EFFECTS OF PRECOMMERCIAL THINNING AND MIDSTORY CONTROL ON AVIAN AND SMALL MAMMAL COMMUNITIES DURING LONGLEAF PINE SAVANNA RESTORATION

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Abstract--Restoring longleaf pine (*Pinus palustris* Mill.) savanna is a goal of many southern land managers, and longleaf plantations may provide a mechanism for savanna restoration. However, the effects of silvicultural treatments used in the management of longleaf pine plantations on wildlife communities are relatively unknown. Beginning in 1994, we examined effects of longleaf pine restoration with plantation silviculture on avian and small mammal communities using four treatments in four 8- to 11-year-old plantations within the Savannah River Site in South Carolina. Treatments included prescribed burning every 3 to 5 years, plus: (1) no additional treatment (burn-only control); (2) precommercial thinning; (3) non-pine woody control with herbicides; and (4) combined thinning and woody control. We surveyed birds (1996-2003) using 50-m point counts and small mammals with removal trapping. Thinning and woody control alone had short-lived effects on avian communities, and the combination treatment increased avian parameters over the burn-only control in all years. Small mammal abundance showed similar trends as avian abundance for all three treatments when compared with the burn-only control, but only for 2 years post-treatment. Both avian and small mammal communities were temporarily enhanced by controlling woody vegetation with chemicals in addition to prescribed fire and thinning. Therefore, precommercial thinning in longleaf plantations, particularly when combined with woody control and prescribed fire, may benefit early-successional avian and small mammal communities by developing stand conditions more typical of natural longleaf stands maintained by periodic fire.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) was once the dominant forest type across much of the southeastern United States. Longleaf pine's historic range encompassed most of the Atlantic and Gulf Coastal Plains from southeastern Virginia to eastern Texas and included part of the Piedmont and Ridge and Valley physiographic provinces of Alabama and Georgia (Simberloff 1993). Today less than 3 percent of the estimated 37 million ha of longleaf that existed prior to European colonization remain, and much of the remainder is in a degraded condition (Frost 1993). Losses of moist tropical rainforest worldwide amount to 40 percent of that ecosystem in comparison to the loss of 97 percent of the historic longleaf ecosystem, making the longleaf pine ecosystem critically endangered (Noss 1989, Ware and others 1993).

Historically, the longleaf ecosystem occupied a wide variety of site types, and the structure and composition of the vegetative communities varied greatly across this site gradient (Peet and Allard 1993). Commonalities among these communities include an overstory dominated by longleaf pine, lack of midstory hardwoods, and rich and diverse herbaceous ground cover. The longleaf ecosystem supports some of the most diverse vegetative and faunal communities in the temperate zone, including many endemic species (Peet and Allard 1993, Simberloff 1993).

The longleaf pine ecosystem depends on disturbance, particularly frequent low-intensity fires (Ware and others 1993). Early-successional plant and animal communities in longleaf pine ecosystems rely upon periodic fire to persist, particularly endemic species such as red-cockaded woodpecker (*Picoides borealis*) and Bachman's sparrow (*Aimophila aestivalis*) (Conner and others 2001, Kilgo and Blake 2005, Plentovich and others 1998). In general, early-successional plant and animal communities associated with pine forests decline with the establishment of midstory woody species, which eventually leads to crown closure and understory shading (Atkeson and Johnson 1979, Lane and others 2011). Without fire, the southern pine ecosystems succeed to other forest types, often the southern mixed hardwood

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forest (Frost 1993, Landers and others 1995, Ware and others 1993). . Unfortunately, early-successional forest habitats are in decline throughout the United States due to the removal of natural disturbances (notably fire) which slow or prevent early-successional habitats from succeeding to climax communities (Trani and others 2001). Pine plantation management frequently seeks to create early-successional habitat via treatments such as precommercial or commercial thinning and understory woody plant control, especially in situations where hunting leases generate additional income or restoration of native pine communities is a management goal (Hedman and others 2000, Stroh and others 2002).

During the last 2 decades, interest has increased to restore longleaf pine savanna on appropriate sites throughout its historical range (McMahon and others 1998). Because there is often an insufficient seed source to regenerate these areas naturally, plantation silviculture has been suggested as a means of restoring this species and associated ecosystems (Harrington and Edwards 1999, Landers and others 1995). Although the floral and faunal characteristics of natural longleaf forests have been well documented (Peet and Allard 1993, Ware and others 1993), the effects of longleaf plantation silviculture on plant and wildlife communities are less well understood (Repenning and Labisky 1985). Loblolly pine (*Pinus taeda* L.) plantations can support early-successional plant and animal communities through a combination of site preparation methods, herbaceous and/or woody control, and thinnings (Krementz and Christie 2000, Lane and others 2011), but the characteristics and persistence of these communities in longleaf plantations are not fully understood. Therefore, we examined the effects of thinning and woody competition control on avian and small mammal communities in longleaf pine plantations through 10 years post-treatment in the Upper Coastal Plain of South Carolina.

MATERIALS AND METHODS

We established a long-term study to assess longleaf pine ecosystem restoration techniques using plantation silviculture at the Savannah River Site (SRS), a National Environmental Research Park of the U.S. Department of Energy near Aiken, SC (Harrington and Edwards 1999). The study was conducted in the Sandhills physiographic province of South Carolina (Miller and Robinson 1995), similar to work initiated by Brunjes and others (2003). During the winter of 1993-1994, we selected four longleaf pine plantations established between 1982 and 1986. We selected sites that contained fully stocked stands of longleaf pine (> 1,200 stems/ha) and hardwoods (> 600 stems/ha). Sites ranged from 17.4 to 20.6 ha. Each plantation had been established by machine planting 1-year-old bare-root seedlings at 1.8- by 3-m spacing in clearcut-harvested areas in which woody debris had been windrowed or piled, then burned. The sites supported mature stands of naturally regenerated longleaf and loblolly pines prior to longleaf plantation establishment. The study sites represent a range of moisture classifications from xeric to moderately mesic (Van Lear and Jones 1987). Soils are loamy sands, which range from well-drained to excessively well-drained (Rogers 1990).

The USDA Forest Service, Savannah River, applied a prescribed fire of moderate to high intensity to each site in February 1994, which top-killed all shrubs and most hardwoods < 5 cm d.b.h. Similar prescribed fires were applied to all sites in February 1998 and January-February 2003.

Each site was divided into four treatment areas of similar size at the initiation of the study, burned every 3 to 5 years with prescribed fire, and randomly assigned one of the following treatments to each: (1) nontreated: no treatments applied other than prescribed fire; (2) pine thinning: in May 1994, we thinned the pines to leave a uniform spacing of trees at approximately half the original stem density, resulting in 635 and 1,440 pine trees/ha for thinned and unthinned plots, respectively. We cut the trees with a brush saw and left them to decay, resulting in minimal litter and soil disturbance; (3) non-pine woody control: in April 1995, we applied undiluted Velpar® L (hexazinone, E.I. du Pont de Nemours and Company, Wilmington, DE) at a rate of 1.7 kg active ingredient/ha with a spotgun to grid points on approximately 1-m spacing. In March 1996, we targeted surviving non-pine stems with a basal spray of Garlon® 4 (triclopyr ester, Dow AgroSciences LLC, Indianapolis, IN) at 7 percent concentration in oil. In late June 1996, we applied a directed foliar spray of Arsenal® AC (imazapyr, American Cyanamid Company, Wayne, NJ), Accord® (glyphosate, Monsanto Company, St. Louis, MO), and X-77® surfactant

(Loveland Industries, Inc, Greeley, CO) mixed in water at 0.5, 5, and 0.5 percent concentrations, respectively, to surviving target vegetation within 8 m of each sample point (described below). We applied all herbicides with a backpack sprayer and left vegetation standing; and (4) combined treatment: we combined pine thinning with woody control.

We used a randomized complete block design with four blocks, each with a 2 x 2 factorial arrangement of treatments. These treatment plots were the experimental units. Within each of the 16 treatment plots, we permanently marked 10 small mammal sampling points on a 40-m grid and 1 avian sample point near the center of each plot for repeated measurements. We hypothesized that both silvicultural treatments would increase the abundance of early-successional birds and small mammals and decrease the abundance of mature forest wildlife. We further hypothesized that the duration of any effects noted would be relatively short when treatments were applied separately but that combining the treatments would extend the duration of the effects.

Avian Sampling

We surveyed the breeding bird community using 50-m fixed-radius point counts within the first 4 hours following sunrise. We performed five counts at the permanent avian sample points in each treatment area in April-June 1996 and 1997 and in May 2001-2003. During each 5-minute count, we recorded all birds seen or heard within 50 m of the point. We calculated the mean number of individuals of each species encountered on each treatment area by year. We also calculated Shannon H´ diversity and richness of these bird communities (Ricklefs 1997).

Small Mammal Sampling

We surveyed small mammal populations by removal trapping at two sites during 1996-1997 and surveyed two additional sites (four total) during 2001-2004. We placed one Victor® (Woodstream Corporation, Lititz, PA) rat-trap 4 m north or south of each of the 10 sample points per treatment area and placed one Victor® mousetrap opposite the rat-trap, 4 m from the sample point. We baited traps daily with peanut butter and oatmeal. We trapped the original two sites in April 1996, December 1996, and April 1997, and all four sites in May 2001, May 2002, December 2002, May 2003, and December 2003. We surveyed all sites simultaneously. Each trapping period consisted of four consecutive nights, and captured animals were identified using morphological characteristics (Cothran and others 1991). *Peromyscus leucopus* Raf. and *P. gossypinus* Le Conte were difficult to differentiate morphologically (Burt and Grossenheider 1976, Cothran and others 1991). Although Cothran and others (1991) reported that only two *P. leucopus* have been found from the SRS, we combined *Peromyscus leucopus* and *P. gossypinus* into a *Peromyscus* spp. category.

Vegetation Sampling

We sampled vegetation characteristics to explain potential differences in avian and small mammal communities among treatments. In winter 1994-1995, 1995-1996, 1997-1998 and 2002-2003, we measured diameter at breast height (d.b.h.) of each hardwood and pine tree rooted within 6 m of each small mammal sampling point and measured total height, height to the base of the live crown (HBLC), and crown width (CW) of 20 percent of randomly selected surrounding stems.

We recorded each understory species rooted within 3.6 m of each small mammal sampling point in August 1994-1996. We estimated percent ground cover of each species and woody debris at each sample point using the line-intercept method (Mueller-Dombois and Ellenberg 1974). Understory plant cover data were grouped into categories of forbs, grasses, vines, shrubs, or tree seedling according to Radford and others (1968). In 1998, 2001, and after the fire in 2003, we employed sampling protocols developed for the North Carolina Vegetation Survey (Peet and others 1996) to provide more comprehensive estimates of herbaceous species density and understory cover. At each odd-numbered sample point (120 total), we located nested square subplots of 0.01, 0.1, 1, 10, and 100 m^2 with their diagonal overlaid onto the original vegetation transect. We generated a list of understory species rooted within each subplot. We visually assessed species percent within the 10-m^2 subplot using the following cover classes and assigned class midpoint values: trace (class midpoint 0.1 percent), 0-1, 1-2, 2-5, 5-10, 10-25, 25-50, 50-75, 75-95, 95-100 percent. All values were averaged by vegetation category to provide one estimate per category for each experimental unit to correlate with avian and small mammal metrics.

Analysis

We analyzed treatment effects as a 2 x 2 factorial design with repeated measurements for each response variable (mean avian abundance, avian species richness, avian Shannon H´ diversity, and mean small mammal capture rates). Square root transformations of bird abundance data were used to satisfy the normality assumptions of analysis of variance (ANOVA). Once transformed, the residuals from all avian analyses were approximately normal. When residuals for small mammals were severely non-normal, we transformed the data to improve the distribution of the residuals. If standard transformations did not normalize the residuals, we used the rank transformation approach of Conover and Iman (1981) for small mammal data. We ranked treatment area means within each trapping period, assigning average rank to ties. ANOVA performed on ranks was a non-parametric test that retained the advantages of the full experimental design (Conover and Iman 1981). We used SAS® System version 8.02 (SAS Institute, Cary, NC) for all analyses, and used GLM, MIXED, and CORR procedures to perform ANOVA and correlations procedures, respectively. We considered significance at α = 0.10 for all analyses.

RESULTS

Avian Community Responses

We analyzed 80 point counts from each year that we surveyed: 1996, 1997, 2001, 2002, and 2003. Overall, we detected 746 birds of 41 species, including 28 residents (including short distance migrants) and 13 neotropical migrants (table 1). We detected 133 individuals of 25 species in 1996, 99 individuals of 18 species in 1997, 132 individuals of 23 species in 2001, 258 individuals of 25 species in 2002, and 124 individuals of 24 species in 2003. Sampling year explained variability in all of our habitat and migration strategy groupings ($F_{4,36} \geq 2.23$, $P \leq 0.09$).

Total avian abundance was affected by the interaction of thinning and midstory-control ($F_{1,9} = 9.71$, $P = 0.01$). Total avian abundance was greatest in the combined treatment in 1996 and 2001-2003, while total avian abundance was similar among all other treatments (fig. 1). Total avian abundance was weakly correlated with sampling year (Pearson's r = 0.26, $P = 0.02$), number of years since the last burn (r = 0.26, $P = 0.02$), mean pine d.b.h. (r = 0.26, $P = 0.02$), and mean pine crown width (r = 0.25, $P = 0.02$). Total avian abundance was weakly negatively correlated with mean density of pine trees/ha (r = -0.28, $P = 0.01$) and the mean density of hardwood trees/ha (r = -0.21, $P = 0.07$).

Avian species richness and diversity were not affected by midstory-control alone ($F_{1,9} \leq 2.39$, $P \geq 0.16$) but were affected by thinning alone ($F_{1,9} \geq 6.94$, $P \leq 0.03$) and by the interaction of thinning and midstory-control ($F_{1,9} \geq 3.72$, $P \leq 0.09$). Avian species richness and diversity were greatest in the combined treatment in all years except 2003, when values on all treated plots were less than the control (fig. 1). Thinned plots also contained greater avian species richness and diversity than midstory-control alone and the control in most years except 2003 (fig. 1).

Small Mammal Community Responses

We captured 211 mammals of eight species during 8,320 trap nights (table 2). *Peromyscus* species other than *P. polionotus* accounted for 64 percent of all captures. Oldfield mice (*P. polionotus*) comprised 18 percent of captures, and eastern woodrats (*Neotoma floridana*) comprised 8 percent. We also captured cotton rats (*Sigmodon hispidus*, 6 percent), golden mice (*Ochrotomys nuttalli*, 3 percent), pine voles (*Microtus pinetorum*, 1 percent), and eastern harvest mice (*Reithrodontomys humulis*,

Table 1--Common and scientific names, migratory strategy, and habitat association of bird species encountered during the breeding season in longleaf pine plantations at the Savannah River Site, South Carolina, in 1996, 1997, and 2001-2003. Species are classified as year-round residents (R), short distance migrants (SD), or neotropical migrants (T)

Common name	Scientific name	Migratory strategy
American crow	*Corvus brachyrhynchos*	SD
American goldfinch	*Carduelis tristis*	SD
Black-and-white warbler	*Mniotilta varia*	T
Blue jay	*Cyanocitta cristata*	SD
Blue-gray gnatcatcher	*Polioptila caerulea*	SD
Brown thrasher	*Toxostoma rufum*	SD
Brown-headed nuthatch	*Sitta pusilla*	R
Carolina chickadee	*Poecile carolinensis*	R
Carolina wren	*Thryothorus ludovicianus*	R
Downy woodpecker	*Picoides pubescens*	R
Eastern bluebird	*Sialis sialis*	SD
Eastern towhee	*Pipilo erythrophthalmus*	SD
Eastern wood-pewee	*Contopus virens*	T
Field sparrow	*Spizella pusilla*	SD
Golden-crowned kinglet	*Regulus satrapa*	SD
Gray catbird	*Dumetella carolinensis*	T
Great crested flycatcher	*Myiarchus crinitus*	T
Hairy woodpecker	*Picoides villosus*	R
Indigo bunting	*Passerina cyanea*	T
Mourning dove	*Zenaida macroura*	SD
Northern bobwhite	*Colinus virginianus*	R
Northern cardinal	*Cardinalis cardinalis*	R
Northern flicker	*Colaptes auratus*	SD
Northern parula	*Parula Americana*	T
Ovenbird	*Seirus aurocapillus*	T
Pileated woodpecker	*Dryocopus pileatus*	R
Pine warbler	*Setophaga pinus*	SD
Prairie warbler	*Setophaga discolor*	T
Red-bellied woodpecker	*Melanerpes carolinus*	R
Red-eyed vireo	*Vireo olivaceus*	T
Red-shouldered hawk	*Buteo lineatus*	SD
Red-tailed hawk	*Buteo jamaicensis*	SD
Song sparrow	*Melospiza melodia*	SD
Summer tanager	*Piranga rubra*	T
Tufted Titmouse	*Baeolophus bicolor*	R
White-eyed vireo	*Vireo griseus*	SD
Wild turkey	*Meleagris gallopavo*	R
Wood thrush	*Hylocichla mustelina*	T
Yellow-breasted chat	*Iceria virens*	T
Yellow-rumped warbler	*Setophaga coronata*	SD
Yellow-throated vireo	*Vireo flavifrons*	T

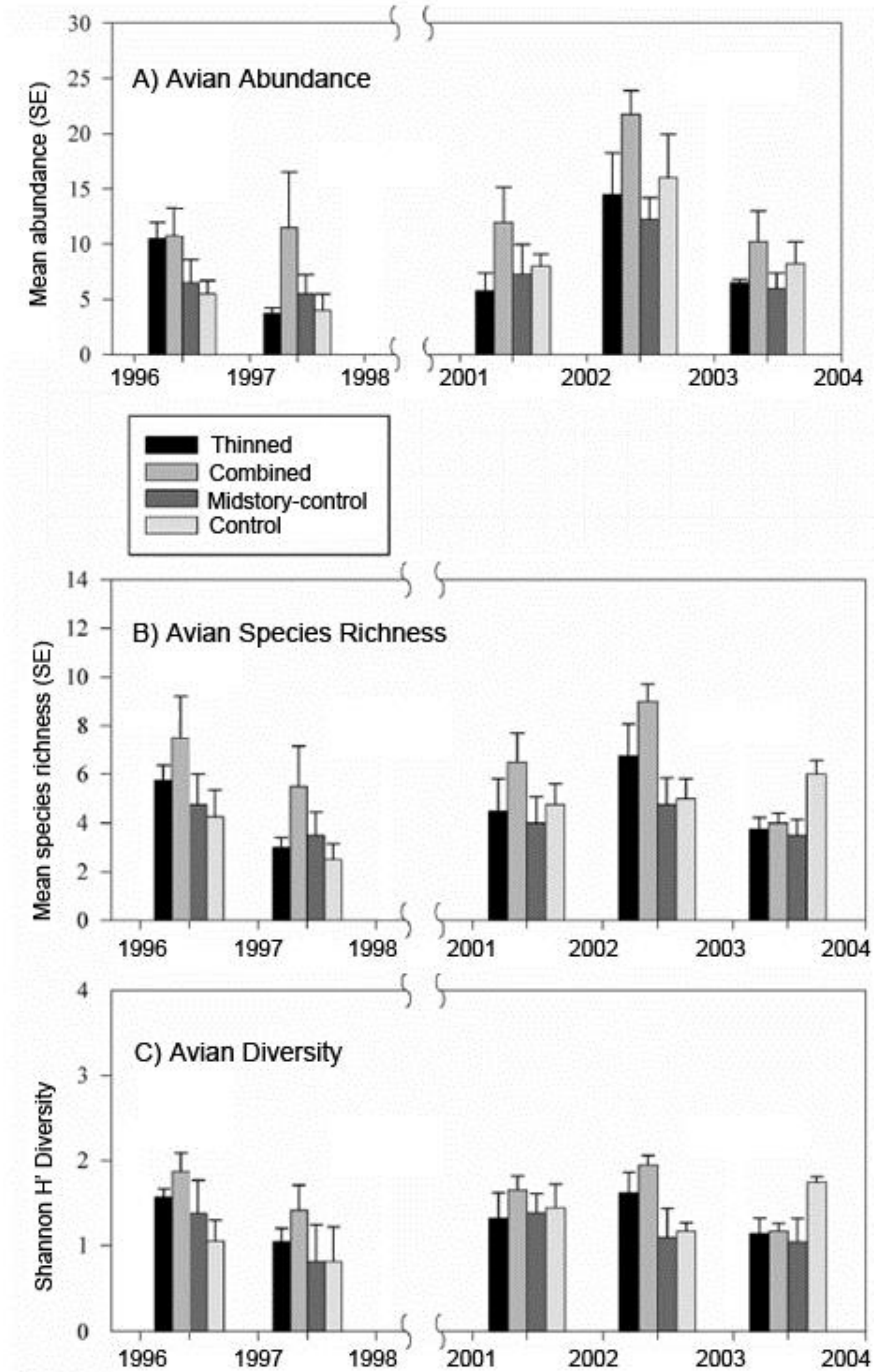

Figure 1--Total avian abundance, species richness, and Shannon's H' diversity in factor level combinations of thinning and midstory-control in longleaf pine plantations at the Savannah River Site, SC, in Spring 1996, 1997, 2001-2003. Abundance values are the mean number of birds counted per treatment area per year. Stands were thinned in May 1994. Moderate- to high-intensity prescribed fire occurred in winter 1994, 1998, and 2003. Midstory-control occurred in spring 1995 and 1996.

Table 2--Count of small mammals captured in longleaf pine plantations on the Savannah River Site, South Carolina, in 1996-2003 among four treatments

Year	Treatment	Other *Peromyscus* spp.	*Peromyscus polionotus*	*Neotoma floridanum*	*Sigmodon hispidus*	Other	Total	Trap success
								%
Spring	Thinned	4	9	2	1		16	10.0
1996	Combined	4	12			1	17	10.6
n[b]=2	MC[a]	7	1	1		1	10	6.3
	Control	2		3	1		6	3.8
Winter	Thinned			2	3		5	3.1
1996	Combined	4	8	1			13	8.1
n=2	MC	2		1	1		4	2.5
	Control			2			2	1.3
Spring	Thinned	4		1			5	3.1
1997	Combined	2	8			1	11	6.9
n=2	MC	5		2			7	4.4
	Control	2					2	1.6
Spring	Thinned	7					7	2.2
2001	Combined	2				2	4	1.3
n=4	MC	6				1	7	2.2
	Control	5					5	1.6
Spring	Thinned	3					3	0.9
2002	Combined	6					6	1.9
n=4	MC	3					3	0.9
	Control						0	0.0
Winter	Thinned	7					7	2.2
2002	Combined	3				3	6	1.9
n=4	MC	6					6	1.9
	Control	5				1	6	1.9
Spring	Thinned	6					6	1.9
2003	Combined	11				1	12	3.8
n=4	MC	11		1			12	3.8
	Control	7					7	2.2
Winter	Thinned	4					4	1.3
2003	Combined	1			5		6	1.9
n=4	MC	2			1		3	0.9
	Control	3					3	0.9
	Total	134	38	16	12	11	211	

[a]MC = Midstory-control
[b]Number of sites sampled

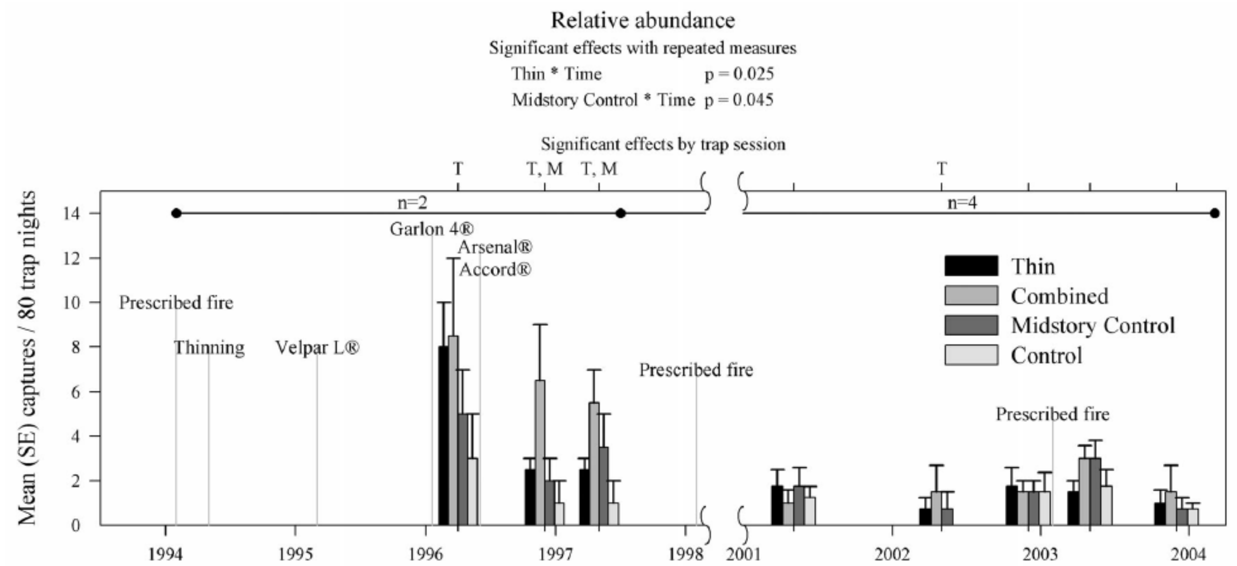

Figure 2--Small mammal relative abundance by factor level combination of precommercial thinning and midstory-control in longleaf pine plantations at the Savannah River Site, SC, by trapping session (spring and winter) 1996, 1997, 2001-2003. Abundance values are mean small mammals of all species captured per 80 trap nights. Significant treatment effects of repeated measures analysis are reported below the title. Significant effects for each trapping session are included on the upper x-axis [thinning (T), midstory-control (M), and interaction (I)]. Significance level is α = 0.10.

1 percent). Thinning and midstory-control alone affected small mammal relative abundance, but the interaction of thinning and midstory-control was nonsignificant, indicating a simple additive effect of treatments in the combined treatment (fig. 2). Combined treatment plots contained the most small mammal captures for spring 1996, winter 1996, and spring 1997, but captures were similar among treatments in later years. Small mammal relative abundance was greatest in 1996-1997 (average 8.0 captures per 80 trap nights in combined treatment); by 2001, small mammal relative abundance was low (average 1.8 captures per 80 trap nights in combined treatment) and remained low for the rest of the study. Small mammal captures were negatively correlated to all pine overstory characteristics that we measured (pine height, d.b.h., crown width, height to base of live crown, and basal area; $r = -0.20$ to -0.50, $P = 0.04$ to <0.001). Small mammal relative abundance was also negatively correlated with trapping period ($r = -0.48$, $P < 0.001$), hardwood height ($r = -0.20$, $P = 0.03$), hardwood d.b.h. ($r = -0.19$, $P = 0.05$), hardwood crown width ($r = -0.20$, $P = 0.04$), hardwood height to base of live crown ($r = -0.24$, $P = 0.01$), and hardwood trees/ha ($r = -0.19$, $P = 0.06$).

DISCUSSION

Avian Community Responses

Our combination treatment of thinning and midstory-control was most effective at creating early-successional vegetative conditions that supported the greatest bird species richness and abundance. Application of thinning and midstory-control alone frequently created conditions similar to conditions observed in the nontreated control, thus they were likely ineffective at altering understory vegetation characteristics beyond the effects of periodic prescribed fire. Thinning also increased abundance of midstory hardwoods, which increased shading in the understory (Harrington 2011). A combination of thinning and intensive midstory-control has also been used in Texas loblolly and shortleaf (*P. echinata* Mill.) pine forests to stabilize endemic red-cockaded woodpecker[*Picoides borealis* (Vieillot)] populations with moderate success (Conner and Rudolph 1994). In contrast, a study in young loblolly pine plantations in the Coastal Plain of North Carolina observed positive effects of wide pine spacing on bird communities but alternating effects of understory woody control; in early years, bird abundance was less in plots receiving understory woody control, but this trend reversed in later years due to decreased understory herbaceous vegetation structure and diversity as pines reached canopy closure (Lane and others 2011). However, Kilgo and Bryan (2005) observed increased abundance of birds following removal of understory woody vegetation in longleaf pine forests. Similarly, a study in Georgia Piedmont and Coastal Plain pine stands did not observe any bird species whose abundance was positively related with increasing understory woody vegetation, but 10 species were negatively associated with this condition (Klaus and Keyes 2007). Thus, avian diversity and abundance in southern pine stands appear to be associated with open canopy and midstory conditions.

We did not measure fauna or flora characteristics prior to implemented treatments; thus we are unable to discern direct before and after effects of our treatments. However, other studies suggest that early-successional plant and wildlife species show a rapid but short-lived response to disturbances such as thinning and midstory-control (Lane and others 2011, O'Connell and Miller 1994). Although sampling year significantly explained some variation in our results, we did not observe a noticeable, consistent change in avian abundance, species richness, diversity, or change in bird assemblages throughout our study. This suggests that periodic prescribed fire used in our study was likely effective at holding a relatively stable early- to mid-successional vegetation community in our stands. Thus, treatments used to restore early-successional pine communities may create conditions that will remain fairly stable in following years with the use of periodic prescribed fire unless additional treatments are used to further change plant communities and vegetation structure.

Our results indicate that a combined treatment of thinning and midstory-control benefit avian communities in longleaf pine plantations by developing stand conditions more typical of natural stands when maintained by periodic fire. However, the optimal fire return interval to maintain the savanna conditions and abundant herbaceous vegetation in longleaf stands is likely more frequent than the 4- to 5-year interval we implemented. Shortening fire intervals to 2 to 3 years may facilitate further reductions in understory woody cover that will likely promote the establishment of early-successional forbs and grasses and make singular thinning or midstory-control treatments more effective (Glitzenstein and others 2003). Otherwise, additional midstory-control treatments may be necessary to mitigate establishment of understory woody vegetation, particularly stems that grow large enough to survive low-intensity prescribed fire during prolonged fire rotations.

Small Mammal Community Responses

All treatments resulted in short-term increases in small mammal relative abundance over the control, but treatment effects were minimal by 2001. Few studies have examined the effects of herbicides on small mammals in southern pines, and most of these have focused on site preparation rather than mid- or late-rotation stands (Hood and others 2002, Miller and Miller 2004). We did not observe correlations between small mammal relative abundance and understory herbaceous and woody cover as previously cited (Atkeson and Johnson 1979). However, small mammal relative abundance was negatively correlated with the density and size of hardwood stems, suggesting midstory-control when combined with thinning created habitat conditions favorable to small mammals, particularly *Peromyscus* spp., if only for short time.

Short-term increases of 1 to 3 years and then precipitous declines to low but apparently stable populations have been observed in small mammal communities following anthropogenic and natural disturbances in southern pine forests (Moore 1993, O'Connell and Miller 1994). Decreasing the return interval of prescribed fires (from 4 years to 2 to 3 years) may provide better long-term hardwood control and thus support greater numbers of small mammals, especially pioneer species that utilize early-successional habitats (Bechard 2008). A 4-year prescribed-fire return interval is considered the upper limit of the range generally recommended to maintain longleaf dominance and understory abundance and diversity (Frost 1993, Glitzenstein and others 2003). Provided there is sufficient fuel to result in a moderately intense fire, shorter fire-free periods may prevent hardwoods from becoming large enough to be fire resistant.

Our findings support Brennan and others' (1998) assertion that combining herbicide use with fire may be more beneficial than either treatment alone and could have long-lasting (10 to 15 year) effects on understory flora and fauna communities. Therefore, precommercial thinning in longleaf plantations, particularly when combined with woody control and prescribed fire, may benefit early-successional avian and small mammal communities by developing stand conditions more typical of natural longleaf stands maintained by periodic fire.

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