Effects of Thinning and Herbicide Application on Vertebrate Communities in Longleaf Pine Plantations

Kristina J. Brunjes,[1] *D. B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602*

Karl V. Miller, *D. B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602*

W. Mark Ford, *USDA Forest Service, Northeastern Research Station, Parsons, WV 26287*

Timothy B. Harrington,[2] *D. B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602*

M. Boyd Edwards, *USDA Forest Service, Southern Research Station, Athens, GA 30602*

Abstract: Currently, nearly 98% of the land area once dominated by longleaf pine ecosystems has been converted to other uses. The U.S. Forest Service is replanting logged areas with longleaf pine at the Savannah River Site, New Ellenton, South Carolina, in an effort to restore these ecosystems. To ascertain the effects of various silvicultural management techniques on the vertebrate communities, we surveyed small mammal, herpetofaunal, and avian communities in six 10- to 13-year-old longleaf pine plantations subjected to various thinning and herbicide regimes. Areas within each plantation were randomly assigned one of four treatments: thinning, herbicide spraying, thinning and herbicide, and an untreated control. For all vertebrate groups, abundance and species diversity tended to be less in the controls than treated areas. Birds and small mammals were most abundant and diverse in thinned treatments versus spray only and control. Herpetofauna capture rates were low and, thus, we were unable to detect treatment-related differences. Silvicultural treatments that reduce hardwood stem density and pine basal area can enhance habitat conditions for numerous vertebrate species.

Key words: avian communities, herpetofauna, longleaf pine, silvicultural treatment, small mammals.

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Nearly 98% of the land area once dominated by longleaf pine (Pinus palustris) ecosystems has been converted to other uses such as suburban development, agriculture, or production of faster-growing pine species (Ware et al. 1993). This decline

1. Present address for Kristina Brunjes: Department of Range, Wildlife, and Fisheries Management, Texas Tech University, Lubbock, TX 79409

2. Present address for Timothy Harrington: Pacific Northwest Research Station, USDA Forest Service, 3625 93rd Ave. SW, Olympia, WA 98512

continues, making restoration of this critically endangered ecosystem a priority for many agencies, including the U.S. Forest Service (USFS). Historically, the area which is now the Savannah River Site National Environmental Research Park (SRS) in the Upper Coastal Plain of South Carolina was dominated by longleaf pine systems. By the 1950s, when the area was acquired by the Department of Defense, most areas which had not already been converted to agriculture or other uses were logged by displaced residents. These areas were reforested, naturally and by planting, primarily with loblolly pine (*P. taeda*; Workman and McLeod 1990). In recent decades, the USFS at the Savannah River Forest Station has placed greater emphasis on restoration and management of longleaf pine communities including replanting logged areas with longleaf pine.

Many of these longleaf pine plantations on SRS have begun to reach canopy closure. Time to canopy closure depends on site quality, pine species, planting density, and other silvicultural treatments. Populations of many wildlife species decline dramatically after canopy closure. Intensive silvicultural practices, such as chemical site preparation and machine planting, may be used to regenerate longleaf pine (Nelson et al. 1982). However, intensive management results in earlier crown closure and subsequent exclusion of understory vegetation (Harrington and Edwards 1999). In the Georgia Piedmont, small mammal density declined significantly following canopy closure in loblolly pine stands (Atkeson and Johnson 1979, Langley and Shure 1980). Studies in other southern pine forests have documented similar rapid declines in the abundance and diversity of songbirds (Johnson and Landers 1982, Childers et al. 1986). These decreases in wildlife are attributed to reductions in understory vegetation diversity and cover, and other changes in vegetation structure as the stands mature (Johnson and Landers 1982). Thinning in loblolly-shortleaf stands in Mississippi and Louisiana (McComb and Noble 1980) and in loblolly stands in the Georgia Piedmont (King 1982) resulted in increased small mammal abundance and diversity. Similarly, thinning in combination with prescribed burning can increase wildlife forage yields in natural stands of longleaf pine (Grelen and Enghardt 1973) and in plantations of loblolly pine (Hurst et al. 1981). Herbicides have been used to suppress competition from other woody and herbaceous plants in longleaf plantations (Nelson et al. 1982) and help restore the wiregrass (*Aristida stricta*) community typically associated with longleaf pine (Wilkins et al. 1993). Conversely, some herbicides can eliminate or reduce species diversity of understory vegetation, which can be important food sources for wildlife (Santillo et al. 1989).

Canopy closure results in decreased habitat suitability for herpetofauna in longleaf pine forests (Guyer and Bailey 1993). Williams and Mullin (1987) found that amphibians were uncommon in poletimber size longleaf-slash pine stands in Louisiana, primarily due to lack of water sources and shaded cover. In addition, they found fewer individuals and species of herpetofauna in the intermediate-aged pine stands than in older, sawtimber-sized stands. Conversely, at the Savannah River Site (SRS), amphibian diversity was greatest in intermediate-aged (three and eight years) loblolly pine stands compared to mature stands (Grant et al. 1994). Intensivemanagement associated with establishing plantations may decrease amphibian diversity by eliminating important microhabitats. For example, plantations typically have less coarse woody debris than unmanaged stands (deMaynadier and Hunter 1995).

In longleaf plantations, pre-commercial thinning and herbicide applications may delay the onset of canopy closure or re-open closed stands. Several studies have investigated the effects of thinning or herbicide treatments on particular components of the wildlife community, such as small mammals, in southern pines. However, these studies did not examine the combined effects of such treatments on the birds, small mammals, and herpetofauna of young longleaf pine stands. To make management decisions that will provide habitat conditions for a variety of wildlife species within these plantations, it is necessary to determine if measurable changes in vertebrate abundance and species assemblages occur within and between stands treated mechanically and with herbicides. We compared small mammal, herpetofaunal, and avian communities in longleaf pine plantations subjected to various thinning and herbicide regimes over a 2-year period.

Study Area

The study was conducted within an existing research project (Harrington and Edwards 1999) in the Sandhills region of the Upper Coastal Plain physiographic province at the Savannah River Site near New Ellenton, South Carolina. We selected 6 longleaf plantations as study sites. All sites were within well-stocked plantations (≥ 1,500 trees/ha; ≥ 60% closure estimated visually) with an intermediate to co-dominant stratum of hardwoods (≥ 500 trees/ha). Hardwoods consisted primarily of sand post oak (*Quercus margaretta*), turkey oak (*Q. laevis*), water oak (*Q. nigra*) and hickories (*Carya* spp.) saplings. At study initiation in early 1996, the plantations ranged in age from 8 to 11 years and were relatively productive for longleaf pine (site $index_{50} \geq 24$ m). Soils were well drained to excessively well drained and included the Blanton, Lakeland, and Troup series.

Methods

All study sites were prescribed-burned in February–March 1994. We used a randomized complete block design consisting of six replications and four treatments. Treatment areas were 3–7 ha in size and included:

1) Untreated control—No other treatments were applied except the 1994 prescribed burn.

2) Thin—Pines were thinned to an average stem density of 635 tree/ha. Trees were cut and left on the ground to decay, resulting in minimal disturbance to the litter layer and soil and increased woody debris.

3) Spray—Pines were unthinned. Hardwoods and shrubs were treated with herbicides as described below. All dead vegetation was left standing.

4) Thin + Spray—Combination of thin and spray treatments as described above.

Within each of the 24 treatment areas (six sites x four treatments), we marked 10 permanent sample points spaced on a 40-m by 40-m grid. Two of the six sites were burned again in February 1997 when a prescribed fire in an adjacent mature pine stand escaped. Consequently, data from these replicates in spring and summer of 1997 were not included in analyses.

In May–June 1994, pines in thin and thin + spray treatment areas were cut to leave an average of 625 trees/ha (4.0 m spacing). Hardwood/shrub removal in spray and thin + spraytreatment areas was initiated in March 1995 with a 1- x 1-m spot-grid application of Velpar L herbicide (hexazinone). The application rate was 1.7 kg active ingredient (a.i.)/ha, except in dense hardwood/shrub areas where it was 2.2 kg a.i./ha. Surviving hardwoods and shrubs (eg., *Vaccinium* spp., *Prunus* spp., and *Carya* spp.) were treated in March 1996 with a basal stem application of Garlon 4 herbicide (triclopyr, 7% in oil). During summer 1996, directed foliar applications of Arsenal (imazapyr, 0.5%) plus Accord (glyphosate, 5%), and stem injections of the two chemicals (5% and 50% concentrations in water, respectively) were applied to eliminate most surviving hardwoods and shrubs.

Vegetation was sampled in August 1996 as described in Harrington and Edwards (1999). Coverage (%) was estimated for each species using the line-intercept method. For each sample point, crown intersections (nearest cm) per species along a permanently-marked plot radius (3.6 m) were recorded. Percentage cover of a given species was calculated by dividing the total length of its crown intersections by transect length then multiplying by 100. In December 1996, diameter (cm) at breast height (1.37 m) was measured on each tree >2.5 cm rooted within 6 m of a given sample point. Height (m) was measured on a random sample of 20% of the trees. Stand basal area (m^2/ha) and stem density (*N*/ha) were calculated from these data.

We sampled small mammal populations by removal trapping (Jones et al. 1996) at four of the six sites. One Victor rat-trap was placed 4 m north or south of each sample point. One Victor mousetrap was placed opposite the rat-trap, 4 m from each sample point. Traps were baited daily with peanut butter and oatmeal. Each trapping period consisted of sampling all treatment plots in sites 1–4 for four consecutive nights (1,280 trapnights/sampling period). Trapping was conducted in April 1996, July–August 1996, December 1996, April 1997, and August 1997. Animals were identified to species using morphological characteristics (Cothran et al. 1991).

Herpetofauna and soricid abundances were assessed using drift fence arrays with pitfall traps (Kirkland and Sheppard 1994, Ford et al. 1999). We constructed 32 drift fence arrays on the same four sites where snap-trapping was conducted. Drift fences were linear, 9m long, perpendicular to the slope, each with five 5-gallon buckets evenly spaced along its length. A small amount of soil, litter, and water was maintained in each bucket to provide captured animals with shelter and protection from desiccation and fire ants. Mammals, lizards, and amphibians were toe-clipped in a cohort-marking scheme (Donnelly et al. 1994) and released immediately at the point of capture. Snakes were held until the end of the trapping period and released at the point of capture. During April 1996, July/August 1996, April 1997, and August 1997 pitfalls were opened for 10 consecutive nights.

To index abundance and diversity of breeding birds, permanent point-count locations were established at the center of each treatment area on all six study sites.

Table 1. Mean (SE) size and abundance of trees (December 1996) and ground coverage of understory vegetation and woody debris (August 1996) in longleaf pine plantations at the Savannah River Site, South Carolina. Pines were thinned in May 1994, hardwoods and shrubs were removed with herbicides in 1995–1996, or the combined treatments were applied.

	Treatment[a]			
Vegetation parameter	Thin	Thin+spray	Spray	Control
DBH (cm)[b]				
Pines	11.8 (0.7)a	10.9 (0.5)ab	10.9 (0.6)ab	10.5 (0.6)b
Hardwoods	4.8 (0.3)a			4.3 (0.3)a
Height (m)				
Pines	8.2 (0.6)a	7.7 (0.4)a	8.3 (0.5)a	8.3 (0.6)a
Hardwoods	5.0 (0.6)a			4.8 (0.5)a
Stem density (*N*/ha)				
Pines	641 (57.5)b	641 (54.1)b	1400 (74.9)a	1502 (36.6)a
Hardwoods	655 (237.3)a			803 (157.6)a
Basal area (m^2/ha)[c]				
Pines	7.3 (1.0)b	6.2 (0.6)b	13.7 (1.4)a	14.1 (1.6)a
Hardwoods	1.5 (0.5)a			1.5 (0.5)a
Herb coverage (%)	33.7 (0.7)a	25.5 (0.4)a	14.4 (0.8)b	18.3 (0.4)b
Shrub coverage (%)[d]	17.9 (0.6)a	2.1 (0.7)c	3.4 (0.2)bc	9.3 (0.7)ab
Tree seedling coverage (%)[d]	7.8 (0.3)a	0.1 (0.1)b	1.2 (0.1)b	11.7 (2.0)a
Vine coverage (%)[d]	8.8 (0.1)a	0.6 (0.2)b	1.0 (0.3)b	5.5 (0.2)a
Woody debris coverage (%)[d]	3.0 (0.1)a	1.5 (0.1)a	0.2 (0.2)b	0.2 (0.2)b

a. Means within a row followed by the same letter do not differ significantly ($P > 0.05$).
b. Stem diameter at 1.37 m above ground.
c. Total cross-sectional area of all tree stems of dbh ≥2.5 cm.
d. Harrington and Edwards (1999)

Each point was visited twice weekly for six weeks—the last two weeks of April, first week of May, last week of May and the first two weeks of June 1996 and 1997. During each 5-minute count, all birds heard or seen within 50 m of the center markers were recorded (Hutto et al. 1986). Counts were conducted within four hours of sunrise. Species were categorized as either neotropical migrants or residents, which included year-round residents, winter residents, and short distance migrants. We calculated Shannon diversity and richness of avian communities according to Magurran (1988).

Vegetation coverage data were arcsine transformed prior to analysis (Harrington and Edwards 1999). Small mammal and herpetofauna abundance data were log-transformed to improve non-normality. We used the multivariate analysis of variance (MANOVA) procedure in SAS (SAS 1989) to test for differences in abundance among treatments and trapping periods (season and year) for herpetofauna and small mammals. If the F-test from the MANOVA was significant ($P < 0.05$) for a species, then we conducted means separation for treatments with Duncan's Multiple Range Test. We used analysis of variance to test for differences and interactions in species richness for all vertebrate groups and for avain abundance among trapping periods and treatments and used Duncan's Multiple Range Test for means separation.

Results

Vegetation

Diameter and height of pines and hardwoods did not differ among treatments, except that pine diameter was greater in thin only treatments compared to controls (Table 1). Thinning increased coverage of herbs, shrubs, and woody debris, whereas herbicide treatment decreased cover of shrubs, vines, and tree seedlings. Additional information regarding vegetation responses can be found in Harrington and Edwards (1999).

Snap-trapping

We captured 217 mammals of nine species during 6,381 trapnights (3.4% trap success). Oldfield mice (Peromyscus polionotus) were captured most frequently (44% of all captures). Cotton mice (P. gossypinus) comprised 34% of all captures. Other species captured were Eastern woodrat (Neotoma floridana, 9%), cotton rat (Sigmodon hispidus, 5%), golden mouse (Ochrotomys nuttalli, 3%), Southern short-tailed shrew (Blarina carolinensis, 3%), least shrew (Cryptotis parva, 1%), pine vole (Microtus pinetorum, 1%), and Eastern harvest mouse (Reithrodontomys humulis, 0.5%).

The overall abundance of small mammals did not differ among periods (Wilks' $\lambda = 0.01$, df = 36, $F = 1.67$, $P = 0.11$) or treatments (Wilks' $\lambda = 0.02$, df = 27, $F = 1.21$, $P = 0.37$). Intraspecific differences in abundance among treatments were observed only for oldfield mice (Table 2). In December 1996, oldfield mice were captured more frequently ($F = 4.38$, df = 3, $P = 0.02$) in thin + spray areas than in spray only or untreated areas. The following spring (April 1997), oldfield mice were captured only in thin + spray areas (Table 2).

Species richness of small mammals (number of species captured) differed among periods (F = 9.42, df = 4, P = 0.01) but not treatments ($F = 0.44$, df = 3, $P = 0.73$). The mean number of species captured declined over the course of the study: spring 1996 [= 5.25 (1.50)] > summer 1996 [= 4.00 (2.00)] = winter 1996 [= 3.25 (1.71)] = spring 1997 [= 3.25 (0.50)] > summer 1997 [= 1.75 (.050)].

Pitfall Trapping

We captured 283 individuals representing 24 species during 8,960 trapnights (Table 3). Of these, 63% were herpetofauna, 20% were shrews, and 17% were rodents. The herpetofauna were 28% lizards (five species), 19% snakes (six species), 14% frogs (four species), and 2% salamanders (two species). Six-lined racerunners (Cnemidophorus sexlineatus, 14% of total captures) were the most common vertebrate captured in pitfalls (all seasons combined), followed by southeastern crowned snakes (Tantilla coronata, 13%) and least shrews (11%). Least shrews accounted for 57% of shrew captures, followed by southern short-tailed shrews (30%) and south-eastern shrews (Sorex longirostris, 13%).

Abundance of reptile and amphibians differed among periods (Wilks' $\lambda = 0.01$, df = 36, $F = 1.02$, $P = 0.01$) but not among treatments (Wilks' $\lambda = 0.44$, df = 36, $F = 0.44$, P = 0.91). Soricid abundance also differed among periods (Wilks' $\lambda = 0.18$, df

=15, F = 2.60, P = 0.01) but not differ among treatments (Wilks' λ = 0.59, df = 9, F = 0.84, P = 0.58). Four species of rodents also were captured in the pitfall traps (cotton mouse, Eastern wood rat, oldfield mouse, and pine vole) but numbers were insufficient for analysis. No individual species of vertebrate captured in pitfalls exhibited differences in. abundance among treatments. Species richness of herpetofauna species also differed among periods (F = 10.61 , df = 3, P = 0.01) but not among treatments (F = 0.40, df = 3, P = 0.75). However, no trend over time was observed in the number of herpetofauna species.

Point Counts

Thirty-five avian species were heard or observed in 1996, and 26 in 1997. In 1996, total avian abundance was greater in thin only and thin + spray treatments than in spray only or control areas (F = 5.00, df = 3, $P \leq 0.01$; Table 4). The following year, total avian abundance and resident abundance were greater in thin + spray areas than in any of the other 3 treatments (F = 3.76, df = 3, P = 0.01). In 1996, neotropical migrants were more abundant in thin only and thin + spray areas than in untreated areas (F = 3.93, df = 3, P = 0.03). The following year (1997), neotropical migrants were more abundant in thin + spray areas than in any other treatment areas (F = 2.75, df = 3, $P \leq 0.01$). Year-round residents and winter residents were more abundant in thin only and thin + spray areas than in controls in 1996 (F = 2.87, df = 3, P = 0.05). In 1997, residents were more abundant in thin + spray areas than any other treatment (F= 6.50, df = 3, $P \leq 0.01$). Shannon diversity indices did not vary among treatments .in 1996 (F = 0.44, df = 3, P = 0.78) or in 1997 (F = 1.21, df = 3, P = 0.33). However, species richness was greater in thin only and thin + spray areas compared to untreated areas in 1996 (F = 3.70, df = 3, P = 0.03). The following year, richness was greater in thin + spray areas than in any of the other treatments (F = 0.72, df = 3, $P \leq 0.01$).

Discussion

Low capture rates of herpetofauna and small mammals are typical in sandhill habitats (Stout and Marion 1993), making treatment effects difficult to detect. While our plots did sample the entire stands, the stands themselves were not large and the surrounding forest types varied, which may have confounded treatment effects. For all vertebrate groups, abundance and species richness tended to be less in untreated control areas.

Though not significant across species, mammal capture rates tended to be greater in the thin only and thin + spray treatment areas. This trend was due in part to the increased amount of coarse woody debris left on the ground compared to unthinned areas (Table 1). In addition, herbaceous plants were more abundant and had greater plant species richness in these stands (Harrington and Edwards 1999). This complexity may have allowed a more diverse community of small mammals to exist in these stands compared to more homogenous, unthinned stands (King 1982). Increasing the amount of woody debris by leaving cut trees and slash and minimizing disturbance to herbaceous cover during treatments may benefit small mammals.

Oldfield mice prefer sites with sandy soils, plentiful herbaceous vegetation, and

Table 2. Mean (SE) small mammal snap-trap captures per plot by treatment (80 trap nights/replicate) in longleaf pine plantations at the Savannah River Site, South Carolina, in 1996 and 1997.

Season	Treatment[a]	Oldfield Mouse	Cotton mouse	Eastern woodrat	S. short-tailed shrew	Cotton rat	Golden mouse	Others[b]	All species combined
Spring	Thin	3.00 (1.22)	2.00 (0.00)	0.50 (0.50)		.50 (0.50)		.50 (0.50)	6.25 (1.44)
1996	Thin + spray	3.75 (2.10)	1.50 (0.50)		0.25 (0.25)		0.25 (0.25)		5.75 (2.25)
N = 4	Spray	0.75 (0.48)	2.00 (1.08)	0.25 (0.25)	0.25 (0.25)			0.50 (0.50)	3.75 (1.25)
	Control	0.75 (0.48)	1.50 (0.29)	0.75 (0.75)	0.25 (0.25)	0.25 (0.25)			3.50 (1.04)
Summer	Thin	1.75 (0.75)	0.50 (0.29)	0.50 (0.50)	0.25 (0.25)	0.75 (0.48)	0.50 (0.50)	0.25 (0.25)	4.50 (1.19)
1996	Thin + spray	0.75 (0.48)	0.75 (0.48)		0.25 (0.25)				1.75 (0.25)
N = 4	Spray	0.50 (0.29)	0.75 (0.48)				0.50 (0.50)		1.75 (1.11)
	Control	0.75 (0.48)	1.00 (0.58)	0.50 (0.50)					2.25 (0.86)
Winter	Thin	1.75 (1.44)ab[c]	0.25 (0.25)	0.50 (0.50)		0.75 (0.48)			3.25 (0.95)
1996	Thin + spray	3.25 (0.63)a	1.00 (0.71)	0.25 (0.25)					4.50 (1.55)
N = 4	Spray	0.75 (0.48)b	0.50 (0.29)	0.25 (0.25)		0.25 (0.25)		0.25 (0.25)	2.00 (0.58)
	Control	0.00 (0.00)b		0.50 (0.50)					0.50 (0.50)
Spring	Thin		2.00 (0.00)	0.50 (0.50)	0.50 (0.50)				3.00 (1.00)
1997	Thin + spray	5.00 (2.00)					0.50 (0.50)		5.50 (1.50)
N = 2	Spray		2.50 (0.50)	1.00 (1.00)					3.50 (1.50)
	Control		1.00 (1.00)						1.00 (1.00)
Summer	Thin	0.50 (0.50)							0.50 (0.50)
1997	Thin + spray	1.00 (1.00)							1.00 (1.00)
N = 2	Spray								
	Control		1.00 (1.00)						1.00 (1.00)

a. Least shrew, woodland vole, and Eastern harvest mouse.

b. In thin and thin + spray treatments, pine basal area was reduced to approximately one-half. In thin + spray and spray treatments, hardwoods and shrubs were removed with herbicides.

c. Within a season and species, means followed by the same letter are not different at $P < 0.01$.

little woody vegetation (Golley et al. 1965, Briese and Smith 1975). The most commonly captured vertebrate over the two years, oldfield mice were more abundant in thin only or thin + spray areas and least abundant in untreated areas. Densities of oldfield mice on the SRS are greatest from November to March and least in June and July (Cothran et al.1991). However, our greatest capture rates for this species occurred in April both years.

Although cotton rats are abundant on the SRS where suitable grassy habitat oc-

Table 3. Mean (SE) amphibians, reptiles, and small mammal captures by treatment using pitfall arrays in young longleaf pine plantations at the Savannah River Site, South Carolina, in 1996 and 1997. Pitfalls were open for 400 nights per treatment. In 1996 $N = 4$ sites, in 1997, $N = 2$ sites.

	Spring 1996				Summer 1996			
	Thin	Thin + spray	Spray	Untreated	Thin	Thin + spray	Spray	Untreated
All amphibians					1.00 (0.41)	1.50 (0.65)	1.50 (0.87)	1.75 (0.63)
Southern toad *(Bufo terrestris)*					0.75 (0.25)	0.75 (0.48)	0.25 (0.25)	0.75 (0.48)
E. narrow-mouthed toad *(Gastrophryne carolinensis)*					0.25 (0.25)	0.75 (0.48)	0.75 (0.75)	0.50 (0.29)
Green frog *(Rana clamitans)*							0.25 (0.25)	0.25 (0.25)
Slimy salamander *(Plethodon glutinosis)*								0.25 (0.25)
Red salamander *(Pseudotriton ruber)*							0.25 (0.25)	
All lizards	1.00 (0.40)	0.75 (0.25)	1.50 (0.65)	1.00 (0.71)	2.25 (0.48)	0.75 (0.48)	3.75 (1.11)	4.50 (1.44)
Green anole *(Anolis carolinensis)*	0.25 (0.25)	0.25 (0.25)	0.75 (0.48)	0.75 (0.48)		0.25 (0.25)		0.50 (0.50)
Fence lizard *(Sceloporus undulatus)*	0.75 (0.25)	0.50 (0.29)	0.75 (0.75)	0.75 (0.25)	0.25 (0.25)		0.25 (0.25)	
Six-lined racerunner *(Cnemidophorus sexlineatus)*					2.00 (0.41)	0.50 (0.50)	3.50 (0.96)	3.50 (1.19)
Ground skink *(Scincella lateralis)*								0.25 (0.25)
Five-lined skink *(Eumeces fasciatus)*								0.25 (0.25)

Table 3. Continued

	Spring 1996				Summer 1996			
	Thin	Thin + spray	Spray	Untreated	Thin	Thin + spray	Spray	Untreated
All snakes					0.75 (0.48)	1.25 (0.25)	1.50 (0.50)	1.00 (0.00)
Southeastern crowned snake *(Tantilla coronata)*					0.25 (0.25)	1.25 (0.25)	1.50 (0.50)	0.75 (0.25)
Smooth earth snake *(Virginia valeriae)*								0.25 (0.25)
Scarlet kingsnake *(Lampropeltis triangulum)*					0.25 (0.25)			
Mud snake *(Farancia abacura)*					0.25 (0.25)			
All shrews	0.50 (0.50)		0.50 (0.50)		1.00 (0.41)	2.00 (1.08)	1.50 (0.65)	1.50 (0.29)
Least shrew *(Cryptotis parva)*	0.25 (0.25)		0.50 (0.50)		0.25 (0.25)	1.25 (0.95)	0.50 (0.29)	1.00 (0.00)
S. short-tailed shrew *(Blarina carolinensis)*					0.25 (0.25)	0.25 (0.25)	1.00 (0.41)	0.50 (0.29)
Southeastern shrew *(Sorex longirostris)*	0.25 (0.25)				0.50 (0.29)	0.50 (0.29)		
All rodents			0.25 (0.25)	0.25 (0.25)	2.00 (1.41)	2.50 (0.87)	0.50 0.29)	1.25 (0.48)
Oldfield mouse *(Peromyscus polionotus)*			0.25 (0.25)		0.25 (0.25)	2.25 (0.63)	0.50 (0.29)	0.50 (0.29)
Cotton mouse *(P. gossypinus)*				0.25 (0.25)	1.25 (0.95)			0.50 (0.29)
Woodland vole *(Microtus pinetorum)*						0.25 (0.25)		
E. woodrat *(Neotoma floridana)*					0.50 (0.50)			

Table 3. Continued

	Spring 1997				Summer 1997			
	Thin	Thin + spray	Spray	Untreated	Thin	Thin + spray	Spray	Untreated
All amphibians			1.00 (0.00)	0.50 (0.50)	0.50 (0.50)	1.50 (1.50)		
E. narrow-mouthed toad *(Gastrophryne carolinensis)*					0.50 (0.50)	1.50 (1.50)		
Bullfrog *(Rana catesbiana)*				0.50 (0.50)				
Green frog *(Rana clamitans)*								
Red salamander *(Pseudotriton ruber)*			0.50 (0.50)					
All lizards	0.50 (0.50)		2.00 (2.00)				1.50 (1.50)	
Green anole *(Anolis carolinensis)*								
Six-lined racerunner *(Cnemidophorus sexlineatus)*								
All snakes	0.50 (0.50)	2.00 (1.00)			0.50 (0.50)	1.00 (0.00)	0.50 (0.50)	2.00 (1.00)
Southeastern crowned snake *(Tantilla coronata)*		1.00 (0.00)			0.50 (0.50)		0.50 (0.50)	
Common garter snake *(Thamnophis sirtalis)*		0.50 (0.50)						
Smooth earth snake *(Virginia valeriae)*						1.00 (0.00)		2.00 (0.50)
Black racer *(Coluber constrictor)*	0.50 (0.50)	0.50 (0.50)						
All shrews	1.00 (1.00)	0.50 (0.50)	1.50 (0.50)	0.50 (0.50)	0.50 (0.50)	0.50 0.50)		0.50 (0.50)
Least shrew *(Cryptotis parva)*			0.50 (0.50)		0.50 (0.50)	0.50 (0.50)		
S. short-tailed shrew *(Blarina carolinensis)*	1.00 (1.00)	0.50 (0.50)	1.00 (1.00)	0.50 (0.50)				

Table 3. Continued

	Spring 1997				Summer 1997			
	Thin	Thin + spray	Spray	Untreated	Thin	Thin + spray	Spray	Untreated
All rodents			0.50 (0.50)		1.00 (0.00)	0.50 (0.50)		0.50 (0.50)
Oldfield mouse *(Peromyscus polionotus)*			0.50 (0.50)		0.50 (0.50)			
Cotton mouse *(P. gossypinus)*					0.50 (0.50)			0.50 (0.50)
Woodland vole *(Microtus pinetorum)*						0.50 (0.50)		

Table 4. Mean (SE) breeding season avian abundance, diversity, and richness by treatment in longleaf pine plantations at the Savannah River Site, South Carolina, in spring 1996 and 1997. Abundance values represent mean number of birds per survey. Two sites were eliminated from analysis in 1997 due to an accidental burn.

	Treatments			
Migration Strategy	Thin	Thin + spray	Spray	Control
1996 ($N = 6$ sites)				
Avian abundance				
Neotropical migrant	0.40 (0.09)a[a]	0.42 (0.11)a	0.19 (0.05)ab	0.15 (0.07)b
Year-round or winter resident	1.38 (0.17)a	1.60 (0.21)a	1.08 (0.17)ab	0.94 (0.16)b
Total abundance	1.77 (0.20)a	2.02 (0.25)a	1.23 (0.17) b	1.13 (0.18)b
Shannon diversity (H')	1.99 (0.09)	2.13 (0.11)	1.94 (0.12)	1.91 (0.08)
Species richness[b]	1.65 (0.18)a	1.83 (0.22)a	1.09 (0.13)ab	1.08 (0.16)b
1997 ($N = 4$ sites)				
Avian abundance				
Neotropical migrant	0.19 (0.07)b	0.44 (0.12)a	0.15 (0.05)b	0.04 (0.03)b
Year-round or winter resident	1.02 (0.16)b	1.88 (0.25)a	1.06 (0.16)b	0.79 (0.12)b
Total abundance	1.21 (0.18)b	2.31 (0.30)a	1.21 (0.17)b	0.83 (0.12)b
Shannon diversity (H')	1.46 (0.16)	1.66 (0.19)	1.33 (0.22)	1.52 (0.12)
Species richness	0.98 (0.13)b	1.79 (0.25)a	1.13 (0.18)b	0.81 (0.11)b

a. Within a row, means followed by the same letter do not differ at $P \leq 0.05$.
b. Mean number of species per survey.

curs (Golley et al. 1965), we captured only 10 individuals. Prior to canopy closure in loblolly pine plantations cotton rats account for up to 90% of total small mammal captures (Atkeson and Johnson 1979, Mengak et al. 1989). The low capture rates in our study may have been a result of the lack of heavy herbaceous cover preferred by cotton rats, the relatively small size of the treatment areas (Yates et al. 1997), or reduction in habitat suitability of pine stands over time.

All of our sites were characterized by well-drained soils and were not close to permanent water sources, making them generally unsuitable habitat for amphibians regardless of treatment (Williams and Mullins 1987). However, southern toads and eastern narrow-mouthed toads, common, ubiquitous species on the SRS (Gibbons and Semlitsch 1991) were captured on our sites during both summers. Species diversity (eight) was less than that in 8-year old loblolly plantations (15 species) on SRS (Grant et al. 1994).

Reptiles were more numerous on the study area than amphibians, particularly six-lined racerunners and southeastern crowned snakes. Abundance and diversity did not vary by treatment, however, whether this was due to insufficient captures or lack of treatment effects is unknown. Maintenance of early successional stages, rather than the specific method of maintenance used may be more important for reptiles in pine habitats (Greenberg et al. 1994).

In both years, avian abundance and species richness were greatest in thin + spray areas, which had less vegetation coverage at the canopy and midstory levels. Abundance and richness were least in untreated stands for neotropical migrants and residents, possibly because these stands have the greatest canopy cover. Furthermore, none of our stands had more than three large snags (>20 cm dbh) within any treatment area and mast had no snags. Presence of snags positively influences bird abundance in early-successional habitats (Johnson and Landers 1982, Childers et al. 1986) and managers should leave standing dead trees or create snags in these plantations during future thinning operations.

Precommercial thinning benefits small mammals and avifauna by increasing herbaceous ground cover and the amount of coarse woody debris. However, pine thinning was a less selective method than herbicide application to modify abundance of specific plant species with greater value as wildlife forage. Herbicides can be used to improve forage availability for favored species of wildlife (McComb and Hurst 1987) and may increase structural diversity by leaving standing dead shrubs and saplings within the understory. Individual herbicides have specific selectivity, there-fore plant species composition and abundance vary with the chemical used. In this study, three herbicides were used to virtually eliminate all non-pine woody vegetation. Thinning opened the canopy and increased coarse woody debris, offsetting negative effects of herbicides without thinning seen in spray-only areas, thus resulting in greater species diversity and abundance of vertebrates in thin + spray treated stands. In our study, using multiple herbicides was necessary because of the need to control all deciduous and evergreen species that comprised the understory for other research being conducted on our sites (Harrington and Edwards 1999). However, other researchers have successfully established longleaf pines using only one or two herbicide treatments (Nelson et al. 1982). Use of fewer herbicides may be desirable on SRS to improve habitat for wildlife during reestablishment and throughout the rotation. Our results suggest that periodic thinning, herbicide application, and prescribed burning can increase diversity and abundance of wildlife by delaying canopy-closure in young plantations. Additional research is needed to determine what management is needed to maintain a diverse wildlife community within longleaf plantations as they age.

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