC)) and glyphosate (Roundup@) were applied at maximum labeled rates at each site (1.1 kg acid equivalent (ae)/ha for imazapyr and 1.7 kg ae/ha for glyphosate). Both hexazinone products, the liquid formulation (Velpar L®) and the granular formulation (Pronone 10G®), were prescribed according to soil texture and percent organic matter per label recommendations. Specific application rates by site for Pronone 10G were 1 .O kg active ingredient (ai)/ha for the Duggins and Patton sites and 1.7 kg ai/ha for the Robinson site. Specific application rates by site for Velpar L were 0.7 kg ai/ha (Duggins site), 1.1 kg ai/ha (Patton site), and 2.5 kg ai/ha (Robinson site). Applications were made in the summer of 1985. A spray system mounted on a crawler-tractor was used for applying the liquid herbicides, and a similarly-mounted spreader system was used for the granular herbicide. Both systems had onboard micro-processor systems that maintained uniform application rates despite variation in tractor speed. Application uniformity was further assured by the use of flaggers to guide the tractor swath passes across plots.

Data collection

Twenty 2x2 m square quadrats were positioned by means of a stratified-random procedure within each treatment plot. Quadrats were marked so that they could be re-located. Initial understory data collection began in August 1992, the seventh growing season after treatment and the tenth growing season for the planted pines. Data for each quadrat consisted of the estimated percent cover of those species with canopies covering at least a portion of the quadrat below a height of 1.5 m (referred to as the understory layer). Cover by vine species was estimated without regard to the 1.5 m height limitation imposed on all other species (including arborescent and nonarborescent woody species). Quadrats were revisited during late March 1993 to collect data on spring herb species not encountered the previous summer.

Data on arborescent and nonarborescent woody species were collected in November-December 1992 using the same sample points used to locate the quadrats. At each point a circular 0.005ha plot (4-m radius) was established, and all arborescent and nonarborescent woody plants taller than 1.5 m were tallied by species (referred to as the overstory layer). Stem numbers and rootstock numbers were recorded along with the dbh of each arborescent stem.

Data analysis

Species diversity can be defined and measured in several ways. Diversity indices have different sensitivities to rare species, so that the values generated for a given data-set may vary markedly among the analysis techniques (Swindel et al. 1987). Connell (1978) argued that number of species (i.e., species richness) is a useful measure of diversity for areas of similar size because it is not subject to the interpretation problems of diversity indices. We examined our data both for species richness and two indices of diversity: Simpson and Shannon-Wiener.

Species richness. Total species counts in each plot were categorized by growth form as arborescent (examining the combined overstory and understory data sets), nonarborescent woody (examining the combined overstory and understory data sets), forb (non-legume only), legume (both forb and semiwoody species), grasses-grasslike, and woody vine. Too few representatives of fern and semiwoody species were found to allow separate analyses of these categories. The Appendix contains a list of species included within each of these growth form categories.

Diversity. Simpson and Shannon-Wiener diversity indices were calculated separately for overstory and understory data. Density data (rootstocks/ha) for all overstory woody species and cover data for herbaceous species were averaged for each treatment plot and used to calculate these indices. All diversity index values were calculated using the DIVERS program of Krebs (1988), which represents the Simpson index as l-Simpson.

Structure and composition. To examine structural changes, plot basal area (BA in m^2/ha) of arborescents was tested for treatment effects. Pine and hardwood BA's, the pine/hardwood BA ratio, and data for both rootstocks/ha and stems/ha for all nonarborescent species were also analyzed.

To examine composition shifts, Importance Values (IV's) for arborescent species were calculated by plot as the mean of summed relative BA, relative frequency, and relative density. The IV's for nonarborescent woody species were calculated as the mean of their relative frequency and relative density (rootstocks/ha).

The IV's for understory species were calculated as the mean of relative cover and relative frequency. Understory species were grouped by the following growth form categories: arborescent, nonarborescent, semiwoody, forb, grass-grasslike, fern, and woody vine. In addition, IV's for legumes were grouped into a separate category. Individual species' IV's were summed according to growth form, and the totals for each treatment plot were analyzed. Selected ratios of IV's for growth forms were also calculated and analyzed. Importance Values for individual species were analyzed for those species that occurred in all Check plots. In some cases, IV values were summed for all members of a genus for analysis (e.g., *Quercus, Eupatorium).*

A randomized complete block model ANOVA was used to analyze data in which sites were treated as blocks. The Tukey Compromise Test was used for post-hoc mean separation (Abacus Concepts 1989). Variables that represent percentages (i.e., IV's, IV ratios) were arc-sine square-root transformed prior to analysis so they would better meet the normality assumption underlying the ANOVA procedure (Zar 1984). For the same reason, variables representing

Table I. Treatment means for total species richness, species richness subdivided into growth form categories, and species diversity (SE in parentheses).

Group	Check	Pronone	Velpar	Roundup	Arsenal
Species Richness					
Total species	75(14)	75(7.0)	72(5.2)	83(8.1)	73(11.0)
Arborescents (over and understory)	21(2.4)	19(2.0)	18(0.58)	16(1.2)	17(2.7)
Nonarborescents (over and understory)	11(2.0)	11(1.5)	10(0.88)	9.0(1.2)	9.3(3.2)
Forbs (nonlegumes)	20(7.0)	21(2.5)	20(2.2)	29(6.1)	20(4.4)
Legume forbs	6.3(2.6)	6.7(1.3)	8.0(3.0)	7.3(1.7)	8.0(2.1)
Grasses-grasslike	9.0(1.7)	9.7(0.88)	7.7(1.7)	9.3(1.7)	8.7(1.9)
Woody vines	6.0(1.7)	6.3(1.5)	6.3(0.88)	8.7(0.67)	8.0(1.2)
Species diversity					
Overstory					
Simpson	0.75(0.030)	0.77(0.040)	0.72(0.054)	0.74(0.035)	0.84(0.005)
Shannon-Wiener	2.7(0.24)	2.8(0.16)	2.5(0.20)	2.6(0.20)	3.2(0.03)
Understory					
Simpson	0.92(0.007)	0.91(0.024)	0.84(0.046)	0.90(0.031)	0.83(0.085)
Shannon-Wiener	4.0(0.20)	4.3(0.21)	3.6(0.42)	4.3(0.41)	3.7(0.45)

counts (species richness, rootstocks per ha, stems per ha) were square-root transformed (Zar 1984) prior to analysis. Significance was accepted when the probability (P) of a greater F-value was less than alpha = 0.05.

Results

Species richness

Species richness did not significantly differ by herbicide release treatments (Table 1). A total of 243 species were differentiated, but 50 of these were not identified to the species level (see list of species in the Appendix). Mean species counts ranged from a low of 72 species for the Velpar plots to 83 species for the Roundup plots. Check plots had the greatest variation (largest SE). The ANOVA yielded a significant effect of site ($p = 0.0008$) but not treatment ($p = 0.53$).

Table 2. Over-story component abundance and pine/hardwood proportion by treatment (SE in parentheses).

Component	Check	Pronone	Velpar	Roundup	Arsenal
Arborescent species basal area (m^2/ha)	8.1(0.6)	7.4(1.0)	6.7(1.8)	7.8(1.9)	8.2(2.5)
Pines (m^2 ha)	3.8(0.7)	4.2(1.3)	4.0(1.5)	3.8(1.4)	5.8(2.7)
Hardwoods (m^2/ha)	4.3(0.6)	3.2(0.7)	2.7(0.7)	4.0(1.3)	2.4(0.3)
Pine/hardwood basal area ratio	0.9(0.2)	1.5(0.5)	1.7(0.6)	1.5(0.6)	2.7(1.5)
Nonarborescent species (rootstocks/ha)	1800(980)	1400(360)	1700(360)	580(180)	730(350)
Nonarborescent species (stems/ha)	3300(1500)	2700(440)	4500(920)	700(260)	1300(590)

Species richness was greatest for arborescent and nonlegume forb categories (Table 1); comparable mean numbers (6-11 species) were found for nonarborescents, legumes, grasses-grasslike, and woody vines. Separate ANOVA's for species richness by growth form also yielded no significant treatment effects. However, significant site effects were found for all groups except for vine and grasses-grasslike categories.

Diversity

Treatment had no significant influence on diversity after seven years (Table 1). The ANOVA's of diversity index values for overstory woody species showed no significant effect of either treatment or site as indicated by the Simpson and Shannon-Wiener indices ($p > 0.069$ in all cases). Relative rankings of treatments were unaffected by the index used to calculate diversity; Velpar plots averaged the lowest diversity and Arsenal the highest.

Diversity of herbaceous understory species was similarly unaffected by treatments ($p = 0.344$ for Simpson's index, $p = 0.280$ for the Shannon-Wiener index). However, diversity was significantly influenced by site for the Shannon-Wiener index ($p = 0.038$), whereas site was nonsignificant for the Simpson index ($p = 0.083$). Relative ranking of treatments was slightly affected by the index used. For example, Check plots had the highest mean diversity using the Simpson index, whereas Pronone and Roundup plots were tied for highest mean diversity as measured by the Shannon-Wiener index (Table 1).

Table 3. Overstory arborescent and nonarborescent mean IV’s by treatment for prevalent species and/or genera with ANOVA results. Superscripts denote significantly different means within a row ($p < 0.05$) by Tukey’s compromise test.

Group	Treatment					P-values’	
	Check	Pronone	Velpar	Roundup	Arsenal	Treatment	Site
Arborescents (mean % IV’s)							
nigra	20”	$15^{a,b}$	12^{b}	20^{a}	21”	0.0063	0.000 I
Diospyros virginiana	$1.9^{a,b}$	2.5^{a}	2.2”	3.1^{a}	0.4^{b}	0.022	0.021
Pinus taedu	27	33	28	31	37	0.325	0.0032
Quercus spp. (all)	27	19	17	26	26	0.14	0.0008
Liquidambar styraciflua	15	13	14	14	9.7	0.57	0.0002
Cornus florida	5.0	5.4	5.3	6.3	5.8	0.87	0.000 1
Quercusfalcata	3.8	2.8	4.2	4.4	4.1	0.78	0.012
Prunus serotina	3.2	2.8	2.5	2.1	7.4	0.21	0.44
Nonarborescents (mean % IV’s).							
Rhus copallina	39	25	28	61	19	0.23	0.078
Vaccinium spp. (all)	23	38	25	11	34	0.33	0.90

[1] ANOVA results: probabilities of making a type I error.

Structure and composition

Differences in overstory structure (as judged by pine and hardwood BA) due to treatment were not detectable (Table 2). Arborescent BA in the overstory ranged only from 6.7 m^2/ha for Velpar plots to 8.2 m^2/ha for Arsenal plots. Checks averaged 8.1 m^2/ha. Pine BA values ranged from 3.8 m^2/ha for Check and Roundup to 5.8 m^2/ha for Arsenal. Hardwoods ranged from a low of 2.4 m^2/ha for Arsenal to 4.3 m^2/ha for the Check. Ratios of pine/hardwood BA showed means above unity for herbicide treatments but not the Check, and these ratios were not significantly different.

Nonarborescent abundance varied strongly (but not significantly) due to treatment (Table 2). Rootstock mean densities ranged from 580/ha (Roundup) to 1800/ha (Check), and stem counts ranged from 700/ha (Roundup) to 4500/ha (Velpar). Check plots had the greatest variation in nonarborescent numbers.

Overstory composition did change due to treatment (Table 3). Of the eight arborescent taxa present in *all* Check plots, only *Quercus nigra* and *Diospyros*

Table 4. Mean understory layer IV's (expressed as %) divided into growth form categories with ANOVA results. Superscripts denote significantly different means within a row ($p <$ 0.05) by Tukey's compromise test.

Growth form	Treatment					P-values[1]	
	Check	Pronone	Velpar	Roundup	Arsenal	Treatment	Site
Forbs:							
All understory	18.9	24.0	21.3	27.8	25.5	0.18	0.0008
Legumes	6.2”	6.2^a	5.7^a	$7.6^{a,b}$	10.0^b	0.027	0.0001
Woody vines	22.1	25.6	23.2	23.4	21.3	0.95	0.0013
Nonarborescents	25.2	23.4	23.8	11.2	14.9	0.029	0.0015
Arborescents	21.4	12.1	12.4	16.4	14.1	0.089	0.94
Grasses-grasslikes	8.6	10.3	15.7	13.1	11.2	0.47	0.17
Semiwoody	3.1”	4.2’	3.7”	6.0”	12.3^b	0.0023	0.0024
Ferns	0.50	0.40	0.10	0.30	0.70	0.74	0.35

[1] ANOVA results: probabilities of making a type I error.

virginiana showed significantly differing IV's due to treatments. Importance Values for *Quercus nigra*, a dominant hardwood species, were lowest for Velpar, intermediate for Pronone, and highest for the Check, Arsenal, and Roundup plots (Table 3). The IV of *Diospyros virginiana* on Check plots was fully four-fold that on Arsenal plots. The ANOVA's for the genus *Quercus* and all of the remaining arborescent and nonarborescent species yielded nonsignificant treatment effects.

The understory in these 9-year old pine plantations was composed mainly of forbs and woody vines, often mixed with comparable portions of nonarborescent shrubs. Checks appeared to have more equal proportions of these components along with a comparable arborescent component (Table 4). Select treatments resulted in significant shifts in the proportion of semiwoody and legume species that may be critical wildlife food sources. Nonarborescent IV's were less by almost 50% for Arsenal and Roundup compared to other treatments (although not separated by Tukey's test), whereas semiwoody and legumes were increased with Arsenal treatment. Roundup was intermediate in legume dominance between Arsenal and the other treatments. The lower amounts of understory arborescent hardwoods on treated plots, especially those treated with hexazinone (Velpar and Pronone), were near significance (p = 0.089).

Only three species that were present on all Check plots in the understory layer showed a significant treatment effect on IV's (Table 5). The IV's of the nonarborescent species *Vuccinium stamineum* and *all Vuccinium* species combined were significantly less on Roundup plots compared to Pronone

Table 5. Under-story layer mean IV’s (expressed as %) for species occurring on all Check plots by growth forms with ANOVA results. Vine data include cover in both over-story and understory layers. Superscripts denote significantly different means within a row ($p < 0.05$) by Tukey’s compromise test.

Growth form and species	Treatment					P-values’	
	Check	Pronone	Velpar	Roundup	Arsenal	Treatment	Site
Forbs: non-legumes							
Galium hispidulum	1.7	1.4	1.6	1.3	1.8	0.27	0.0002
Eupatorium spp.	1.4	2.6	2.8	2.9	2.5	0.47	0.027
Forbs: legumes							
Lespedeza spp.	1.4	3.2	1.6	3.2	2.4	0.33	0.031
Nonarborescents							
Vaccinium stamineum	$5.2^{a,b}$	6.5”	5.1”	1.6^{b}	$3.9^{a,b}$	0.038	0.0003
Vaccinium spp. (all)	9.2”	8.9”	8.2’	1.6^{b}	$4.0^{a,b}$	0.010	0.0020
Rhus copallina	4.2	3.3	3.3	4.0	1.1	0.068	0.70
Arborescents							
Quercus spp. (all)	7.7’	2.2^{b}	2.2^{b}	$5.2^{a,b}$	$5.2^{a,b}$	0.012	0.25
Quercus nigra .	3.1	0.80	0.80	1.8	1.4	0.045	0.010
Diospyros viginiana	1.0	0.70	1.6	1.9	0.70	0.58	0.058
Pinus taeda	0.80	1.4	0.90	0.30	0.20	0.31	0.036
Grasses-grasslikes							
Panicum spp. (all)	3.4	5.2	5.1	6.7	5.7	0.28	0.48
Panicum commutatum	0.80	0.20	0.90	0.70	0.50	0.77	0.80
Andropogon sp.	1.0	1.3	7.3	1.8	2.2	0.25	0.22
Semiwoody							
Rubus argutus	3.7”	4.1^{a}	3.3”	5.5”	11^{b}	0.0092	0.0042
Woody vines							
Vitis rotundifolia	4.3	4.3	3.8	2.9	5.5	0.95	0.72
Gelsemium sempervirens	7.5	9.3	7.6	4.0	3.7	0.40	0.061
Smilax spp. (all)	7.2	8.8	8.1	8.0	6.8	0.89	0.0001
Smilax glauca	5.3	4.4	3.0	4.2	4.3	0.87	0.0006

[1] ANOVA results: probabilities of making a type I error.

and Velpar plots; Arsenal and Check plots were intermediate. Oaks as a group (Quercus spp.) were significantly less important on Pronone and Velpar treatments compared to the Checks. This result was partly due to Quercus *nigra* having a significant treatment effect, but means for this species were not separated by the Tukey's test. The increase in semiwoody plants on Arsenal treatments was mainly due to a significant doubling of *Rubus argutus* compared to all other treatments. Treatment differences were examined for the following common genera, although none were significant: *Panicum* spp., *Andropogon* spp., *Eupatorium* spp., *Lespedeza* spp., and *Smilax* spp. (Table 5).

Discussion

Species richness and diversity as judged by counts and indices were unaffected by herbicide treatments that were applied seven years before, but proportions of understory growth forms were slightly altered. Several species also were decreased or increased by treatments. It should be pointed out that, because we have no pre-treatment data, treatment influences are inferred based upon the random method used to assign treatments to plots and were not directly documented, Sampling these sites at this point in stand development provided a good opportunity to detect species richness differences. Seven years after treatment, initial herbicide effects had vanished, yet because the pine canopy had not closed early successional species still were present.

Similar results have been found by two other studies that examined diversity of herbaceous species following single herbaceous control treatments. Blake et al. (1987), studying a loblolly pine plantation in Mississippi, found that hexazinone treatments (Pronone and Velpar L) produced differences in herbaceous' biomass and species richness during the year of treatment, but these differences disappeared by the end of the second growing season. A study of herbaceous weed control treatments in a loblolly pine plantation in Alabama (Zutter et al. 1987) showed that plots treated with sulfometuron (Oust) were equivalent in diversity (measured by Simpson and Shannon-Wiener indices) to control plots by the second and third years post-treatment.

It is important to emphasize that intensity and duration of herbicide use are important determinants of diversity. In our study, herbicide was used once, and diversity measurements were taken seven years later. Studies that contrast intensive (usually yearly) herbicide use with one or a few applications early in the development of a plantation show that intensive use depresses diversity throughout the period of herbicide use. For example, Near-y et al. (1990) reported dramatic decreases in diversity of herbaceous species on plots treated annually for two to six years. Zutter et al. (1987) found lower diversity on plots treated for two years with sulfometuron than on plots treated with a single initial application.

It should also be noted that the conclusions of our study (and others) dealing with diversity within planted pine stands may depend greatly on the ecologic context of the study. Long-term study of the response of Appalachian herbaceous understories to clearcutting suggests that decreases in cover and species richness may be detectable more than 90 years after harvesting (Duffy and Meier 1992). We have examined pine plantations developed from previous pine/hardwood forest that, in turn, developed through secondary succession from abandoned row-crop fields. Thus, the flora we studied probably differed from that of old-growth forest species in resilience to disturbance and ability to recolonize disturbed areas. A study design similar to ours, but established upon recently cut old-growth forest, might reach different conclusions. The results of our study should be interpreted in ecological context and may not pertain to ecosystems developing from less-disturbed forest types.

It is also important to realize that the value of increased biodiversity depends on the nature of the species being considered (Hunt 1991; Kimmins 1993). Increases in biodiversity due to natural successional processes may occur after forest disturbance, including disturbance by logging (Conde et al. 1983a). However, the species typical of early secondary succession may not have the same value as herbs typical of old-growth stands.

Pine growth can be significantly boosted by early control of the herbaceous or woody components (or both). On 13 plantation sites in the southeastern US, pine volume was about four-fold greater on sites with total control than on check sites 5 years post-treatment (Miller et al. 1991). Volume was increased by an average of 67% with woody control but increased 17 1% after four years of herbaceous control, showing a greater influence of herbaceous competition on pine growth. Creighton et al. (1987) summarized results from 16 locations where completeness and duration of herbaceous control were studied. Significant early growth gains were reported where loblolly pines received 1 or 2 years of herbaceous control versus no control. Growth gains from multi-year herbaceous control treatments have persisted to as long as year 12 (Glover et al. 1989). Michael (1985) concluded that a single post-emergent application of herbicides for herbaceous control significantly increased pine growth. Clason (1978) found that herbaceous control in the seventh year of a loblolly pine plantation in North Louisiana yielded no growth gains while woody component control did. Thus, it appears that herbaceous control is the most effective in the early years while woody plant control yields volume gains in the later years of stand development.

In contrast to the above studies, our study showed no effect of release treatments on pine or hardwood density and basal area. Release treatments did not consistently increase pine basal area or IV, nor were hardwoods significantly lessened in abundance when compared to the Check plots. Miller and Edwards (1991), using the same sites and plots, found that diameters (but not height) of 80 tagged pines per plot were significantly greater with herbicide treatment in the fourth year. Tree volumes were not significantly different. They suspected these results stemmed from inconsistent control of resistant species depending upon the locations and herbicides used as well as toxicity of some of the herbicides to pines. A companion site preparation study did find significant volume increases with herbicide treatment versus no treatment (Edwards and Miller 1991). These results also may be partially attributed to the timeframe of our study, which involved data collection seven years post-treatment. Initial differences may have converged to similar values by this point in stand development as a consequence of succession (Conde et al. 1983b).

The IV's of some growth form categories and some particular species were influenced by certain treatments. Excepting the decrease for *Vuccinium, we* found no effects for the Roundup (glyphosate) treatment. Unlike Zutter and Zedaker (1987), we found no increase in *Vuccinium* with hexazinone treatment but did detect a similar decrease in *Quercus* spp. Shiver et al. (1990) reported that glyphosate provided the best control for red maple (*Acer rubrum*) and sweetgum (*Liquidambar styraciflua*), a result not duplicated in our study. In our study, Arsenal decreased importance of *Diospyros* in the overstory. It also increased the importance of *Rubus argutus* in the understory, resulting in an overall significant increase in the importance of semiwoody species on Arsenal-treated plots. Pronone and Velpar also significantly decreased understory oaks relative to Check plots. Shiver et al. (1990) reported best control of water oak (*Quercus nigra*) and willow oak (*Q. phellos*) by Velpar. Blake et al. (1987) found that *Rubus, Lonicera,* and *Smilax were* resistant to Velpar treatments. Differences between these studies and ours may be due to the longer period of time that elapsed between treatment and data collection for our study.

Effects on wildlife may be an important consideration in selection of forestry practices because the choice made may decrease (e.g., Hebb 197 1) or increase (e.g., Lewis et al. 1984) forage for wildlife species. Given the importance of legumes for certain wildlife species, our study showed that Arsenal treatment may increase the value of treated stands for wildlife. Legumes had significantly increased IV on Arsenal-treated plots. Blake et al. (1987) reported that *Chamaecrista* and *Lespedeza* were somewhat resistant to hexazinone and that legumes in general were more numerous on herbicide-treated plots. Brooks et al. (1993) also reported first-year increases in legumes on plots treated with either Velpar or Arsenal compared to other site preparation treatments. Our finding of increased legume IV indicates a long-term enhancement of legume cover that may result in improved wildlife habitat in Arsenal-treated stands.

The current decrease in the Earth's biodiversity is severe, and concern about the biodiversity crisis is justified (Wilson 1989). Integrating the maintenance of biodiversity into forest management objectives is a logical response to this crisis (Probst and Crow 1991), but disagreement may arise over how to best accomplish this (Norse et al. 1986; Gillis 1990; Westman 1990). This study demonstrates that floristic diversity of forest stands in the mid-South is not significantly decreased by short-term herbicide use and recovers within a few seasons post-treatment.

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Appendix

Species encountered in study plots grouped by growth form category. Species identified only to family are not listed.

Arborescent woody growth form

Acer barbatum Michaux
Acer rubrum L.
Betula nigra L.
Carpinus caroliniana Walter
Carya glabra (Miller) Sweet
***Carya* sp.**
Carya tomentosa (Poiret) Nuttall
Castanea pumila (L.) Miller
Celtis laevigata Willd.
Celtis occidentalis L.
Cornus florida L.
Diospyros virginiana L.
Fagus grandifolia Ehrhart
Fraxinus pennsylvanica Marshall
Ilex decidua Walter
Ilex opaca Aiton
Juniperus virginiana L.
Liquidambar styraciflua L.

tulipifera L.
Malus angustifolia (Aiton) Michaux
Morus rubra L.
Nyssa sylvatica Marshall
Ostrya virginiana (Miller) K. Koch.
Oxydendrum arboreum (L.) DC.
Pinus echinata Miller
Pinus taeda L.
Platanus occidentalis L.
Prunus americana Marshall
Prunus serotina Ehrhart
Pyrus sp.
Quercus alba L.
Quercus incana Bartram
Quercus laurifolia Michaux
Quercus margaretta Ashe
Quercus marilandica Muench.
Quercus michauxii Nuttall
Quercus nigra L.
Quercus phellos L.
Quercus stellata Wang.
Quercus velutina Lam.
Sassafras albidum (Nuttall) Nees
Ulmus alata Michaux
Ulmus americana L.

Nonarborescent woody growth form

Aralia spinosa L.
Asimina parviflora (Michaux)Dunal
Baccharis halimifolia L.
Callicarpa americana L.
Ceanothus americanus L.
Chimaphila maculata (L.) Pursh
Crataegus flabellata (Bosc) K. Koch
Crataegus flava Aiton
Crataegus spathulata Michaux
Crataegus uniflora Muench.
Crataegus virdis L.
Euonymus americanus L.
Gaylussacia dumosa (Andrz.) T. & G.
Hypericum hypericoides (L.) Crantz
Ilex glabra (L.) Gray
Myrica cerifera L.
Rhododendron sp.
Rhus aromatica Aiton
Rhus copallina L.
Rosa Carolina L.
Sambucus canadensis L.
Sebastiania ligustrina (Michaux) Muell-Arg.
Vaccinium arboreum Marshall
Vaccinium effiottii Chapman
Vaccinium sp.

L.
Viburnum nudum L.
Viburnum prunifolium L.

Grasses-grasslike growth form

Andropogon sp.
Bulbostylis ciliatifolia (Ell.) Femald var. *ciliatifolia*
Carexsp. 1
Carex sp. 2
Carex sp. 3
Chasmanthium sessiliflorum (Poiret) H. 0. Yates
Cynodon dactylon (L.) Persoon
Cyperus retrorsus Chapman
Cyperus sp.
Eragrostis sp.
Erianthus sp.
Juncus sp.
Panicum aciculare Desvaux ex Poiret
Panicum angustifolium Ell.
Panicum commutatum Schultes
Panicum dichotomiflorum Michaux
Panicum laxiflorum Lam.
Panicum ovale Ell.
Panicum scoparium Lam.
Panicum sp. 1
Panicum sp. 2
Panicwm sp. 3
Panicum sphaerocarpon Ell.
Panicum virgatum L.
Paspalum setaceum Michaux

Forb growth form: legumes

Amphicarpaea bracteata (L.) Femald
Centrosema virginianurn (L.) Bentham
Chamaecrista fasciculata (Michaux) Greene
Chamaecrista nictitans (L.) Moench
Clitoria mariana L.
Desmodium ciliare (Muhl. ex Willd.) DC.
Desmodium laevigatum (Nuttall) DC.
Desmodium lineatum DC.
Desmodium panicuiatum (L.) DC
Desmondium sp. 1
Galactia volubilis (L.) Britton
Indigofera caroliniana Miller
Lespedeza angustifolia (Pursh) Ell.
Lespedeza intermedia (Watson) Britton
Lespedezaprocumbens Michaux
Lespedeza repens (L.) Barton
Lespedeza sp. 1
Lespedeza spp.
Petalostemum pinnatum (Walter ex J. F. Gmelin) Blake

Phaseolus sinuatus Nuttall ex T. & G.
Rhynchosia reniformis DC.
Rhynchosia tomentosa (L.) H. & A.
Stylosanthes biflora (L.) BSP.
Tephrosia hispidula (Michaux) Persoon
Tephrosia virginiana (L.) Persoon

Forb growth form: nonlegumes

Acalypha gracilens Gray
Agalinis setacea (J. F. Gmelin) Raf.
Agalinis sp.
Ambrosia artemisiifolia L.
Apocynum cannabinum L.
Aristolochia serpentaria L.
Asclepias tuberosa L.
Aster concolor L.
Aster patens Aiton
Aster sp. 1
Cacalia sp.
Carduus sp.
Chrysopsis gossypina Nutt.
Cnidoscolus stimulosus (Michaux) Engelm. & Gray
Conyza canadensis (L.) Cronq.
Diodia teres Walter
Elephantopus tomentosus L.
Epilobium angustifolium L.
Erechtites hieracifolia (L.) Raf.
Erigeron strigosus Muhl. ex Willd.
Eupatorium album L.
Eupatorium aromaticum L.
Eupatorium compostifolium Walter
Eupatorium cuneifolium Willd.
Eupatorium mohrii Greene
Eupatorium rotundifolium L.
Eupatorium semiserratum DC.
Eupatorium serotinum Michaux
Eupatorium spp.
Euphorbia corollata L.
Fragaria virginiana Duchesne
Galium hispidulum Michaux
Geranium carolinianum (Walter) Michaux
Gnaphalium obtusifolium L.
Gnaphalium purpureum L.
Granola viscidula Pennell
Helianthemum carolinianurn (Walter) Michaux
Helianthus hirsutus Raf.
Heterothecagossypina (Michaux) Shinners
Hieracium sp. 1
Hieracium sp. 2
Houstonia pusilla Schoepf
Hypericum gentianoides (L.) BSP.
Hypericumpunctatum Lam.

Ipomoea sp. 1
Krigia virginica (L.) Willd.
Lechea minor L.
Lechea sessiliflora Raf.
Lepidium virginicum L.
Lobelia puberula Michaux
Monarda sp.
Monotropa uniflora L.
Oxalis florida Salisbury
Paronychia riparia Chapman
Passiflora lutea L.
Physalis sp.
Polygala polygama Walter
Polypremum procumbens L.
Potentilla canadensis L.
Potentilla simplex Michaux
Pterocaulon pycnostachyum (Michaux) Ell.
Rhexia mariana L.
Rumex hastatulus Baldwin ex Ell.
Sanicula canadensis L.
Scutellaria integrifolia L.
Senecio anonymus Wood
Seymeria pectinata Pursh
Silphium compositum Michaux
Silphium dentatum Ell.
Solanum carolinense L.
Solidago arguta Aiton
Solidago odora Aiton
Solidago sp. 1
Solidago sp. 2
Solidago sp. 3
Solidago sp. 4
Solidago sp. 5
Solidago sp. 6
Stipulicida setacea Michaux
Stylisma humistrata (Walter) Chapman
Tradescantia sp.
Tragia urens L.
Verbena carnea Medicus
Vernonia angustifolia Michaux
Viola sororia Willd.
Viola walteri House
Wahlenbergia marginata (Thunberg) DC

Semiwoody growth form

Opuntia compressa (Salisbury) Macbride
Rubus argutus Link
Rubus flagellaris Willd.

Woody vine growth form

(L.) Koehne
Berchemia scandens (Hill) K. Koch
Campsis radicans (L.) Seemann
Cocculus *carolinus* (L.) DC.
Gelsemium sempervirens (L.) Aiton
Lonicera japonica Thunberg
Lonicera sempervirens L.
Parthenocissus quinquefolia (L.) Planchon
Smilax *glauca* Walter
Smilax *laurifolia* L.
Smilax *rotundifolia* L.
Smilax smallii Morong
Toxicodendron radicans (L.) Kuntze
Vitis rotundifolia Michaux

Fern growth form

Asplenium platyneuron (L.) Oakes
Botrychium dissectum Sprengel
Pteridium aquilinum (L.) Kuhn

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