THE EFFECTS OF PRECOMMERCIAL THINNING AND MIDSTORY-CONTROL ON THE FLORA AND FAUNA OF YOUNG LONGLEAF PINE PLANTATIONS

by

ROBERT PATTERSON SIMMONS

(Under the Direction of Richard F. Daniels and Karl V. Miller)

ABSTRACT

I examined the effects of longleaf pine (*Pinus palustris*) restoration using plantation silviculture on the avian, small mammal, and herpetofauna communities on the Savannah River Site, a National Environmental Research Park near Aiken, South Carolina. Vertebrate populations were surveyed from 1995 through 2003 on a series of plantations that had been precommercially thinned and/or received midstory-control via herbicides between 1994 and 1996. Understory and overstory vegetation was surveyed from 1994 through 2004. Thinning and midstory vegetation reduction treatments had greater herbaceous cover than the control through 2004 after a 1-2 year decline on midstory-control plots. Initially, thinned plots had the greatest herbaceous cover. However from 1998 through 2004, the combined treatment had the most herbaceous cover. Without midstory-control, thinning released midstory hardwoods. The effect of thinning or midstory-control alone on bird abundance was positive but short-lived. The positive effects were larger and persisted longer on combined treatment plots. My results indicate that precommercial thinning longleaf plantations, particularly when combined with midstory-control and prescribed fire, had a modest beneficial impact on avian communities by developing stand conditions more typical of natural longleaf stands maintained by periodic fire.

All treatments resulted in short-term increases in small mammal abundance, but effects were minimal by 5-7 years after treatment. By 2001, pine basal area had returned to pre-treatment levels on thinned plots suggesting that frequent thinning may be required to maintain abundant and diverse small mammal communities in longleaf pine plantations. I did not detect any treatment related differences in herpetofauna abundance. These results suggest that restoring longleaf with a combination of precommercial thinning, midstory-control with herbicides, and prescribed fire can have a short-term positive effect on the avian and small mammal communities without affecting the herpetofauna community. However, periodic thinnings may be necessary to extend the positive effects.

INDEX WORDS: Accord®, Amphibian, Arsenal®, Avian, Breeding bird, Garlon®, Herbicide, Herpetofauna, Longleaf pine, *Pinus palustris*, Precommercial thinning, Prescribed fire, Reptile, Restoration, Savannah River Site, Small mammal, South Carolina, Velpar®

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ROBERT PATTERSON SIMMONS

B. A., The University of the South, 1988

M. B. A., Georgia State University, 1994

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ROBERT PATTERSON SIMMONS

Major Professor:	Richard F. Daniels Karl V. Miller
Committee:	Robert J. Cooper John C. Kilgo Michael B. Kane

Electronic Version Approved:
Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

I dedicate this work to my family. My wonderful wife Paige graciously allowed me to pursue my dream of becoming a forester and wildlife biologist, perhaps without fully understanding the ramifications of this decision. She supported me, even when she felt like a single parent to our wonderful children Elizabeth, Robert, and Georgia Blue. I look forward to having more time to devote to being a husband and father, my most important responsibilities.

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CHAPTER 1

INTRODUCTION

The longleaf pine (*Pinus palustris*) ecosystem once stretched from Texas to Virginia, and at the time of European colonization was the most prevalent southern pine ecosystem covering as much as 37 million hectares (Frost 1993). More than 97% of the original range has been converted to other forest types or to non-forest land uses, and less than 1% of the original range is in good, fire-maintained condition (Frost 1993). The overwhelming dominance of longleaf in the overstory can give the impression of uniformity. However, the longleaf ecosystem has extremely high floral and faunal diversity with many endemic species (Peet and Allard 1993, Simberloff 1993, Engstrom et al. 2001). Peet and Allard (1993) described 23 vegetation communities across the range of longleaf pine.

The typical structure of intact, ecologically functioning longleaf stands is often described as a pine savannah with a sparse overstory dominated by longleaf, an open midstory, and a rich and diverse herbaceous layer. This herbaceous diversity and the perpetuation of longleaf as the dominant overstory species are tied to frequent fire (Means and Grow 1985, Noss 1989, Frost 1993, Ware et al. 1993, Landers et al. 1995). Without fire, southern pines are successional, but their dominance can be maintained with frequent fire (Monk 1968, Stout and Marion 1993). Longleaf forests often succeed to southern mixed hardwoods if fire is excluded (Monk 1968, Ware et al. 1993).

The early stages of succession are a dynamic period of forest stand development often characterized by abundant resources, which facilitate high floral and faunal diversity and high productivity (Oliver and Larson 1996, Litvaitis 2001). Fire-maintained mature longleaf forests provide habitat with characteristics of both young and mature pine stands. Early-successional plant and animal communities flourish in mature, fire-maintained pine forests (Buhlmann et al. 2005, Imm and McLeod 2005, Kilgo and Bryan 2005). Periodic fire can maintain the early-successional attributes of these mature stands indefinitely, as opposed to the short duration of early-succession proper.

There has been an emphasis on restoring longleaf pine to portions of its original range, but natural regeneration is often not an option due to lack of a natural seed source (McMahon et al. 1998). Plantation silviculture has been suggested as a method of restoring this species (Landers et al. 1995, Harrington and Edwards 1999). Although the plant and animal communities of natural longleaf forests are well documented (Peet and Allard 1993, Ware et al. 1993, Engstrom et al. 2001), the effects of longleaf plantation silviculture on these communities are less well understood (Repenning and Labisky 1985).

In fully stocked longleaf plantations, crown closure follows the regeneration stage of stand development. Emergent species form a canopy that excludes shade-intolerant species in the understory and ends the period of high understory productivity and diversity (Oliver and Larson 1996). Vertebrate populations, which depend on these understory plants, decline after crown closure. Atkeson and Johnson (1979) and Langley and Shure (1980) documented such declines in small mammal populations in Georgia Piedmont loblolly pine (*P. taeda*) stands. Similarly, Johnson and Landers (1982) reported declines in bird abundance and diversity after crown closure in southern slash pine (*P. elliottii*) stands.

The depauperate closed canopy phase of southern pine stand development continues until the canopy is re-opened, allowing the understory vegetation to again thrive and to support abundant vertebrate populations (Grelen et al. 1972, Grelen and Enghardt 1973, Harris et al. 1974, Loeb 1997). In unmanaged stands, the canopy often remains closed until competition leads to overstory self-thinning or until natural disturbance opens the canopy. In managed stands, this phase usually lasts until the crop trees are large enough to justify commercial thinning. However, precommercially thinning southern pine stands has been suggested as a tool to maintain the abundant resources of the stand initiation stage (Grelen et al. 1972, Hurst et al. 1980) and for ecological restoration (Harrington and Edwards 1999). For example, precommercial thinning in combination with prescribed burning more than doubled the deer forage in 7-year old loblolly plantations in Mississippi, and the effect persisted longer than on unthinned burned plots (Hurst et al. 1980). Nine-years after thinning, herbaceous production was inversely related to overstory basal area in precommercially thinned and frequently burned, direct-seeded Louisiana slash pine stands (Grelen et al. 1972). Grelen and Enghardt (1973) found a similar relationship between basal area and herbaceous production in longleaf plantations.

The relationship between reduced overstory basal area resulting in increased herbaceous productivity is not universal. Midstory conditions mitigate the herbaceous response to thinning. Several studies found that thinning pines released shrub and understory hardwood competition, which reduced herbaceous production (Blair 1967, Blair and Feduccia 1977, Wolters et al. 1982). Prescribed fire and herbicides are tools to control this hardwood invasion. Thinning and woody competition control with herbicides can delay crown closure or reopen closed canopies

(Oliver and Larson 1996). These treatments allow sunlight to reach the forest floor, reduce competition for other resources, and extend or reestablish early-successional habitat.

Herbicide release treatments in southern pine stands can control the woody midstory while maintaining or enhancing herbaceous cover and diversity after a brief decline following treatment (Guynn et al. 2004, Miller and Miller 2004). These treatments can increase timber growth and yield (Wagner et al. 2004), be fire surrogates in situations where prescribed fire is not viable (Wigley et al. 2002), and restore the ability to effectively use fire in pine stands where fire exclusion has allowed hardwoods to become large enough to be fire resistant (Wilkins et al. 1993, Brockway and Outcalt 2000). Following hardwood control with herbicides, frequent prescribed fire and periodic thinning can maintain an open midstory with an abundant herbaceous community. In young longleaf plantations, Harrington and Edwards (1999) reported greater herbaceous species density in stands treated with thinning and midstory-control than in untreated stands at least through the fifth year after treatment. On these same sites, Brunjes et al. (2003) found that small mammals and birds were more abundant and diverse 3-5 years after precommercial thinning young longleaf plantations than in unthinned stands, during an earlier phase of my current study. They suggested that differences between the vertebrate communities resulted from differences in the herbaceous understory communities.

Herpetofauna species richness of the Southeastern Coastal Plain is among the highest in North America (Kiester 1971), and many species use longleaf pine forests for part of their life cycle (Means 2006). These upland amphibians often use isolated wetlands for their primary breeding habitat. These ephemeral, fishless ponds are embedded in the uplands and contribute to amphibian abundance and diversity disproportionately to their size (Russell et al. 2002a). The quality of upland habitat associated with isolated wetlands is important to herpetofauna abundance and diversity (Burke and Gibbons 1995, Kirkman et al. 1999, Gibbons 2003). However, there is little research on the effects of southern pine silviculture on herpetofauna, and these studies have largely been descriptive studies of the effects of clearcutting and site preparation (Means 2005). In one of the few designed experiments, Russell et al. (2002b) found no treatment effects of clearcutting and mechanical site prep on herpetofauna abundance and species richness. They concluded that herpetofauna communities in pine forests may be resilient to some upland disturbance from silviculture and may require some disturbance, particularly frequent fire, to thrive. Renken et al. (2004) found no effect of clearcutting or uneven-age management on amphibian abundance in Missouri oak-hickory and oak-pine forests, suggesting that the amphibian communities in these forests also are tolerant of some disturbance. Nevertheless, these studies have been relatively short-term, and Gibbons et al. (1997) found that the variability associated with herpetofauna populations requires long-term sampling to draw accurate conclusions about abundance, richness, and diversity.

My experiment is part of a long-term study of longleaf pine restoration using plantation silviculture. The study was established in 1993 on the Savannah River Site (SRS), an 80.3-km^2 National Environmental Research Park in the Sandhills and Upper Coastal Plain physiographic provinces in South Carolina (Harrington and Edwards 1999, White 2005). Historically, longleaf dominated the uplands of the SRS (White 2005). Currently, loblolly and longleaf pines are dominant on approximately 65% of the SRS (Imm and McLeod 2005).

My experiment investigated the effects of thinning and woody competition control on the avian, small mammal, and herpetofauna communities in young longleaf pine plantations through the tenth year post-treatment. My objective was to determine the nature and duration of these effects on the composition and abundance of the vertebrate community in young longleaf pine plantations in the Upper Coastal Plain of South Carolina. I hypothesized that both silvicultural treatments would increase the abundance of small vertebrates associated with early succession, and decrease the abundance of small vertebrates associated with mature forests. I further hypothesized that the duration of any effects would be relatively short when treatments were applied separately but that combining the treatments would extend the duration of the effects.

This dissertation is organized in the manuscript format. Chapters 2, 3 and 4 examine the effects of the treatments on the bird, small mammal, and herpetofauna communities respectively. Chapter 5 summarizes the conclusions of these manuscript chapters.

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CHAPTER 2

EFFECTS OF PRECOMMERCIAL THINNING AND MIDSTORY-CONTROL ON THE AVIAN COMMUNITY IN YOUNG LONGLEAF PINE PLANTATIONS[1]

[1] Simmons, R. P., K. J. Brunjes, R. J. Cooper, J. C. Kilgo, T. B. Harrington, R. F. Daniels, and K. V. Miller. To be submitted to *Forest Ecology and Management*.

ABSTRACT

We examined the effects of longleaf pine (*Pinus palustris*) restoration with plantation silviculture on the avian community. We precommercially thinned (1994) and controlled the woody midstory with herbicides (1995-1996) using a large scale factorial experiment in well stocked 8-11 year old longleaf plantations on the Savannah River Site, a National Environmental Research Park near Aiken, South Carolina. We surveyed the avian community during the breeding season (1996-2003) using fixed radius point counts. The effects of thinning or midstory-control alone on bird abundance, diversity, and richness were positive but short-lived. The positive effects were larger and persisted longer on combined treatment plots. Bird abundance and diversity in longleaf plantations appears to be enhanced by open canopy and midstory conditions. Our results indicate that precommercial thinning in longleaf plantations, particularly when combined with midstory-control and prescribed fire, has a beneficial impact on avian communities by developing stand conditions more typical of longleaf stands maintained by periodic fire.

Key words: Breeding birds, herbicide, longleaf pine, midstory control, *Pinus palustris*, precommercial thinning, prescribed fire, restoration, Savannah River Site, South Carolina.

INTRODUCTION

Longleaf pine (*Pinus palustris*) was once the dominant forest type across much of the Southeastern United States. Its historic range encompasses most of the Atlantic and Gulf Coastal Plains from southeastern Virginia to eastern Texas and includes part of the Piedmont and Ridge and Valley physiographic provinces of Alabama and Georgia (Simberloff 1993). Today less than 3% of the estimated 37 million hectares of longleaf that existed prior to European colonization remain, and much of the remainder is in a degraded condition (Frost 1993). In comparison, losses of moist tropical rainforest worldwide amount to 40% of that ecosystem compared to the loss of 97% of the historic longleaf ecosystem (Simberloff 1993). These facts combine to make the longleaf ecosystem critically endangered (Noss 1989, Simberloff 1993, Ware et al. 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, an open midstory, 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, Engstrom et al. 2001).

The longleaf pine ecosystem depends on disturbance, particularly frequent low-intensity fires (Means and Grow 1985, Ware et al. 1993). Without fire, the longleaf forest succeeds to other forest types (Frost 1993, Peet and Allard 1993, Rebertus et al. 1993, Ware et al. 1993, Landers et al. 1995, Engstrom et al. 2001), often the southern mixed hardwood forest (Ware et al. 1993). Periodically burned mature longleaf forests provide habitat with relatively stable early-successional attributes, compared to the short duration of early-succession proper. Early-successional plant and animal communities regain importance in mature, fire-maintained, pine forests (Kilgo and Blake 2005).

There has been a recent focus on restoring longleaf pine on appropriate sites in its historical range (McMahon et al. 1998). Because there is often insufficient seed source to regenerate these areas naturally, plantation silviculture has been suggested as a means of restoring this species (Landers et al. 1995, Harrington and Edwards 1999). Although the floral and faunal characteristics of natural longleaf forests have been well documented (Peet and Allard 1993, Ware et al. 1993, Engstrom et al. 2001), the effects of longleaf plantation silviculture on plant and wildlife communities are less well understood (Repenning and Labisky 1985).

In well-stocked longleaf plantations, a period of increasing competition and crown closure follows the early-successional regeneration stage of stand development. Emergent species form a canopy that excludes shade-intolerant species in the understory (Oliver and Larson 1996). Vertebrate populations dependent on these understory plants decline with crown closure. Atkeson and Johnson (1979) and Langley and Shure (1980) documented such declines in small mammal populations in Georgia Piedmont loblolly pine (*Pinus taeda*) stands. Bird population abundance and diversity also declines following crown closure in southern pine stands (Johnson and Landers 1982). Thinning and woody competition control can delay crown closure or reopen closed canopies (Oliver and Larson 1996). In young longleaf plantations, Brunjes et al. (2003) found that small mammals and birds were more abundant and diverse 3-5 years after precommercial thinning young longleaf plantations than in unthinned stands and attributed these differences to differences in the herbaceous understory communities. On these same sites, Harrington and Edwards (1999) reported greater herbaceous species density in stands treated with thinning and midstory-control than that in untreated stands at least through the fifth year after treatment.

Herein, we report the effects of thinning and woody competition control on the avian communities in longleaf pine plantations through 10 years post treatment. Our objective was to investigate the effects of thinning and hardwood midstory-control and the duration of these effects on the composition and abundance of the bird community in young longleaf pine plantations in the Upper Coastal Plain of South Carolina. We hypothesized that both silvicultural treatments would increase the abundance of early-successional birds and decrease the abundance of mature forest associated birds. 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.

STUDY AREA AND METHODS

On the Savannah River Site (SRS), a National Environmental Research Park near Aiken, South Carolina, we established a long-term study in 1993 to assess longleaf pine ecosystem restoration techniques using plantation silviculture (Harrington and Edwards 1999). The study area and methods have largely been described by Harrington and Edwards (1999) for treatments and vegetation sampling. The study was conducted in the Sandhills physiographic province of South Carolina (Miller and Robinson 1995). During the winter of 1993-1994, we selected 4 longleaf pine plantations established between 1982 and 1986. We selected sites that contained fully stocked stands of longleaf pine (>1200 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 x 3 m spacing in clearcut-harvested areas in which woody debris had been windrowed or piled, and burned. Before harvest, the sites supported mature stands of old-field longleaf and loblolly pines. 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).

We applied a prescribed fire of moderate to high intensity to each site in February 1994, which topkilled all shrubs and most hardwoods less than 5 cm DBH. We applied similar prescribed fires to all sites in February 1998 and January-February 2003.

We divided each site into 4 treatment areas of similar size at the initiation of the study and randomly assigned one of the following treatments to each:

1. Untreated: 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 1440 pines/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. Woody control: In April 1995, we applied undiluted Velpar® L (hexazinone, E.I. du Pont de Nemours and Company, Wilmington, Del.) at a rate of 1.7 kg a.i./ha with a spotgun to grid points on approximately 1 m spacing. In March 1996, we targeted surviving nonpine stems with a basal spray of Garlon® 4 (triclopyr ester, Dow AgroSciences LLC, Indianapolis, Ind.) at 7% concentration in oil. In late June 1996, we applied a directed foliar spray of Arsenal® AC (imazapyr, American Cyanamid Company, WAYNE, N.J.), Accord® (glyphosate, Monsanto Company, St. Louis, Mo.), and X-77® surfactant (Loveland Industries, Inc, Greeley, Colo.) mixed in water at 0.5, 5, and 0.5% 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.

4. Combined treatment: We combined pine thinning with woody control.

Our experimental design was a randomized complete block with 4 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 vegetation sample points on a 40 m grid and 1 avian sample point near the center of each plot for repeated measurements.

Measurements

Vegetation Sampling.--In winter 1993-1994, we quantified pretreatment basal areas of pines and hardwoods at about half of the sample points by measuring each tree ≥2.5 cm rooted within 3.6 m of the sample point. In winter 1994-1995, 1995-1996, 1997-1998 and 2002-2003, we measured diameter at breast height (DBH) of each tree rooted within 6 m of each sample point and measured the total height, height to the base of the live crown (HBLC), and crown width (CW) of 20% of the stems selected randomly. We grouped our observations for pines and hardwoods and calculated crown ratio (CR) and timber volume (VOL) from these data.

We recorded each understory species rooted within 3.6 m of a sample 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). The understory plant cover data were grouped into categories of forbs, grasses, vines, shrubs, or tree seedling according to Radford et al. (1968). In 1998, 2001, and after the fire in 2003, we employed sampling protocols developed for the North Carolina Vegetation Survey (Peet et al. 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 cover (%) within the 10-m^2 subplot using the following cover classes and assigned class midpoint values: trace (class midpoint 0.1 %), 0-1, 1-2, 2-5, 5-10, 10-25, 25-50, 50-75, 75-95, 95-100%.

In an effort to explain the mechanisms of any treatment-related differences in the bird communities, we assessed vertical foliage density (FD) in each treatment area during May 2002 (MacArthur and MacArthur 1961, MacArthur et al. 1966, Karr and Roth 1971). At each FD sample point, we raised a telescoping fiberglass measuring rod perpendicular to the ground and recorded the number of times foliage touched the pole in 3 height strata: $\leq 1\text{m}$ above the ground (the shrub-scrub vegetation layer), $1\text{m} < x \leq 5\text{m}$ (the midstory layer), and > 5m (the canopy layer). We sampled FD at 5-m intervals along 4, 50-m transects radiating from each avian point count location in the cardinal directions. This measurement is an approximation of the foliage height profile described by MacArthur and MacArthur (1961) and is theoretically similar to leaf area index (Kimmins 1987). We summed these measurements by strata at each avian sampling point to create a composite index of the forest structure of the area sampled by each sampling location.

Avian Sampling.--We surveyed the breeding bird community using 50-m fixed radius point counts within the first 4 hours following sunrise. We performed 5 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 categorized species as either Neotropical migrants or residents, which included year-round residents and short-distance migrants present during the breeding season, and grouped them by habitat affinity: shrub-scrub associates, mature forest associates, or habitat generalists (Canterbury et al. 2000, Hunter et al. 2001, United States Geological Survey 2006). We also calculated Shannon diversity and richness of these bird communities (Ricklefs 1997).

We analyzed the treatment effects as a 2x2 factorial design with repeated measurements over time for each of the bird groupings. We investigated the relationship between the various bird groupings and their habitat through Pearson correlation with habitat characteristics (described in Table 2.1). We investigated the number of years since the last burn (YSLB) as a covariate as well as through correlation. We used a square root transformation of bird abundance data to satisfy the normality assumptions of analysis of variance (ANOVA). Once transformed, the residuals from all analyses were approximately normal. We used a significance level α = 0.10 in all analyses. We used the SAS System® version 8.02 (SAS Institute, Cary, N.C.) for all statistical analyses. We used the GLM procedure to perform analysis of variance and the CORR procedure for correlation analysis.

RESULTS

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, 28 residents (including short distance migrants), and 13 Neotropical migrants (Table 2.2). Resident species were relatively evenly divided among habitat associations: 32% habitat generalists, 36% mature forest associates, and 32% shrub-scrub associates. Neotropical migrant species were predominately mature forest associates (60%) and shrub-scrub associates (30%). 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. Time significantly explained variability in all of our habitat and migration strategy groupings. The number of years since the last burn was not significant as a covariate for any grouping, and no means were significantly different within each year.

For total bird abundance, there was an interaction between the thinning and midstory-control effects across all years (Table 2.3), indicating that the effect of the combined treatment not merely the sum of the separate treatment effects. Thinned and combined treatment plots had the highest abundance in 1996, and combined treatment plots had the greatest abundance in all other years (Figure 2.1). During 2001-2003, the thinned alone and midstory-controlled alone plots had lower total bird abundance than control plots. Total bird abundance was positively correlated with time, the number of years since the last burn, the mean diameter at breast height (1.4 m) of the pines, and the mean crown width of the pines. It was negatively correlated with canopy layer foliage density, the mean density of pine trees per hectare, and the mean density of hardwood trees per hectare (Table 2.4).

Species richness and diversity were greatest on combined plots in all years except 2003 where values on treated plots were lower than the control (Figure 2.2). The thinning and midstory-control main effects interacted; the combined treatment effect was significantly larger than the sum of the individual effects (Table 2.3).

Resident bird abundance patterns closely followed those of total bird abundance. Thinned and combined treatment plots had the highest abundance in 1996, and combined treatment plots had the highest abundance in all other years. During 2001-2003, the thinned alone and midstory-controlled alone plots had lower resident abundance than control plots (Figure 2.1). The interaction effect significantly affected abundance (Table 2.3). Resident bird abundance was positively correlated with time, year since last burn, and pine crown width, and negatively correlated with canopy layer foliage, combined midstory and canopy foliage, and percent cover of saplings and shrubs (Table 2.4).

Only the thinning treatment effect significantly explained Neotropical migrant bird abundance (Table 2.3). We found more migratory birds on thinned and combined treatment plots in 1996, on combined treatment plots from 1997-2002, and on thinned plots again in 2003 (Figure 2.1). Migrant bird abundance was positively correlated with time, height of the pines, pine DBH, pine crown-width, height to base of the live crown of pines, and negatively correlated with canopy foliage density, and pine density (Table 2.4).

Shrub-scrub associated bird abundance was highest in thinned and combined plots during 1996 and in combined plots in 1997 (Figure 2.3). The differences in abundance among treatments were less dramatic from 2001-2003. The thinning effect increased shrub-scrub bird abundance, but was short lived (Table 2.3). Shrub-scrub bird abundance was positively related to the early-successional habitat characteristics: grass cover, shrub cover, and pine crown ratio. Shrub-scrub abundance was negatively related to time and characteristics of more mature forests including pine height, pine DBH, pine crown width, height to the base of the live crown, pine density, pine basal area, and pine timber volume (Table 2.4).

Mature forest associated bird abundance generally increased from 1996-2002 and declined the last year of the study (Figure 2.3). Midstory-control and combined plots had the greatest abundance initially, and the combined plots had the greatest abundance in 1997-2003. The individual treatments interacted and led to increased abundance throughout the study on combined treatment plots (Table 2.3). Mature forest bird abundance was positively related to time, number of years since the last prescribed burn, pine height, pine DBH, pine crown width, pine HBLC, pine basal area, and pine timber volume. Mature forest bird abundance was negatively related to early-successional characteristics: sapling cover, pine crown ratio, and to hardwood invasion: hardwood density and hardwood crown ratio (Table 2.4).

The thinning by midstory-control interaction explained habitat generalist bird abundance (Table 2.3). There was no discernable trend in habitat generalist abundance overall. However, the combined treatment plots had the highest abundance until 2003 (Figure 2.3). Habitat generalist bird abundance was positively related to time since the last prescribed fire and negatively related to canopy foliage density (Table 2.4).

DISCUSSION

The effect of thinning on avian abundance, richness, and diversity was generally positive but short lived. Midstory-control alone had no effect on avian community metrics. However, the combination of thinning with midstory-control produced a larger effect than thinning alone, which persisted longer.

Our results mostly did not support the commonly found positive relationship between foliage height diversity and bird species diversity (MacArthur et al. 1966). Conversely, species richness and diversity were generally highest on combined treatment plots, which had the least structural diversity. Decreasing the structural complexity of the stands with midstory-control led to increased abundance of mature forest and habitat generalist birds especially when combined with thinning, a relationship that has been observed in other longleaf pine forests (Kilgo and Bryan 2005). Similarly, a study in Georgia Piedmont and Coastal Plain pine stands found no bird species that was positively related to hardwood invasion, but 10 species were negatively associated with this condition (Klaus and Keyes 2007). Bird diversity and abundance in southern pine stands appear to be associated with open canopy and midstory conditions.

Our findings have implications for longleaf restoration and support midstory-control as a method to prepare sites for reintroduction of fire. Thinning plantation longleaf to emulate more natural stand structure enhances the avian communities. Herbicides are frequently used in conjunction with thinning to control the hardwood midstory response to the newly available resources. The combination of thinning with midstory-control may have longer-term benefits for the avian community than thinning alone, although Neotropical migrants did not statistically benefit from combining treatments.

Similarly, prescribed fire can provide midstory reduction, provided hardwoods have not grown large enough to become fire resistant. Our results suggest that fire had a greater effect than the treatments during the latter years of our study. By the 2001 sampling period, treatment related differences were not obvious. The prescribed fire in 2003 had a similar and pronounced effect on all treatments and reduced species richness and diversity on all treated plots. Because we burned all sites on an approximately 4-year interval, the herbicide effect on the midstory may be confounded with the effects of the fire. Essentially, the control may have been made more similar to the midstory-control treatment. Our approach controlled for treatment effects given a 4-year prescribed fire interval. We believe this is an appropriate control given the wide acceptance of prescribed fire for longleaf management.

The response of the midstory to thinning seems to mediate the thinning effect on the understory, hence the longer duration of the combined treatment effect. Interestingly, shrub-scrub bird abundance was not correlated with the hardwood midstory or overstory parameters we measured. Apparently these species do not respond negatively to the presence of a woody midstory, per se, but to reduction in understory vegetation from shading and other competition.

The abundance of mature forest associates was positively related to measures of forest maturity and succession. However, midstory-control and the combined treatments led to increased mature forest associate abundance. These results are counterintuitive; however our treatment areas may have been only a portion of their territory, which could have included adjacent mature stands. Marshall et al. (2003) document mature forest associates using early successional habitat in the post-fledging period in regenerating clearcuts in West Virginia.

Although we could not investigate the mechanism that caused changes in the bird community, we hypothesized that the abundance and diversity of early-successional species would be directly related to herbaceous plant and shrub abundance. We expected that thinning of the overstory and midstory-control with herbicides would be directly related to understory development. We also expected that in the absence of midstory-control, the midstory would respond to the thinning and thereby limit the duration of the effects on the understory. We found that thinning and the combined treatment supported our hypotheses for shrub-scrub associates, and that their abundance was correlated with grass and shrub cover, but that midstory-control alone had no discernable effect on the early-successional bird community. The duration of the thinning effect for all bird groups was shorter without midstory-control, as anticipated.

Our results indicate that precommercial thinnings in longleaf plantations, particularly when combined with midstory-control, have a beneficial impact on avian communities by developing stand conditions more typical of longleaf stands maintained by periodic fire. However, by 5 to 6 years after treatment periodic fire likely is necessary to maintain these conditions. The optimal fire return interval to maintain the open conditions and abundant herbaceous vegetation in longleaf stands is likely more frequent than the 4-5 year interval we implemented (Rebertus et al. 1993, Glitzenstein et al. 2003). The effects of return interval on the vertebrates and vegetation in restored longleaf stands are topics for future research.

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Table 2.1. Habitat characteristics measured in longleaf pine plantations at the Savannah River Site, South Carolina, in 1994-2004.

Habitat Characteristic	Description
YR	Year of the study 1996-2003
YSLB	Number of years since the last prescribed burn
FD_{SS}	Density of foliage in the shrub-scrub vegetation layer, < 1 m above the ground
FD_{Mid}	Density of foliage in the midstory vegetation layer, 1m - 5m above the ground
FD_{Canopy}	Density of foliage in the canopy vegetation layer, > 5m above the ground
$FD_{M\&C}$	Density of foliage in the midstory and canopy vegetation layers, > 1m above the ground
$\%Cov_{Saplings}$	Percent cover of tree saplings
$\%Cov_{Shrubs}$	Percent cover of shrubs
$\%Cov_{Vines}$	Percent cover of vines
$\%Cov_{Forbs}$	Percent cover of forbs
$\%Cov_{Grass}$	Percent cover of grass
$\%Cov_{Herbaceous}$	Percent cover of grass and forbs
Ht_{Pines}	Mean height of pines
DBH_{Pines}	Mean diameter at breast height of pines
CW_{Pines}	Mean crown width of pines
$HBLC_{Pines}$	Mean height to the base of the live crown of pines
CR_{Pines}	Mean crown ratio of pines
DEN_{Pines}	Mean number of pine per hectare
BA_{Pines}	Mean pine basal area per hectare
VOL_{Pines}	Mean pine volume per hectare
$Ht_{Hardwoods}$	Mean height of hardwoods
$DBH_{Hardwoods}$	Mean diameter at breast height of hardwoods
$CW_{Hardwoods}$	Mean crown width of hardwoods
$HBLC_{Hardwoods}$	Mean height to the base of the live crown of hardwoods
$CR_{Hardwoods}$	Mean crown ratio of hardwoods
$DEN_{Hardwoods}$	Mean number of hardwoods per hectare
$BA_{Hardwoods}$	Mean hardwood basal area per hectare
$VOL_{Hardwoods}$	Mean hardwood volume per hectare

Table 2.2. 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), and as habitat generalists (G), shrub-scrub associates (S), or mature forest associates (M).

Common Name	Scientific Name	Migratory Strategy	Habitat Association
American Crow	*Corvus brachyrhynchos*	SD	G
American Goldfinch	*Carduelis tristis*	SD	S
Black-and-white Warbler	*Mniotilta varia*	T	M
Blue Jay	*Cyanocitta cristata*	SD	G
Blue-gray Gnatcatcher	*Polioptila caerulea*	SD	G
Brown Thrasher	*Toxostoma rufum*	SD	S
Brown-headed Nuthatch	*Sitta pusilla*	R	M
Carolina Chickadee	*Poecile carolinensis*	R	G
Carolina Wren	*Thryothorus ludovicianus*	R	G
Downy Woodpecker	*Picoides pubescens*	R	M
Eastern Bluebird	*Sialia sialis*	SD	S
Eastern Wood-Pewee	*Contopus virens*	T	M
Field Sparrow	*Spizella pusilla*	SD	S
Golden-crowned Kinglet	*Regulus satrapa*	SD	M
Gray Catbird	*Dumetella carolinensis*	T	S
Great Crested Flycatcher	*Myiarchus crinitus*	T	G
Hairy Woodpecker	*Picoides villosus*	R	M
Indigo Bunting	*Passerina cyanea*	T	S
Mourning Dove	*Zenaida macroura*	SD	G
Northern Bobwhite	*Colinus virginianus*	R	S
Northern Cardinal	*Cardinalis cardinalis*	R	S
Northern Flicker	*Colaptes auratus*	SD	G
Northern Parula	*Parula americana*	T	M
Ovenbird	*Seiurus aurocapillus*	T	M
Pileated Woodpecker	*Dryocopus pileatus*	R	M
Pine Warbler	*Dendroica pinus*	SD	M
Prairie Warbler	*Dendroica discolor*	T	S
Red-bellied Woodpecker	*Melanerpes carolinus*	R	M
Red-eyed Vireo	*Vireo olivaceus*	T	M
Red-shouldered Hawk	*Buteo lineatus*	SD	M
Red-tailed Hawk	*Buteo jamaicensis*	SD	G
Rufous-sided Towhee	*Pipilo erythrophthalmus*	SD	S
Song Sparrow	*Melospiza melodia*	SD	S
Summer Tanager	*Piranga rubra*	T	M
Tufted Titmouse	*Baeolophus bicolor*	R	G
White-eyed Vireo	*Vireo griseus*	SD	S
Wild Turkey	*Meleagris gallopavo*	R	G
Wood Thrush	*Hylocichla mustelina*	T	M
Yellow-breasted Chat	*Icteria virens*	T	S
Yellow-rumped Warbler	*Dendroica coronata*	SD	M
Yellow-throated Vireo	*Vireo flavifrons*	T	M

Table 2.3. ANOVA results of the main effects of thinning (Thin) and midstory-control (MSC) and their interaction; between and within subject effects for differences in mean abundance of the total bird community, bird abundance grouped by migration strategy, and habitat association; and species diversity and richness in longleaf pine plantations at the Savannah River Site, South Carolina, in 1996, 1997, 2001-2003.

Bird Grouping	Source	DF	F Value	P	Bird Grouping	Source	DF	F Value	P
All Birds	Between Subject Effects				Mature Forest	Between Subject Effects			
	Thin	1	9.74	0.0123		Thin	1	1.37	0.2725
	MSC	1	5.03	0.0517		MSC	1	10.84	0.0093
	Thin*MSC	1	9.71	0.0124		Thin*MSC	1	4.23	0.0698
	Site	3	4.93	0.0270		Site	3	3.77	0.0531
	Error	9				Error	9		
	Within Subject Effects					Within Subject Effects			
	time	4	12.12	<.0001		time	4	19.78	<.0001
	time*Thin	4	0.59	0.6704		time*Thin	4	0.14	0.9662
	time*MSC	4	0.72	0.5814		time*MSC	4	0.20	0.9383
	time*Thin*MSC	4	0.76	0.5586		time*Thin*MSC	4	0.43	0.7890
	time*Site	12	1.51	0.1644		time*Site	12	0.34	0.9752
	Error(time)	36				Error(time)	36		
Migrants	Between Subject Effects				Generalists	Between Subject Effects			
	Thin	1	10.36	0.0105		Thin	1	0.71	0.4211
	MSC	1	2.5	0.1483		MSC	1	0.80	0.3955
	Thin*MSC	1	0.1	0.7637		Thin*MSC	1	8.50	0.0172
	Site	3	2.07	0.1750		Site	3	1.76	0.2249
	Error	9				Error	9		
	Within Subject Effects					Within Subject Effects			
	time	4	8.19	<.0001		time	4	3.61	0.0142
	time*Thin	4	0.5	0.7361		time*Thin	4	0.53	0.7128
	time*MSC	4	1.62	0.1914		time*MSC	4	0.79	0.5392
	time*Thin*MSC	4	0.7	0.5950		time*Thin*MSC	4	1.01	0.4142
	time*Site	12	2.05	0.0486		time*Site	12	1.33	0.2471
	Error(time)	36				Error(time)	36		
Residents	Between Subject Effects				Diversity	Between Subject Effects			
	Thin	1	2.67	0.1370		Thin	1	6.94	0.0272
	MSC	1	5.58	0.0425		MSC	1	0.97	0.3497
	Thin*MSC	1	24.89	0.0007		Thin*MSC	1	3.72	0.0858
	Site	3	6.18	0.0144		site	3	2.46	0.1289
	Error	9				Error	9		
	Within Subject Effects					Within Subject Effects			
	time	4	14.02	<.0001		time	4	3.15	0.0255
	time*Thin	4	0.75	0.5666		time*Thin	4	1.85	0.1407
	time*MSC	4	0.74	0.5724		time*MSC	4	0.98	0.4332
	time*Thin*MSC	4	1.09	0.3766		time*Thin*MSC	4	0.18	0.9485
	time*Site	12	0.63	0.7996		time*site	12	0.89	0.5654
	Error(time)	36				Error(time)	36		
Shrub-scrub	Between Subject Effects				Richness	Between Subject Effects			
	Thin	1	7.82	0.0208		Thin	1	9.21	0.0141
	MSC	1	0.17	0.6933		MSC	1	2.39	0.1565
	Thin*MSC	1	0.18	0.6848		Thin*MSC	1	6.06	0.0360
	Site	3	8.91	0.0047		site	3	2.07	0.1751
	Error	9				Error	9		
	Within Subject Effects					Within Subject Effects			
	time	4	2.23	0.0856		time	4	4.77	0.0034
	time*Thin	4	3.40	0.0185		time*Thin	4	2.18	0.0915
	time*MSC	4	1.52	0.2163		time*MSC	4	1.23	0.3159
	time*Thin*MSC	4	1.12	0.3642		time*Thin*MSC	4	0.14	0.9682
	time*Site	12	2.49	0.0170		time*site	12	1.14	0.3602
	Error(time)	36				Error(time)	36		

Table 2.4. Pearson correlation coefficients and Prob > |r| under H0: Rho=0 of covariation of the square root transformed total bird abundance and bird abundance grouped by migration strategy, and habitat association with habitat characteristics in longleaf pine plantations at the Savannah River Site, South Carolina, in 1996, 1997, 2001-2003.

Habitat Characteristic	Bird Community Grouping					
	Total	Residents	Migrants	Habitat Generalists	Shrub-scrub Associates	Mature Forest Associates
YR	0.26	0.20	0.39	0.03	-0.20	0.61
	0.019	0.076	0.005	0.804	0.079	<0.001
YSLB	0.26	0.33	0.04	0.21	0.05	0.18
	0.020	0.003	0.732	0.063	0.644	0.103
FD_{SS}	0.03	0.00	0.01	0.11	0.16	-0.10
	0.761	0.975	0.964	0.338	0.148	0.366
FD_{Mid}	-0.03	-0.09	-0.08	0.09	0.07	-0.14
	0.788	0.450	0.498	0.421	0.524	0.217
FD_{Canopy}	-0.22	-0.21	-0.18	-0.20	-0.14	-0.11
	0.051	0.063	0.101	0.073	0.217	0.334
$FD_{M\&C}$	-0.16	-0.19	-0.17	-0.08	-0.05	-0.15
	0.147	0.096	0.140	0.454	0.637	0.182
$\%Cov_{Sapplings}$	-0.15	-0.07	-0.25	0.01	-0.02	-0.27
	0.195	0.554	0.025	0.904	0.885	0.016
$\%Cov_{Shrubs}$	0.18	0.13	0.18	-0.01	0.19	0.12
	0.113	0.241	0.102	0.951	0.091	0.302
$\%Cov_{Vines}$	0.05	0.02	0.07	0.15	0.07	-0.12
	0.656	0.844	0.546	0.194	0.547	0.294
$\%Cov_{Forbs}$	0.08	0.06	0.02	0.13	0.08	-0.02
	0.471	0.608	0.861	0.234	0.503	0.884
$\%Cov_{Grass}$	0.09	0.08	-0.04	0.14	0.18	-0.11
	0.423	0.457	0.738	0.219	0.104	0.346
$\%Cov_{Herbaceous}$	0.10	0.08	-0.01	0.15	0.14	-0.06
	0.396	0.490	0.954	0.175	0.220	0.575
Ht_{Pines}	0.14	0.09	0.30	-0.04	-0.34	0.58
	0.219	0.432	0.008	0.710	0.002	<0.001

Continued

Table 2.4 Continued

Habitat Characteristic	Bird Community Grouping					
	Total	Residents	Migrants	Habitat Generalists	Shrub-scrub Associates	Mature Forest Associates
DBH_{Pines}	0.26	0.17	0.42	0.02	-0.22	0.62
	0.021	0.142	<0.001	0.867	0.048	<0.001
CW_{Pines}	0.25	0.18	0.35	0.06	-0.14	0.52
	0.024	0.105	0.001	0.597	0.209	<0.001
$HBLC_{Pines}$	0.07	0.04	0.23	-0.07	-0.35	0.48
	0.533	0.702	0.044	0.559	0.001	<0.001
CR_{Pines}	0.01	0.01	-0.15	0.08	0.35	-0.35
	0.959	0.925	0.199	0.486	0.001	0.001
DEN_{Pines}	-0.28	-0.14	-0.33	-0.10	-0.26	-0.14
	0.013	0.203	0.003	0.382	0.019	0.219
BA_{Pines}	-0.03	0.03	0.02	-0.08	-0.38	0.36
	0.802	0.772	0.845	0.479	0.001	0.001
VOL_{Pines}	0.06	0.09	0.14	-0.07	-0.37	0.48
	0.575	0.428	0.219	0.552	0.001	<0.001
$Ht_{Hardwoods}$	-0.12	-0.15	-0.07	-0.08	-0.09	-0.06
	0.277	0.192	0.544	0.485	0.449	0.600
$DBH_{Hardwoods}$	-0.13	-0.14	-0.10	-0.08	-0.07	-0.10
	0.235	0.221	0.360	0.486	0.528	0.380
$CW_{Hardwoods}$	-0.13	-0.15	-0.09	-0.09	-0.10	-0.06
	0.233	0.192	0.402	0.446	0.374	0.583
$HBLC_{Hardwoods}$	-0.11	-0.13	-0.05	-0.07	-0.08	-0.05
	0.334	0.246	0.665	0.518	0.490	0.657
$CR_{Hardwoods}$	-0.17	-0.15	-0.15	-0.09	-0.04	-0.20
	0.134	0.175	0.177	0.416	0.699	0.079
$DEN_{Hardwoods}$	-0.21	-0.18	-0.17	-0.13	-0.04	-0.25
	0.068	0.112	0.123	0.233	0.751	0.026
$BA_{Hardwoods}$	-0.18	-0.18	-0.13	-0.13	-0.10	-0.11
	0.119	0.120	0.257	0.237	0.375	0.344
$VOL_{Hardwoods}$	-0.16	-0.17	-0.11	-0.13	-0.11	-0.06
	0.157	0.140	0.339	0.262	0.334	0.577

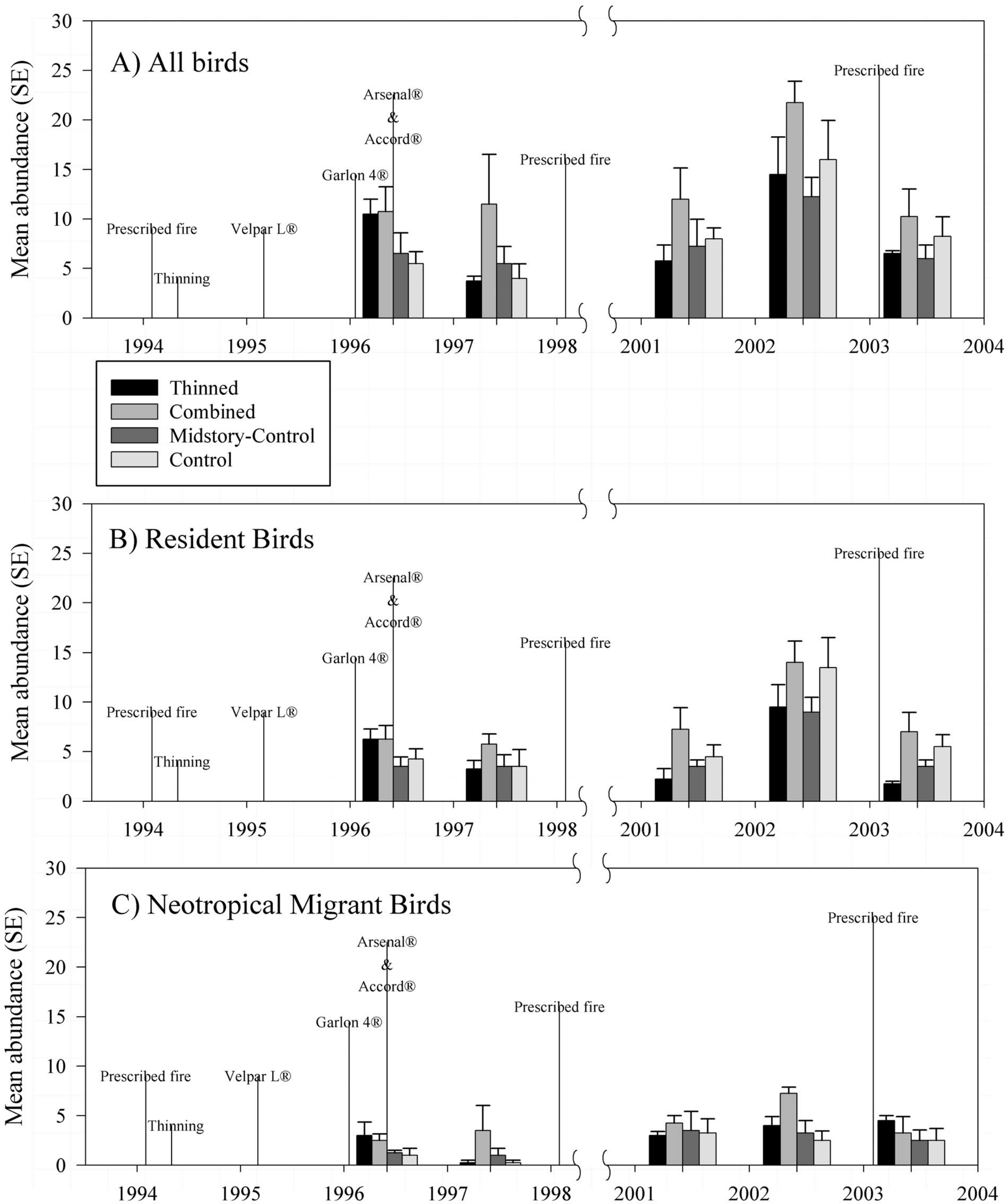

Figure 2.1. Total, resident, and Neotropical migrant breeding bird abundance by factor level combination of thinning and midstory-control in longleaf pine plantations at the Savannah River Site, South Carolina, in Spring 1996, 1997, 2001-2003. Abundance values are the mean number of birds counted per treatment area per year.

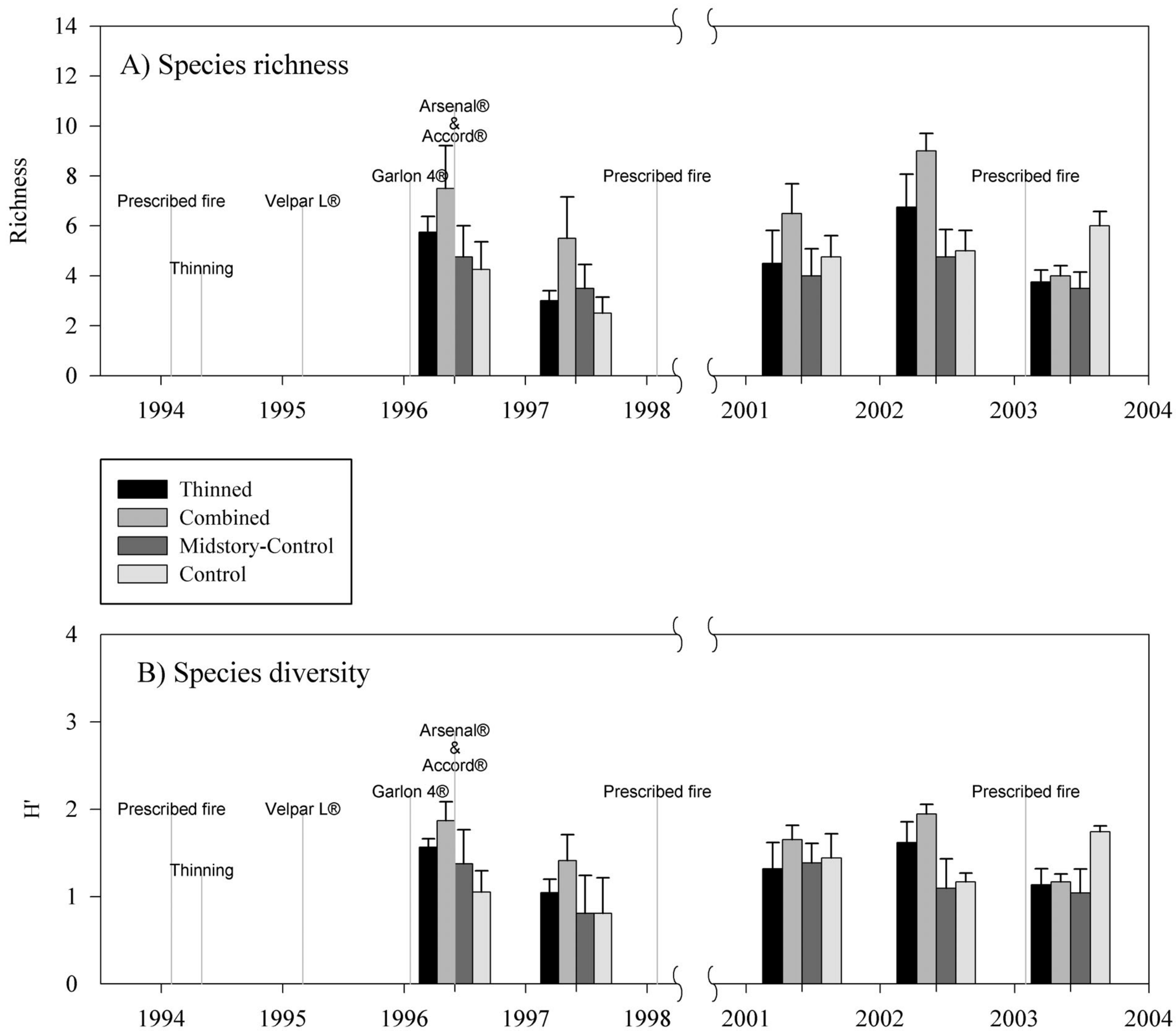

Figure 2.2. Breeding bird species diversity and richness by factor level combination in longleaf pine plantations at the Savannah River Site, South Carolina, in Spring 1996, 1997, 2001-2003. Richness is the mean of the total number of species encountered per treatment area per year.

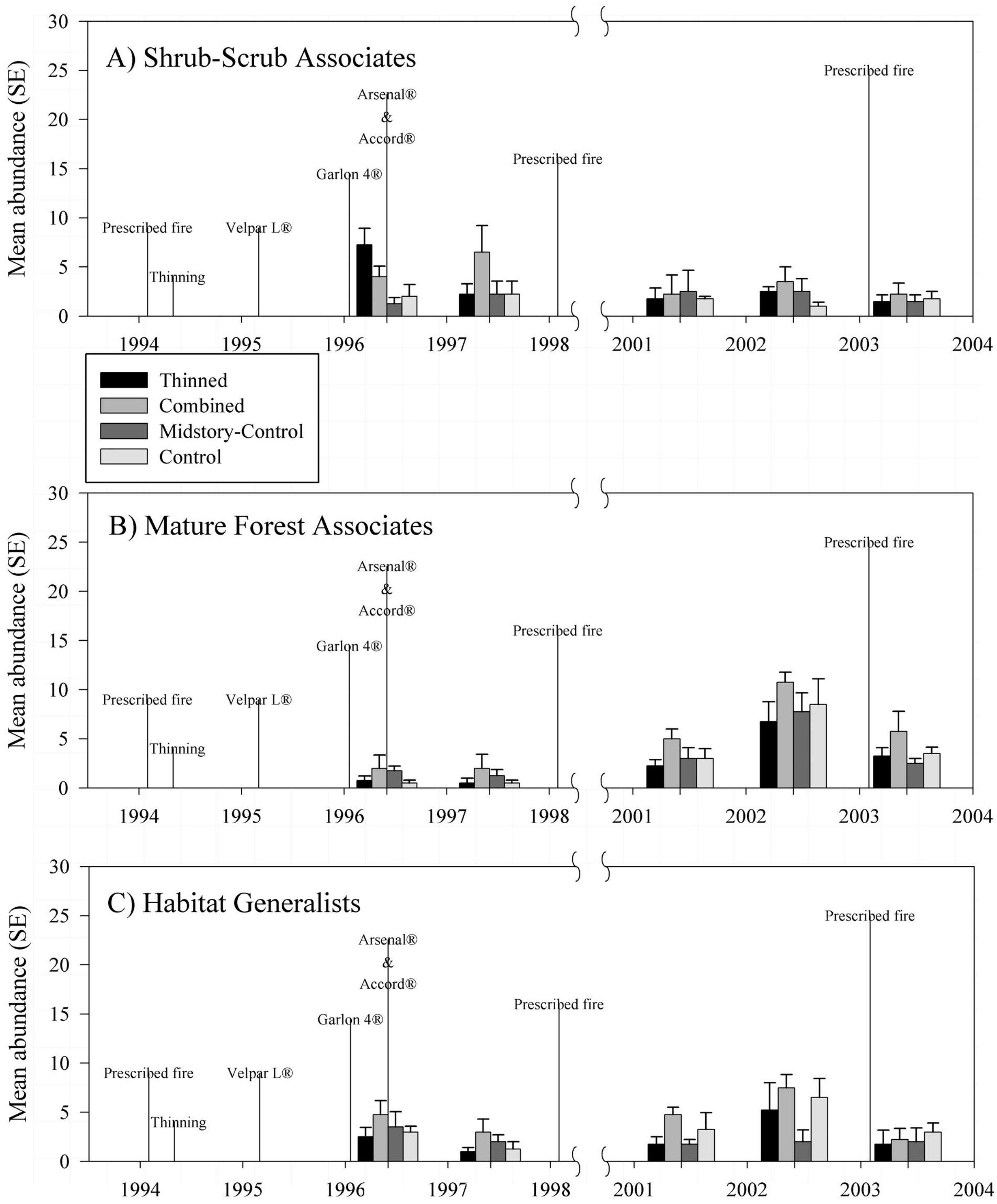

Figure 2.3. Breeding bird abundance by habitat association and factor level combination of thinning and midstory-control in longleaf pine plantations at the Savannah River Site, South Carolina, in Spring 1996, 1997, 2001-2003. Abundance values are the mean number of birds counted per treatment area per year.

CHAPTER 3

EFFECTS OF PRECOMMERCIAL THINNING AND MIDSTORY-CONTROL ON THE SMALL MAMMAL COMMUNITY IN YOUNG LONGLEAF PINE PLANTATIONS[2]

[2] Simmons, R. P., K. J. Brunjes, J. C. Kilgo, T. B Harrington, R. F. Daniels, and K. V. Miller. To be submitted to *Forest Ecology and Management*.

ABSTRACT

We examined the effects of longleaf pine (*Pinus palustris*) restoration with plantation silviculture on the small mammal community. We precommercially thinned (1994) and controlled the woody midstory with herbicides (1995-1996) using a large scale factorial experiment in well stocked 8-11-year-old longleaf plantations on the Savannah River Site, a National Environmental Research Park near Aiken, South Carolina. We surveyed the small mammal community (1995-2003) by removal trapping, and surveyed overstory and understory vegetation (1994-2004). Thinning, midstory-control, and their combination increased herbaceous cover through 2004. Without midstory-control, thinning released midstory hardwoods, which reduced the positive effect on herbaceous cover. All treatments resulted in short-term increases in small mammal abundance, but effects were minimal by 5-7 years after treatment. By 2001, pine basal area had returned to pre-treatment levels on thinned plots suggesting that frequent thinning may be required to maintain abundant and diverse small mammal communities in longleaf plantations.

Key words: herbicide, longleaf pine, midstory-control, *Pinus palustris*, precommercial thinning, prescribed fire, restoration, Savannah River Site, Small mammals, South Carolina.

INTRODUCTION

The longleaf pine ecosystem was once the most dominant southern pine ecosystem covering as much as 37 million hectares of the uplands (Frost 1993). Less than 3% of this area remains in longleaf and less than 1% is in good condition (Frost 1993). The typical structure of intact, ecologically functioning, longleaf stands is an overstory dominated by longleaf, an open midstory, and a rich and diverse herbaceous layer with many endemic plant and animal species (Peet and Allard 1993, Simberloff 1993, Engstrom et al. 2001). The herbaceous diversity and the perpetuation of longleaf as the dominant overstory species is tied to frequent fire that limits hardwood encroachment (Means and Grow 1985, Noss 1989, Frost 1993, Ware et al. 1993, Landers et al. 1995). In the absence of fire, southern pines are successional, but their dominance can be maintained with regular, frequent fire (Monk 1968, Stout and Marion 1993). Without fire, longleaf forests often transition into southern mixed hardwoods (Monk 1968, Ware et al. 1993).

There has been an emphasis on restoring longleaf pine, but natural regeneration is often not an option due to lack of a natural seed source (McMahon et al. 1998). Plantation silviculture has been suggested as a method of restoring this species (Landers et al. 1995, Harrington and Edwards 1999). Although the plant and animal communities of natural longleaf forests are well documented (Peet and Allard 1993, Ware et al. 1993, Engstrom et al. 2001), the effects of longleaf plantation silviculture on these communities are less well understood (Repenning and Labisky 1985).

Small mammal abundance and diversity are often high in early-successional southern pine stands due to the abundance and diversity of herbaceous plant and shrub species (McComb and Noble 1980), but decline precipitously following crown closure (Atkeson and Johnson 1979, Langley and Shure 1980, Mengak et al. 1989) (but see Wolfe and Lohoefener 1983). Approaching crown closure, competition for above and below ground resources leads to dramatic declines in understory vegetation abundance and diversity (Harrington et al. 2003). This depauperate phase continues until the canopy is re-opened, allowing the understory vegetation to again thrive and to support more abundant small mammal populations (Grelen et al. 1972, Grelen and Enghardt 1973, Harris et al. 1974, Loeb 1997). The closed canopy period in unmanaged stands often lasts until competition leads to overstory self-thinning or until disturbance opens the canopy. In managed stands, it usually lasts until the first commercial thinning. However, precommercial thinning of southern pine stands has been suggested as a tool to enhance habitat conditions (Grelen et al. 1972, Hurst et al. 1980) and for ecological restoration (Harrington and Edwards 1999). For example, precommercial thinning combined with prescribed fire more than doubled the deer forage in 7-year old loblolly plantations in Mississippi (Hurst et al. 1980). In a Louisiana study, nine years after thinning, herbaceous production was inversely related to overstory basal area in precommercially thinned and frequently burned, direct-seeded slash pine stands (Grelen et al. 1972). Grelen and Enghardt (1973) reported a similar relationship between basal area and herbaceous production in longleaf plantations. However, several studies have reported that thinning pine stands released shrubs and hardwoods, which resulted in reduced herbaceous production (Blair 1967, Blair and Feduccia 1977, Wolters et al. 1982).

Herbicide release treatments in southern pine stands can control the woody midstory while maintaining or enhancing herbaceous cover and diversity after a brief decline following treatment (Miller and Miller 2004). Herbicide treatments can increase timber growth and yield (Wagner et al. 2004), can be fire surrogates in situations where prescribed fire is not viable

(Wigley et al. 2002), and can restore the ability to use prescribed fire where fire exclusion has allowed hardwoods to become large enough to be fire resistant (Wilkins et al. 1993, Brockway and Outcalt 2000). Following woody control with herbicides, frequent prescribed fire and periodic thinning can maintain an open midstory with an abundant herbaceous community (Harrington and Edwards 1999).

In 1995, a long-term restoration study was initiated on the Savannah River Site (SRS) a National Environmental Research Park near Aiken, South Carolina to investigate the effects of precommercial thinning and total hardwood control in longleaf pine plantations (Harrington and Edwards 1999). In these plantations, precommercial thinning and herbicidal control of midstory hardwoods led to a more abundant and diverse herbaceous community through the fifth year after treatment following short declines after herbicide applications (Harrington and Edwards 1999). However, they cautioned that, even with the 4-year winter prescribed fire rotation planned for these stands, hardwood encroachment would lead to declines in the herbaceous community unless additional treatments were applied (Harrington and Edwards 1999).

Brunjes et al. (2003) found greater small vertebrate abundance and diversity in the precommercially thinned and herbicide treated stands associated with the Harrington and Edwards (1999) study. Oldfield mice (*Peromyscus polionotus*) responded positively to the combination of thinning and midstory-control compared to midstory-control only or the no treatment control (Brunjes et al. 2003). Herein, we report on the vertebrate responses to the precommercial thinning and herbicide treatments through the ninth year post-treatment. This study meets several of the suggestions for future research and experimental design described by Miller (2004) and Lautenschlager and Sullivan (2004) in that it was long-term, interdisciplinary, had multiple replicates, and appropriate controls.

STUDY AREA AND METHODS

The study area and methods have largely been described by Harrington and Edwards (1999) and Brunjes et al. (2003). Modifications of the experimental design or procedures are noted where appropriate. The SRS is in the Sandhills physiographic province of South Carolina (Miller and Robinson 1995). During winter 1993-1994, we selected 4 longleaf pine plantations (17.4 to 20.6 ha in size), which had been established between 1982 and 1986. We selected sites having fully stocked stands of longleaf pine (>1200 stems/ha) and hardwoods (>600 stems/ha). Each plantation had been machine planted with 1-year-old bare-root seedlings at 1.8 x 3 m spacing in clearcut-harvested areas in which woody debris had been either windrowed or piled, and burned. Prior to harvest, the sites supported mature stands of old-field longleaf and loblolly pines. The study sites represent a range of moisture classifications from xeric to moderately mesic (Van Lear and Jones 1987). The soils are loamy sands, which range from well-drained to excessively well-drained (Rogers 1990).

We applied a prescribed fire of moderate to high intensity to each site in February 1994, which topkilled all shrubs and most hardwoods ≤5 cm DBH and applied similar prescribed fires in February 1998 and January-February 2003. Each site was divided into 4 treatment areas of similar size at the initiation of the study, and one of the following treatments was randomly assigned to each area.

1. Untreated: No treatments applied, except prescribed fire.
2. Pine thinning: In May 1994, pines were thinned to approximately 50% of the original stem density, resulting in 635 and 1440 pines/ha in thinned and unthinned plots, respectively. Trees were cut with a brush saw and left to decay, resulting in minimal litter and soil disturbance.

3. Woody control: This treatment virtually eliminated all nonpine woody vegetation with herbicides. In April 1995, we applied undiluted Velpar® L (hexazinone; E.I. du Pont de Nemours and Company, Wilmington, Del.) at 1.7 kg active ingredient/ha with a spotgun to grid points on approximately 1 m spacing. In March 1996, we treated surviving nonpine stems with a basal spray of Garlon® 4 (triclopyr ester; Dow AgroSciences LLC, Indianapolis, Ind.) at 7% concentration in oil. In late June 1996, we applied a directed foliar spray of Arsenal® AC (imazapyr; American Cyanamid Company, Wayne, N.J.), Accord® (glyphosate; Monsanto Company, St. Louis, Mo.) and X-77® surfactant (Loveland Industries, Inc, Greeley, Col.) mixed in water at 0.5, 5, and 0.5% concentrations, respectively, to surviving target vegetation within 8 m of each sample point (described below) received. All herbicides were applied with a backpack sprayer.
4. Combined treatment: Pine thinning was combined with woody control.

Measurements

Vegetation Sampling. Within each of the 16 treatment plots, we permanently marked 10 sample points on a 40-m grid for repeated measurements. The treatment plots are the experimental units. In winter 1993-1994, we quantified pretreatment basal areas of pines and hardwoods by measuring each tree ≥2.5 cm diameter at breast height (DBH) rooted within 3.6 m of 5 sample points in each plot. In winter 1994-1995, 1995-1996, 1997-1998 and 2002-2003, we measured DBH on each tree rooted within 6 m of each sample point, and measured the total height, height to the base of the live crown (HBLC), and crown width (CW) of 20% of the stems selected randomly. We measured heights with a telescoping fiberglass measuring rod until 2002-2003 when we used Vertex III® ultrasonic hypsometer (Haglof Inc., Madison, Miss.) We determined CW by measuring the horizontal distance on the North-South and East-West axes to the branch tips as estimated from the ground. We calculated pine and hardwood timber volume with published regional volume equations (Clark et al. 1986, Clark and Saucier 1990).

We recorded each understory species rooted within 3.6 m of sample points in August 1994-1996 and estimated ground cover of each species and woody debris at each sample point using the line-intercept method (Mueller-Dombois and Ellenberg 1974). We grouped understory plant cover data into forbs, grasses, vines, shrubs, or tree seedling according to Radford et al. (1968). In 1998, 2001, and 2003, we used sampling protocols developed for the North Carolina Vegetation Survey (Peet et al. 1996) to provide more comprehensive estimates of herbaceous species density and understory cover. At 50% of the sample points in each treatment area (120 total), we established 0.01, 0.1, 1, 10, and 100 m^2 nested, square subplots with their diagonal overlaid onto the vegetation transect. We then generated a list of understory species rooted within each subplot. We visually assessed species cover (%) within the 10-m^2 subplot using the following cover classes and assigned class midpoint values: trace (class midpoint 0.1 %), 0-1, 1-2, 2-5, 5-10, 10-25, 25-50, 50-75, 75-95, 95-100%.

Small Mammal Sampling. We surveyed small mammal populations by removal trapping (Jones et al. 1996) at 2 sites during 1996-1997 and surveyed 2 additional sites (4 total) during 2001-2004. We placed 1 Victor® (Woodstream Corporation, Lititz, Pa.) rat-trap 4 m north or south of each of the 10 sample points per treatment area and placed 1 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 2 sites in April 1996, December 1996, and April 1997, and all 4 sites in May 2001, May 2002, December 2002, May 2003, and December 2003. We surveyed all sites simultaneously. Each trapping period consisted of 4 consecutive nights, and captured animals were identified using morphological characteristics (Cothran et al. 1991). *Peromyscus leucopus* and *P. gossypinus* are difficult to differentiate morphologically (Burt and Grossenheider 1976, Cothran et al. 1991). Although Cothran et al. (1991) report that only 2 *P. leucopus* have been found from the SRS, we grouped *Peromyscus* spp. other than *P. polionotus*.

Statistical analysis

The experiment was a block design with 2x2 factorial arrangement of treatments (Harrington and Edwards 1999) and repeated measurements over time. We performed all analyses with SAS Systems (SAS Institute 1999). We performed analysis of variance (ANOVA) with the GLM procedure on the percent cover of understory vegetation by category, and with the Mixed procedure on small mammal relative abundance, species richness, and Shannon diversity to test the effects of thinning, midstory-control, and their interaction. We also tested the interaction of these terms with time. We specified treatment area within site (replication) as a random effect in the mixed model analyses.

We plotted residuals from each ANOVA against predicted values to confirm normal distribution. When residuals were severely non-normal, we transformed the data to improve the distribution of the residuals (Dowdy and Wearden 1991). If standard transformations did not normalize the residuals, we used the rank transformation approach of Conover and Iman (1981). We ranked treatment area means within each trapping period, assigning average rank to ties. ANOVA performed on ranks is a non-parametric test that retains the advantages of the full experimental design (Conover and Iman 1981).

When an interaction proved significant ($P \leq 0.1$), we performed an ANOVA on each time period to investigate the nature of the interaction. When analyses indicated significant effects before treatments had been applied, we used the treatment area mean of the first period as a covariate to account for pretreatment differences.

RESULTS

Vegetation

Herbaceous plant cover responded positively to thinning and midstory-control and both effects changed over time. Because of significant treatment by time interactions, we examined the data by sample period to investigate the nature of the interaction. Herbaceous cover in the combined treatment declined, although not significantly, in 1995, the year following the first midstory-control treatment (Figure 3.1). In the midstory-control plots, herbaceous cover declined for 2 years after beginning the midstory-control regimen, and the thinning and midstory-control means differed in 1996 (Figure 3.1). The decrease in herbaceous cover was more dramatic in the combined treatment in 1995, but rebounded more quickly than in the midstory-control treatment. Following these initial declines, all 3 treatments tended to have greater herbaceous ground cover than the untreated controls until the end of the study. The combined treatment had the highest herbaceous cover from 1998-2004. However, thin by midstory-control interactions were not significant.

Percent cover of all classes of woody plants, shrubs, saplings and vines, had significant thinning by midstory-control and midstory-control by time interaction effects. However, within year effects differed among treatment combinations.

Small mammal abundance

We captured 211 mammals of 8 species during 8,320 trap nights (Table 3.1). *Peromyscus* species other than *P. polionotus* accounted for 64% of all captures. Oldfield mice (*P. polionotus*) comprised 18% of the captures, and Eastern woodrats (*Neotoma floridana*) comprised 8%. We also captured cotton rats (*Sigmodon hispidus,* 6%), golden mice (*Ochrotomys nuttalli*, 3%), pine voles (*Microtus pinetorum*, 1%), and Eastern harvest mice (*Reithrodontomys humulis*, 1%). From spring 2001 until winter 2003, *Peromyscus* spp. was overwhelmingly the most frequently captured species. The thinning by time and midstory-control by time interactions significantly affected the abundance of small mammals (Figure 3.2). These interactions indicate that thinning and midstory-control effects were significant and that the nature of these effects changed over time. Analyzed by period, thinning had a significant effect in the spring and winter of 1996, the spring of 1997, and the spring of 2002, and midstory-control had a significant effect in the winter of 1996 and the spring of 1997 (Figure 3.2). No within period thinning by midstory-control interactions were significant.

Across all years, % cover of grasses was the only understory habitat characteristic significantly correlated to total mammal captures (Table 3.2). All overstory characteristics that we measured were significantly correlated to mammal captures (Table 3.2).

DISCUSSION

All treatments resulted in short-term increases in small mammal abundance, but treatment effects were minimal by 2001. Herbaceous cover remained greater in treated plots than in the control throughout the study, but small mammal abundance did not respond to this increase. Grass cover, however, affected small mammal abundance, more than forb cover, and many native grasses are shade intolerant. The apparent incongruity between herbaceous cover and small mammal abundance may be related to the fact that by 2001 the pine basal area had rebounded to pretreatment levels in thinned stands and continued to increase in unthinned stands. The increase in basal area in thinned stands seems to affect herbaceous cover similar to comparable basal area in the control plots earlier in the study. The greater herbaceous cover in combined plots in the latter years relative to the control may be related to decreased competition from shrubs and other woody plants.

The initial declines in herbaceous cover followed by increased herbaceous production followed the pattern of previous findings for each of the herbicides we used despite the intensity of our herbicide regimen (Witt et al. 1992, Brockway and Outcalt 2000, Jones and Chamberlain 2004, Miller and Miller 2004). The direct effects on herbaceous cover of the latter treatments may have been minor because we applied them selectively, targeting only hardwoods.

We found only short-term effects of our multiple herbicide treatment, which addresses some concerns raised regarding multiple herbicide regimes (Miller and Miller 2004). However, our second and third herbicide treatments were applied more selectively than typical of tank mix applications and are not directly comparable.

Herbaceous cover was greater on combined treatment plots than on the control through 2004. This effect persisted longer than would be anticipated without prescribed fire (Miller and Chapman 1995, Harrington et al. 1998). This longevity supports the common longleaf restoration recommendations to use overstory thinning and hardwood control to restore the structural characteristics of functioning longleaf ecosystems: open canopy, sparse midstory, and abundant herbaceous understory; and, then, to maintain these conditions with frequent fire. Our findings support Brennan et al.'s (1998) assertion that combining herbicide use with fire may be more beneficial than either treatment alone and that the combination could have long-lasting (10-15 year) effects.

Thinning without midstory-control released understory shrubs and reduced the magnitude and duration of the thinning effect on herbaceous cover, as has been previously observed (Blair and Feduccia 1977, Wolters et al. 1982). Both midstory-control combinations with fire reduced woody competition more than fire alone (control). The midstory-control effect on woody cover was detected through 2004, the ninth year after beginning the treatment regime.

The effects of thinning and midstory-control on small mammal abundance were detectible for a shorter period than for the plant community. Few studies have rigorously examined the effects of herbicides on small mammals in southern pines, and most of these have focused on site preparation rather than release (Hood et al. 2002, Miller and Miller 2004). Small mammal abundance was not as closely tied to the herbaceous community as previously cited (Cook 1959, Atkeson and Johnson 1979). Herbaceous cover remained high on thinned only plots through 1998. However, small mammal abundance declined precipitously after the spring of 1996 and remained low for the remainder of the study. We did not capture cotton rats or wood rats from 1996 and 1997, respectively, until after the prescribed fire in 2003. Interestingly, mammal abundance was highest on combined treatment plots in 1996 despite higher herbaceous cover on thinned only plots. Additionally, greater herbaceous cover on combination plots from 1998 until the end of the study did not translate into detectible treatment effects on small mammal abundance.

Small mammal abundance responded positively to the treatments, but the response was very short-term. By 2001, the increase of pine basal to pre-treatment levels on thinned plots suggests that when plantation silviculture is used, frequent thinning may be required to maintain abundant and diverse small mammal communities. The combined treatment created a stand structure, which may allow the resources made available by the thinning to be available to the herbaceous understory rather than a hardwood midstory. The less abundant and smaller hardwood component may allow prescribed fire to more effectively maintain the open midstory conditions. Increasing the frequency of prescribed fires may also provide better hardwood control. A 2 or 3-year fire return interval may be more appropriate than the current 4-year interval. This interval is at the upper limit of the range generally recommended to maintain longleaf dominance and understory abundance and diversity (Frost 1993, Glitzenstein et al. 2003). Provided there is sufficient fuel to result in a moderately intense fire, this shorter fire-free period may prevent hardwoods from becoming large enough to be fire resistant.

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Table 3.1. Small mammals captured in longleaf pine plantations on the Savannah River Site, SC 1996-2003 by factor level combination of thinning and midstory-control.

	Treatment	Other *Peromyscus* spp.	*Peromyscus polionotus*	*Neotoma floridanum*	*Sigmodon hispidus*	Other	Total	Trap Success (%)
	Thinned	4	9	2	1		16	10.00
Spring 1996	Combined	4	12			1	17	10.63
n=2	Midstory-control	7	1	1		1	10	6.25
	Control	2		3	1		6	3.75
	Thinned			2	3		5	3.13
Winter 1996	Combined	4	8	1			13	8.13
n=2	Midstory-control	2		1	1		4	2.50
	Control			2			2	1.25
	Thinned	4		1			5	3.13
Spring 1997	Combined	2	8			1	11	6.88
n=2	Midstory-control	5		2			7	4.38
	Control	2					2	1.25
	Thinned	7					7	2.19
Spring 2001	Combined	2				2	4	1.25
n=4	Midstory-control	6				1	7	2.19
	Control	5					5	1.56
	Thinned	3					3	0.94
Spring 2002	Combined	6					6	1.88
n=4	Midstory-control	3					3	0.94
	Control							
	Thinned	7					7	2.19
Winter 2002	Combined	3				3	6	1.88
n=4	Midstory-control	6					6	1.88
	Control	5				1	6	1.88
	Thinned	6					6	1.88
Spring 2003	Combined	11				1	12	3.75
n=4	Midstory-control	11		1			12	3.75
	Control	7					7	2.19
	Thinned	4					4	1.25
Winter 2003	Combined	1			5		6	1.88
n=4	Midstory-control	2			1		3	0.94
	Control	3					3	0.94
	Total	134	38	16	12	11	211	

Table 3.2. Pearson correlation coefficients and Prob > |r| under H0: Rho=0 of covariation of small mammal snap-trap captures with habitat characteristics in longleaf pine plantations at the Savannah River Site, South Carolina, in 1996, 1997, 2001-2003.

Cover (%)					
Saplings	Shrubs	Vines	Forbs	Grasses	Herbaceous
-0.108	-0.083	-0.057	-0.008	0.177	0.083
0.275	0.401	0.566	0.939	0.072	0.402

Pine							
Height (Ht)	DBH	Crown width	Ht to base of live crown	Crown ratio	Trees/ha	Basal area/ha	Volume
-0.497	-0.418	-0.379	-0.413	0.357	-0.201	-0.446	-0.449
<0.001	<0.001	<0.001	<0.001	<0.001	0.041	<0.001	<0.001

Hardwood							
Height	DBH	Crown width	Ht to the base of live crown	Crown ratio	Trees/ha	Basal area/ha	Volume
-0.20813	-0.19179	-0.20285	-0.24239	-0.16691	-0.18754	-0.17	-0.15529
0.0340	0.0511	0.0389	0.0132	0.0904	0.0566	0.0845	0.1155

Year	Trap Period	YSLB	Season
-0.440	-0.480	-0.087	-0.144
<0.001	<0.001	0.379	0.145

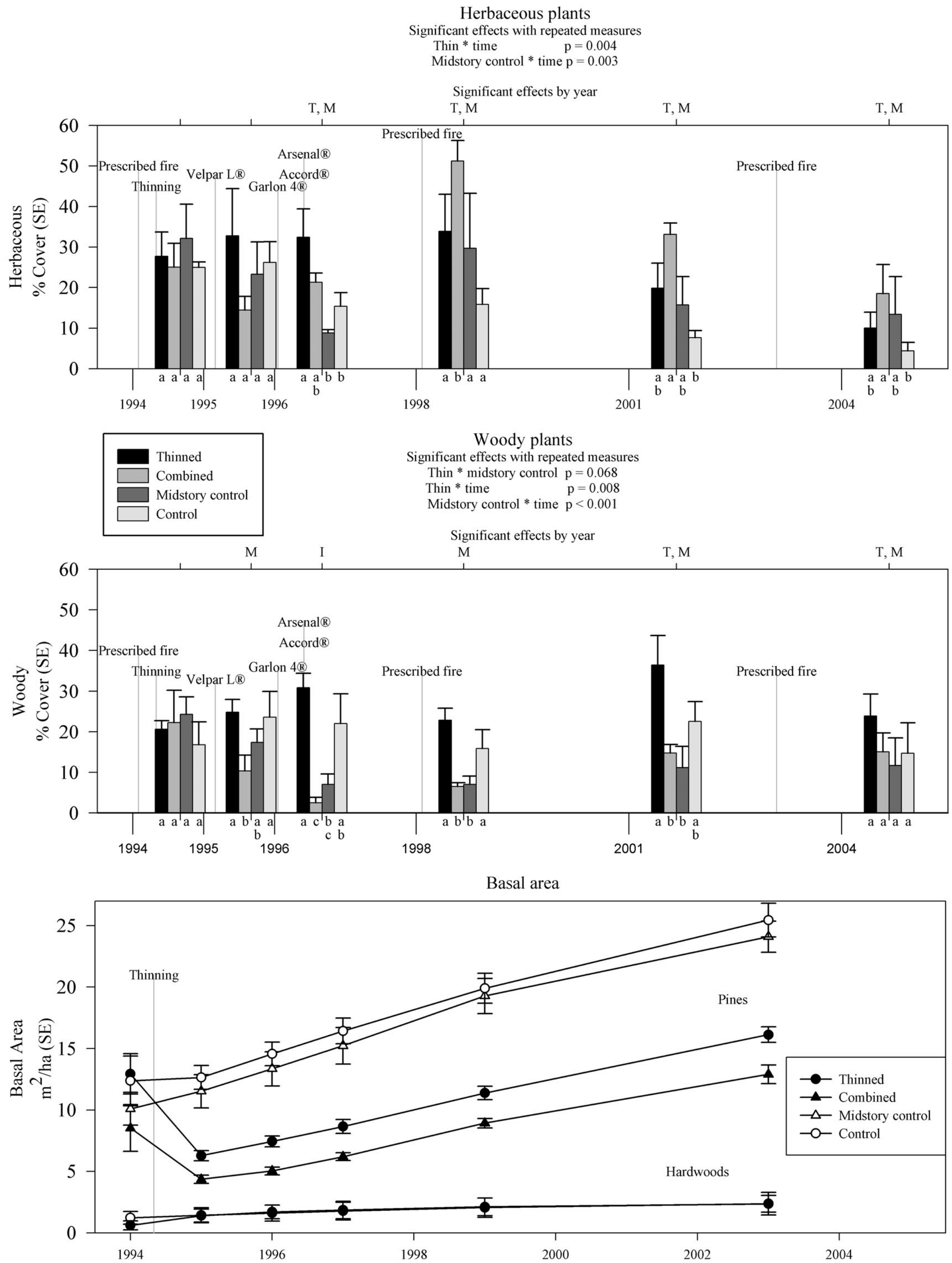

Figure 3.1. Herbaceous and woody cover and overstory basal area by factor level combination of thinning and midstory-control in longleaf pine plantations on the Savannah River Site, South Carolina 1994-2004. Significant effects from repeated measures analysis of variance follow the title, and significant effects by year are included on the upper x-axis [thinning (T), midstory-control (M), and interaction (I)]. Within each year, treatments with the same letter on the lower x-axis are not different. The midstory-control treatment eliminated hardwoods on treated plots.

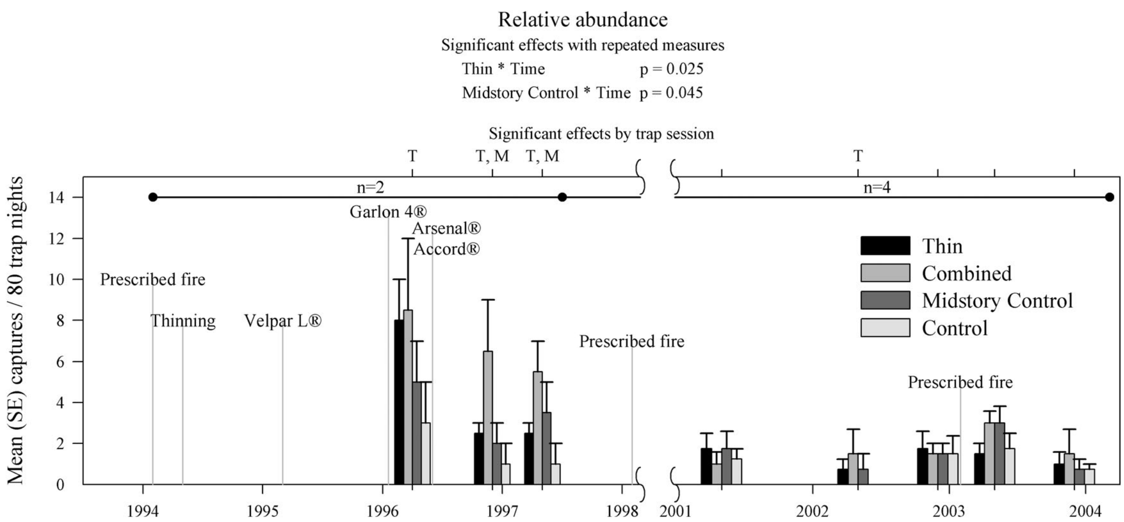

Figure 3.2. Small mammal relative abundance by factor level combination of precommercial thinning and midstory-control in longleaf pine plantations at the Savannah River Site, South Carolina by trapping session [spring and winter] 1996, 1997, 2001-2003. Abundance values are mean small mammals of all 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.

CHAPTER 4

EFFECTS OF PRECOMMERCIAL THINNING AND MIDSTORY-CONTROL ON THE HERPETOFAUNA COMMUNITY IN YOUNG LONGLEAF PINE PLANTATIONS[3]

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[3] Simmons, R. P., K. J. Brunjes, J. C. Kilgo, T. B Harrington, R. F. Daniels, and K. V. Miller. To be submitted to *Georgia Journal of Science*.

ABSTRACT

We examined the effects of longleaf pine (*Pinus palustris*) restoration using plantation silviculture on herpetofauna communities on the Savannah River Site, a National Environmental Research Park near Aiken, South Carolina. We precommercially thinned the pines (1994) and controlled the woody midstory with herbicides (1995-1996) using a large scale factorial experiment in well stocked 8-11 year old longleaf plantations. We surveyed herpetofauna using drift fence arrays with pitfall traps (2001-2003). We did not detect any treatment-related differences in herpetofauna abundance. Our results suggest that using precommercial thinning and midstory-control with herbicides to restore longleaf pine does not negatively affect amphibians and reptiles 7-9 years after treatment.

Key words: amphibian, herbicide, herpetofauna, longleaf pine, *Pinus palustris*, precommercial thinning, reptile, restoration, Savannah River Site, South Carolina.

INTRODUCTION

Herpetofauna species richness of the Southeastern Coastal Plain is among the highest in North America (Kiester 1971), and many species use longleaf pine (*Pinus palustris*) forests for part of their life cycle (Means 2006). These upland amphibians often use isolated wetlands for their primary breeding habitat. These ephemeral, fishless ponds are embedded in the uplands and contribute to amphibian abundance and diversity disproportionately to their size (Russell et al. 2002a).

Restoring longleaf forests has become a recent focus of natural resource managers, and plantation silviculture has been suggested as a restoration technique because natural regeneration sources are often absent (Landers et al. 1995, McMahon et al. 1998, Harrington and Edwards 1999). Silvicultural techniques, such as thinning and controlling hardwood encroachment can also hasten the development of the open stand structure with little midstory and a diverse herbaceous understory usually associated with older, more successionally advanced, fire maintained stands. The flora and fauna of natural longleaf stands are well documented (Peet and Allard 1993, Ware et al. 1993, Means 2006), but the effect of plantation silviculture on these communities is less well understood (Repenning and Labisky 1985, Means 2005).

Several researchers have noted the importance of the quality of upland habitat associated with isolated wetlands to herpetofaunal abundance and diversity (Burke and Gibbons 1995, Kirkman et al. 1999, Gibbons 2003). However, there is little research on the effects of southern pine silvicultural on herpetofauna, and these studies have largely been descriptive studies of the effects of clearcutting and site preparation (Means 2005). In one of the few designed experiments, Russell et al. (2002b) found no treatment effects of clearcutting and mechanical site preparation on herpetofaunal abundance and species richness. They concluded that herpetofaunal communities in pine forests may be resilient to some upland disturbance from silviculture and may require some disturbance, particularly frequent fire, to thrive. Renken et al. (2004) found no effect of clearcutting or uneven-age management on amphibian abundance in Missouri oak-hickory and oak-pine forests, suggesting that the amphibian community in these forests also are tolerant of some disturbance. These studies have been relatively short-term, and Gibbons et al. (1997) found that the variability associated with herpetofauna populations requires long-term sampling to draw accurate conclusions about abundance, richness, and diversity.

Herein, we report the effects of precommercial thinning and woody competition control on the herpetofauna communities of longleaf pine plantations at 7-9 years post treatment. Our objective was to investigate the effects of thinning and hardwood midstory-control and the duration of these effects on the composition and abundance of the herpetofauna community in young longleaf pine plantations in the Upper Coastal Plain of South Carolina.

STUDY AREA AND METHODS

The study area and methods have largely been described by Harrington and Edwards (1999) and Brunjes et al. (2003). The Savannah River Site (SRS) is in the Sandhills physiographic province of South Carolina (Miller and Robinson 1995). During winter 1993-1994, we selected 4 longleaf pine plantations (17.4 to 20.6 ha in size), which had been established between 1982 and 1986. We selected sites having fully stocked stands of longleaf pine (>1200 stems/ha) and hardwoods (>600 stems/ha). Each plantation had been machine planted with 1-year-old bare-root seedlings at 1.8 x 3 m spacing in clearcut-harvested areas in which woody debris had been either windrowed or piled, and burned. Prior to harvest, the sites supported mature stands of old-field longleaf and loblolly (*P. taeda*) pines. The study sites represent a range of moisture classifications from xeric to moderately mesic (Van Lear and Jones

1987). The soils are loamy sands, which range from well-drained to excessively well-drained (Rogers 1990).

We 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 DBH and applied similar prescribed fires in February 1998 and January-February 2003. Each site was divided into 4 treatment areas of similar size at the initiation of the study, and one of the following treatments was randomly assigned to each area.

1. Untreated: No treatments applied, except prescribed fire.
2. Pine thinning: In May 1994, pines were thinned to approximately 50% of the original stem density, resulting in 635 and 1440 pines/ha in 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. Woody control: This treatment virtually eliminated all nonpine woody vegetation with herbicides. In April 1995, we applied undiluted Velpar® L (hexazinone; E.I. du Pont de Nemours and Company, Wilmington, Del.) at 1.7 kg active ingredient/ha with a spotgun to grid points on an approximately 1 m spacing. In March 1996, we treated surviving nonpine stems with a basal spray of Garlon® 4 (triclopyr ester; Dow AgroSciences LLC, Indianapolis, Ind.) at 7% concentration in oil. In late June 1996, we applied a directed foliar spray of Arsenal® AC (imazapyr; American Cyanamid Company, Wayne, N.J.), Accord® (glyphosate; Monsanto Company, St. Louis, Mo.) and X-77® surfactant (Loveland Industries, Inc, Greeley, Col.) mixed in water at 0.5, 5, and 0.5% concentrations, respectively, to surviving target vegetation within 8 m of each sample point

(described below) received. All herbicides were applied with a backpack sprayer.

4. Combined treatment: Pine thinning was combined with woody control.

Measurements

We surveyed the understory and overstory vegetation in permanently marked plots as reported in Simmons (2007). We surveyed herpetofauna populations using drift fence arrays with pitfall traps. On each of the 4 sites, we installed 2 arrays in each treatment area (32 total). Drift fences were 2 perpendicular 9.1-m straight lines of aluminum flashing with several cm buried. We evenly spaced 9, 18.9-l buckets along the length with the mouths of the buckets at or slightly below grade. We opened the arrays for 20 days in May 2001-2003. We identified captures using morphological characteristics (Conant and Collins 1998).

Statistical analysis

The experiment was a block design with 2x2 factorial arrangement of treatments (Harrington and Edwards 1999) and repeated measurements over time. We performed all analyses with SAS Systems (SAS Institute 1999). We performed analysis of variance (ANOVA) with the Mixed procedure on the total number of herpetofauna captured to test the effects of thinning, midstory-control, and their interaction. We also tested the interaction of these terms with time. We specified treatment area within site (replication) as a random effect in the mixed model analyses. We transformed the vegetative cover data with arcsine, square root prior to analysis to improve its normality (Dowdy and Wearden 1991).

We plotted residuals from each ANOVA against predicted values to confirm normal distribution. When residuals were severely non-normal, we transformed the data to improve the distribution of the residuals (Dowdy and Wearden 1991). Standard transformations did not normalize the herpetofauna abundance residuals. Therefore, we used the rank transformation approach of Conover and Iman (1981). We ranked treatment area means within each trapping period, assigning average rank to ties. ANOVA performed on ranks is a non-parametric test that retains the advantages of the full experimental design (Conover and Iman 1981).

We encountered an Eastern spadefoot (*Scaphiopus holbrookii*) breeding event during 2003, which resulted in a disproportionate number of spadefoot captures. Because this increased trap success is likely weather related (Greenberg and Tanner 2004) rather than a treatment effect, we removed Eastern spadefoot from our statistical analyses.

RESULTS

We captured 1308 amphibians of 12 species (Table 4.1, 4.2; Figure 4.1) and 162 reptiles of 13 species (Table 4.3) during 1920 array nights. Of the amphibians, 1104 (84%) were Eastern spadefoot captured in spring 2003. Amphibian abundance was highly variable even after removing spadefoot captures. Neither thinning, midstory-control, nor their interaction effect was significant ($\alpha = 0.05$, df = 132). Amphibian abundance was not correlated with any of the habitat variables that we measured ($\alpha = 0.1$, Table 4.4).

Reptile abundance generally decreased with time but was highly variable (Figure 4.2). No treatment or interaction effects were significant ($\alpha = 0.05$, df = 132), and reptile abundance was not correlated with any habitat variables that we measured ($\alpha = 0.1$).

Herbaceous plant cover responded positively to thinning and midstory-control. The magnitude of the thinning effect decreased over time. Because of the significant treatment by time interaction, we examined the data by sample period to investigate the nature of the interaction. All three treatments had greater herbaceous ground cover than the untreated controls. The combined treatment had the highest herbaceous cover. However, thin by midstory-control interactions were not significant. Midstory-control reduced woody cover and thinning positively affected woody cover. The magnitude of the thinning effect decreased in 2004.

DISCUSSION

Overstory and understory vegetation responded to thinning and midstory-control as expected (Simmons 2007). Thinning and midstory-control had greater herbaceous cover, especially when combined. Thinning alone increased woody vegetation cover (shrubs, saplings, and vines) and midstory-control reduced it. Despite these differences, we did not detect any treatment related differences in herpetofaunal abundance.

Our results corroborate the conclusions of Russell et al. (2002b) that Southeastern Coastal Plain herpetofauna may tolerate some disturbance in the uplands. We expected thinning and reducing the hardwood component of the stands combined with prescribed fire to reduce amphibian abundance. However, the effects of partial harvests, such as thinning, are relatively unstudied (DeMaynadier and Hunter 1995).

Herpetofauna population estimates have high temporal variability (Pechmann et al. 1991, Burke et al. 1995, Gibbons et al. 1997), and our study followed this trend. Characteristics such as fossorial habits, inconspicuousness, and small home ranges contribute to this variability. Factors unrelated to the treatments, such as the timing of breeding events, appear to have had a much larger effect on measured amphibian abundance than did the treatments.

Our results support using plantation silviculture, specifically thinning and midstory-control to restore longleaf ecosystems. At 7-9 years post thinning and 6-8 years after starting the midstory-control regime, we detected no effects of these treatments on herpetofauna populations. These treatments positively affected other components of these stands. With the combined treatment, stand structure was more open with greater herbaceous cover (Simmons 2007) and greater herbaceous species density (Harrington and Edwards 1999). These conditions are more typical of functioning longleaf ecosystems than the dense mixed overstory with pronounced midstory, and depauperate understory in the control plots (Simmons 2007). Our results suggest that using thinning and midstory-control to restore stand structure, enhance pine growth, and promote understory development did not negatively impact herpetofauna in our young longleaf stands.

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Table 4.1. Herpetofauna species captured in young longleaf pine plantations on the Savannah River Site, South Carolina May 2001-2003.

Species	Common name
Acris gryllus	Southern cricket frog
Ambystoma talpoideum	Mole salamander
Anolis carolinensis	Green anole
Bufo americanus	American toad
Bufo terrestris	Southern toad
Cemophora coccinea	Scarlet snake
Cnemidophorus sexlineatus	Six-lined racerunner
Desmognathus brimleyorum	Dusky salamander
Diadophis punctatus	Southern ringneck snake
Eumeces fasciatus	Five-lined skink
Eumeces inexpectatus	Southeastern five-lined skink
Eumeces laticeps	Broadhead skink
Gastrophryne carolinensis	Eastern narrowmouth toad
Plethodon glutinosus	Slimy salamander
Pseudotriton ruber	Southern red salamander
Rana clamitans	Bronze frog
Rana utricularia	Southern leopard frog
Scaphiopus holbrookii	Eastern spadefoot
Sceloporus undulatus	Fence lizard
Scinella lateralis	Ground skink
Tantilla coronata	Southeastern crowned snake
Thamnophis sauritus	Eastern ribbon snake
Thamnophis sirtalis	Eastern garter snake
Virginia striatula	Rough earth snake

Table 4.2. Amphibians captured in longleaf pine plantations on the Savannah River Site, SC May 2001-2003 by factor level combination of thinning and midstory-control 7-9 years post thinning and 6-8 years after starting the midstory-control regime.

Year	Treatment	*Acris gryllus*	*Ambystoma talpoideum*	*Bufo americanus*	*Bufo terrestris*	*Desmognathus brimleyorum*	*Gastrophryne carolinensis*	*Plethodon glutinosus*	*Pseudotriton ruber*	*Rana clamitans*	*Rana utricularia*	*Scaphiopus holbrookii*	Unknown salamander	Total
2001	Thinned						14					3		17
	Combined				1		5			2		19		27
	Midstory-control			1	6		6	3				6		22
	Control				3		9	1	1	1		12		27
2002	Thinned				2			1						3
	Combined				1		1	1		1		1		5
	Midstory-control							3					1	4
	Control				1		1	3		1				6
2003	Thinned				1	2	9				1	225		238
	Combined				10	4	21			4	1	259		299
	Midstory-control	8			2	5	22			10	1	267		315
	Control		1		8	11	8	1	1	2	1	312		345
	Total	8	1	1	35	22	96	13	2	21	4	1104	1	1308

Table 4.3. Reptiles captured in longleaf pine plantations on the Savannah River Site, SC 1995-2003 by factor level combination of thinning and midstory-control 7-9 years post thinning and 6-8 years after starting the midstory-control regime.

Year	Treatment	*Anolis carolinensis*	*Cemophora coccinea*	*Cnemidophorus sexlineatus*	*Diadophis punctatus*	*Eumeces fasciatus*	*Eumeces inexpectatus*	*Eumeces laticepts*	*Sceloporus undulatus*	*Scinella lateralis*	*Tantilla coronata*	*Thamnophis sauritus*	*Thamnophis sirtalis*	*Virginia striatula*	Total
2001	Thinned	1	2	6						3	6			2	20
	Combined		2	11		1		1	1	6	7			2	31
	Midstory-control	1	1		1	1				2	4			1	11
	Control		5	1		1	1	1		4	4			1	18
2002	Thinned	3		1			1							1	6
	Combined	2		6			1	1	5						15
	Midstory-control	11	3	1			2	1		1	1	1		1	22
	Control	7					1	4		1	1				14
2003	Thinned								2		1				3
	Combined			1			2		1						4
	Midstory-control		2	1			2	1			4				10
	Control		1	1				3	2				1		8
	Total	25	16	29	1	3	10	12	11	17	28	1	1	8	162

Table 4.4. Habitat characteristics measured in longleaf pine plantations at the Savannah River Site, South Carolina, in 1994-2004.

Habitat Characteristic
Year of the study 1996-2003
Number of years since the last prescribed burn
Density of foliage in the shrub-scrub vegetation layer, < 1 m above the ground
Density of foliage in the midstory vegetation layer, 1m - 5m above the ground
Density of foliage in the canopy vegetation layer, > 5m above the ground
Density of foliage in the midstory and canopy vegetation layers, > 1m above the ground
Percent cover of tree saplings
Percent cover of shrubs
Percent cover of vines
Percent cover of forbs
Percent cover of grass
Percent cover of grass and forbs
Mean height of pines
Mean diameter at breast height of pines
Mean crown width of pines
Mean height to the base of the live crown of pines
Mean crown ratio of pines
Mean number of pine per hectare
Mean pine basal area per hectare
Mean pine volume per hectare
Mean height of hardwoods
Mean diameter at breast height of hardwoods
Mean crown width of hardwoods
Mean height to the base of the live crown of hardwoods
Mean crown ratio of hardwoods
Mean number of hardwoods per hectare
Mean hardwood basal area per hectare
Mean hardwood volume per hectare

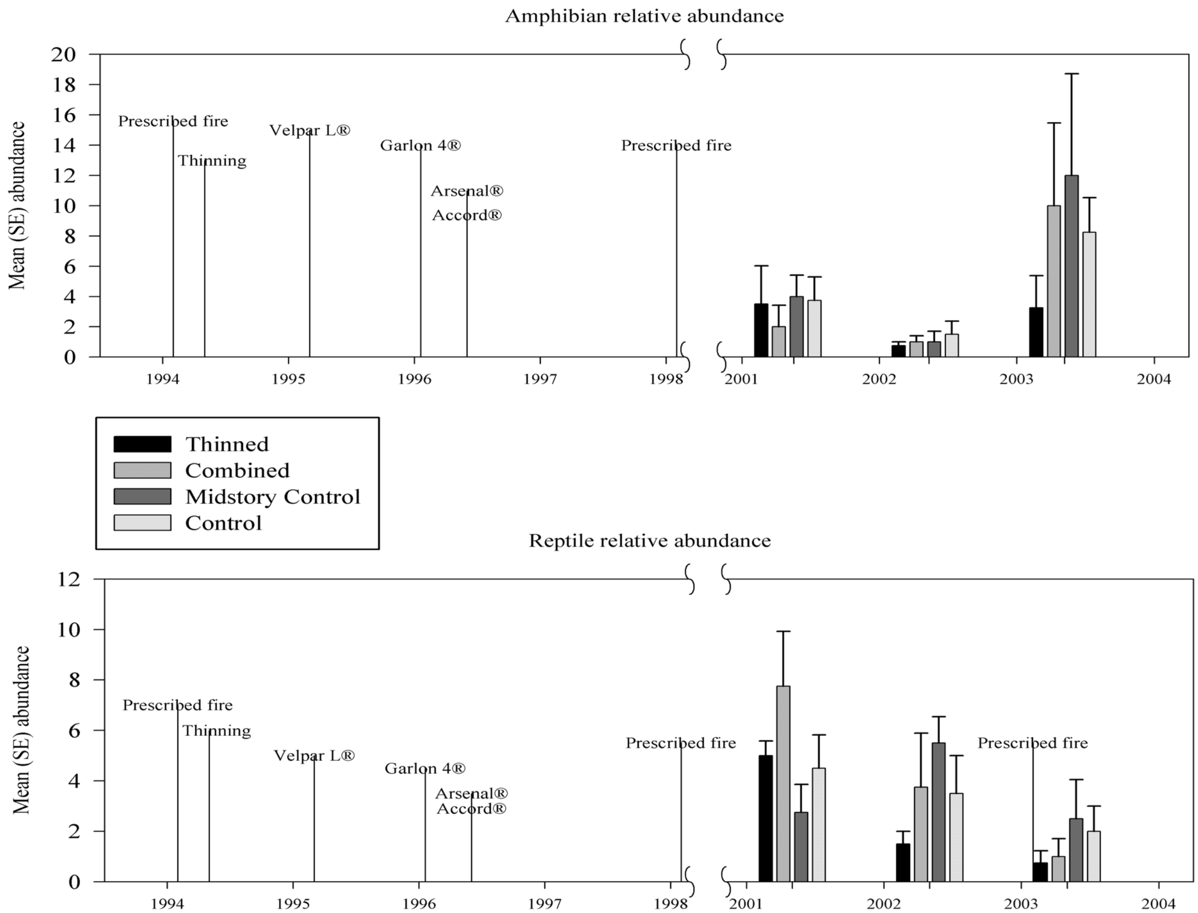

Figure 4.1. Relative abundance (mean/40 array nights) of amphibians and reptiles by factor level combination of precommercial thinning and midstory-control captured in longleaf pine plantations at the Savannah River Site, South Carolina by trapping session May 2001-2003.

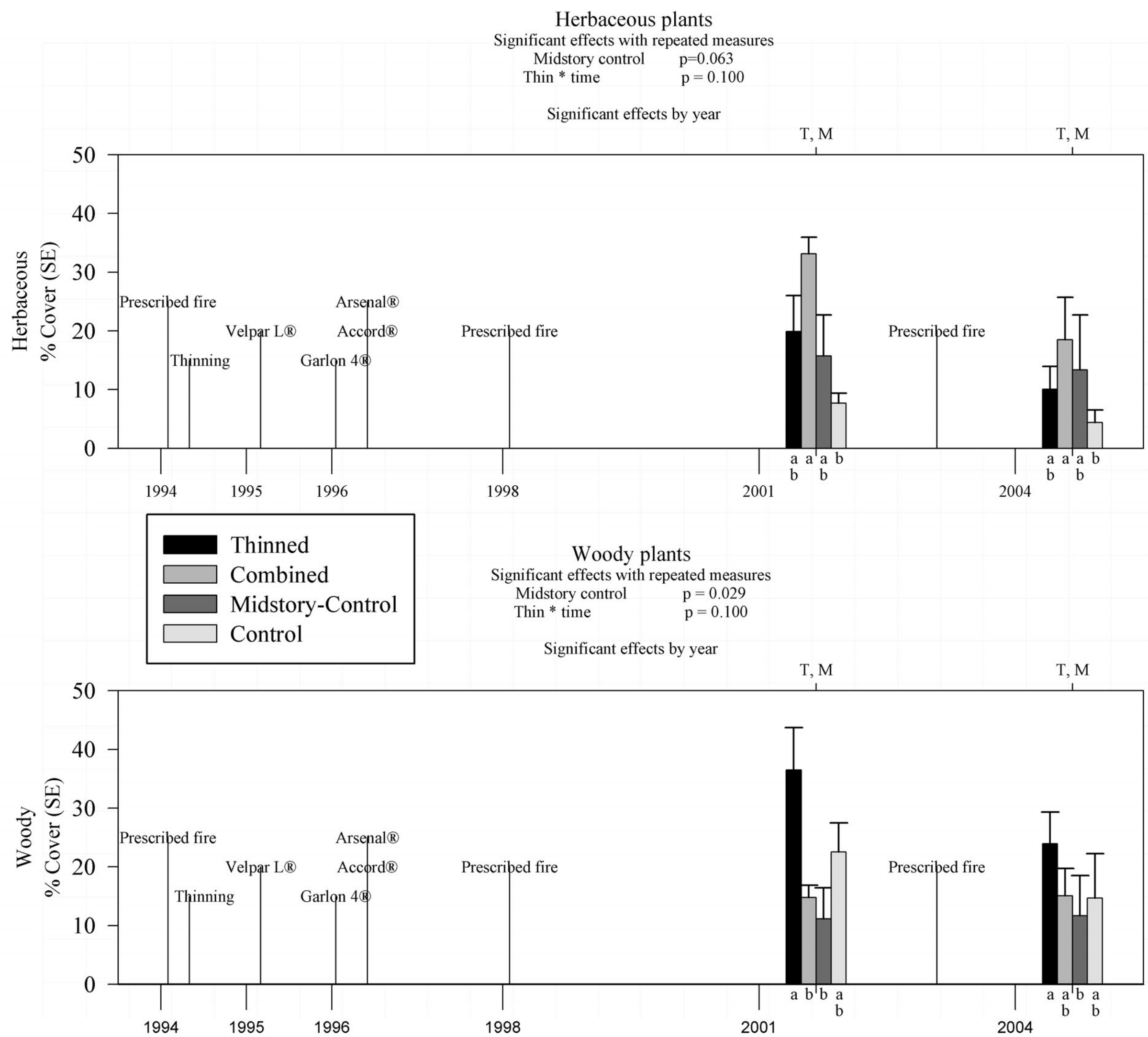

Figure 4.2. Herbaceous and woody cover by factor level combination of thinning and midstory-control in longleaf pine plantations on the Savannah River Site, South Carolina 2001-2004. Significant effects from repeated measures analysis of variance follow the title, and significant effects by year are included on the upper x-axis [thinning (T), midstory-control (M), and interaction (I)]. Within each year, treatments with the same letter on the lower x-axis are not different.

CHAPTER 5

STUDY CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The results of my experiment support using thinning and midstory-control with herbicides as tools to restore longleaf pine ecosystems. Thinning and midstory vegetation control temporarily increased bird abundance, diversity, and richness and small mammal abundance relative to the control. These effects were short-lived when treatments were applied separately. The effects were more pronounced and persisted longer when we combined the treatments. Herpetofauna abundance was not affected by the treatments.

The small mammal and bird response patterns were similar to the pattern of herbaceous plant response, but the effect on these animals did not last as long as the effect on the plants. Herbaceous plant abundance increased after a brief decline following the herbicide treatments. Herbaceous cover diminished with time after 1998, but remained greater than the control through the end of the study. There were no long-term negative effects of the midstory-control treatment on the herbaceous community. The herbaceous response to thinning alone was smaller and shorter than the effect of the combined treatment, likely because thinning released woody plants from pine competition (Blair and Enghardt 1976, Blair and Feduccia 1977, Wolters et al. 1982).

Additional treatments would be required to maintain the treatment effects. The pine basal area returned to pretreatment levels by 2001, 7 years after thinning, which is when the bird and small mammal responses began to decline. After the overstory basal area increased to pre-treatment levels, other factors such as prescribed fire and annual variation unrelated to the treatments affected the bird and small mammal communities more than thinning and midstory vegetation control.

These results support findings that bird diversity in southern pine stands is highest in fire maintained stands with an open overstory, little hardwood encroachment, and an abundant and diverse herbaceous understory (Klaus and Keyes 2007, Krementz and Christie 1999).

Herpetofauna abundance was not affected by the treatments 7-9 years post thinning and 6-8 years post midstory-control. However, annual variability in abundance was high, which could have masked a treatment effect. Our results support a small but growing body of evidence that southern, upland herpetofauna are tolerant of some disturbance (Russell et al. 2002).

Analyzing the differential response of each vertebrate species to habitat characteristics could better elucidate treatment responses, but we did not have enough captures to analyze these effects. Our low trap success is typical of studies in the Sandhills (Stout and Marion 1993) despite our increased sampling effort in 2001-2003. The high variability of our data reduced the ability to detect any biologically significant relationships between taxa and habitat characteristics. Additional research is needed to determine the specific factors that influence small vertebrate response to thinning and midstory-control.

The SRS longleaf restoration study was originally designed to investigate the understory and overstory response to the treatments. Had wildlife implications been integrated from the outset, we might have a more complete picture of their response. Pre-treatment sampling and more consistent sampling throughout the rotation might have provided additional insight into the magnitude, timing, and duration of the treatment effects. Wildlife sampling before and after the anticipated second thinning of these sites would add unique and valuable insights into the wildlife effects of pine plantation management.

A 2- or 3-year fire return interval may be more appropriate than the current 4-year interval to prevent hardwoods from becoming large enough to be fire resistant. Four years is at the upper limit of the range generally recommended to maintain longleaf dominance, and understory abundance and diversity (Frost 1993, Glitzenstein et al. 2003). This recommendation is particularly relevant given the difficulties associated with implementing scheduled prescribed burns in a timely manner. I experienced the effects of these difficulties in January of 2002 and was able to burn only 2 of the 6-study sites. This delay had ecological and practical effects. Ecologically, the fire return interval of the 4 unburned sites was extended outside the recommended range potentially reducing the effectiveness of fire to maintain the open midstory conditions on midstory-control plots. Practically, burning these sites a year earlier than the other 4 made the conditions sufficiently different. Therefore, I removed the 2 burned sites from my analysis, which reduced the power of the experiment.

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