PLANT, SMALL MAMMAL, AND BIRD COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA

by

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(Under the Direction of Karl V. Miller and Steven B. Castleberry)

ABSTRACT

Loblolly pine (*Pinus taeda*) stands are common in the southeastern United States, where combinations of mechanical (MSP) and chemical site preparation (CSP) and herbaceous weed control (HWC) treatments are used during stand establishment to manage competing vegetation and increase pine production. Although these techniques vary widely in their effects on plant communities, few long-term studies have described relationships between site preparation intensity and plant and wildlife diversity. Therefore, I examined effects of 6 treatments of increasing intensity via combinations of mechanical [wide spacing/strip shear (SSW) or narrow spacing/roller chop (RCN)] and CSP (application or no application) treatments with HWC (broadcast or banded) 1 year after site preparation on plant and wildlife communities in loblolly pine plantations (n = 6) in the Coastal Plain of North Carolina, USA, for 8 years following site preparation. Type of MSP or pine spacing had little impact on plant communities. SSW supported more small mammals in years 1-2 and increased bird abundance in years 1-6 over RCN. Chemical SP had the greatest effect on plant communities by reducing woody cover and species richness by approximately 50% in all years over plots lacking CSP. Chemical SP reduced small mammal abundance and species richness in years 1-2, reduced bird abundance in year 2, increased bird abundance in year 6, had no effect on bird abundance after year 7, and did not affect bird species richness in any year. Broadcast HWC reduced herbaceous plant cover and richness in year 1 over banded HWC, but type of HWC had little effect on woody cover, pine cover, or small mammal and bird communities. Increasing intensity through the addition of vegetation control methods had few cumulative impacts on plant and animal communities beyond the effects of MSP or pine spacing (small mammals and birds) or the use of CSP (woody plants). If CSP is needed to control competing vegetation, CSP can be paired with wide spacing and banded HWC to encourage vegetation structure used by small mammals and birds. Intensively managed pine forests can contribute to plant and wildlife conservation due to the diverse array of habitats contained within these forests.

INDEX WORDS: Bird communities, Chemical site preparation, Diversity, Forest regeneration, Herbaceous weed control, Intensive forest management, Lower Coastal Plain, Mechanical site preparation, North Carolina, Pine plantations, Pine spacing, Plant communities, Release treatments, Richness, Small mammal communities, Vegetation

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ... iv

LIST OF TABLES ... viii

LIST OF FIGURES ... xiii

CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW ... 1

INTRODUCTION ... 1

LITERATURE REVIEW ... 3

REFERENCES ... 10

CHAPTER 2. PLANT COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA ... 20

ABSTRACT ... 21

INTRODUCTION ... 22

METHODS ... 24

RESULTS ... 27

DISCUSSION ... 30

CONCLUSION ... 36

REFERENCES ... 37

CHAPTER 3. SMALL MAMMAL COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA ... 52

ABSTRACT 53
INTRODUCTION 54
METHODS 56
RESULTS 58
DISCUSSION 60
CONCLUSION 65
REFERENCES 66
CHAPTER 4. BIRD COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA 75
ABSTRACT 76
INTRODUCTION 77
METHODS 79
RESULTS 81
DISCUSSION 84
CONCLUSION 88
REFERENCES 89
CHAPTER 5: CONCLUSIONS AND MANAGEMENT IMPLICATIONS 102
REFERENCES 107
APPENDIX A: SUMMARY DATA FOR PLANT SPECIES RECORDED ON STUDY SITES 2002-05 AND 2007-09 BY COMPOSITIONAL GROUP 112

LIST OF TABLES

Table 2.1: Treatments used to evaluate plant community responses to combinations of chemical and mechanical site preparation techniques in the Coastal Plain of North Carolina, 2002-05, 2007-09 43

Table 2.2: Pine percent cover, non-pine woody percent cover, and woody species richness means, standard errors, and contrast results for individual treatment component comparisons. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) loblolly pine plantations in the Coastal Plain of North Carolina 44

Table 2.3: Herbaceous vegetation percent cover means, standard errors, and contrast results for individual treatment component comparisons. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) loblolly pine plantations in the Coastal Plain of North Carolina 45

Table 2.4: Herbaceous vegetation species richness means, standard errors, and contrast results for individual treatment component comparisons. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) loblolly pine plantations in the Coastal Plain of North Carolina 46

Table 2.5: Total plant Morista community similarity comparisons and standard errors in descending order by overall average for industrial pine

plantation treatments in the Coastal Plain of North Carolina, from 2002-2005 and 2007-2009 47

Table 3.1: Treatments used to evaluate small mammal community responses to combinations of chemical and mechanical site preparation techniques in the Coastal Plain of North Carolina, 2002-05, 2007-09 71

Table 3.2: Small mammal capture rates (captures/100 trap nights), species richness, and Shannon H′ diversity index means, standard errors, and p-values for within-year treatment comparisons. We removal trapped small mammals for 4 consecutive days in winter in 6 (2002-04) or 4 (2005-06, 2008) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina 72

Table 3.3: Small mammal capture rates (captures/100 trap nights) and species richness means, standard errors, and p-values for within-year treatment component contrasts for years with significant treatment effects. We removal trapped small mammals for 4 consecutive days in winter in 6 (2002-04) or 4 (2005-06, 2008) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina 73

Table 4.1: Treatments used to evaluate bird community responses to combinations of chemical and mechanical site preparation techniques in the Coastal Plain of North Carolina, 2002-05, 2007-09 95

Table 4.2: Bird species detected 1-4 and 6-8 years following site preparation in intensively managed loblolly pine plantations in the Coastal Plain of

North Carolina, and associated Partners in Flight regional combined score, migratory status, and habitat preferences 96

Table 4.3: Means, standard errors, and *P*-values for total bird abundance (males/10 ha), species richness (species/10 ha), and Shannon H′ diversity. We surveyed birds during spring in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina 98

Table 4.4: Total bird abundance (males/10 ha) and species richness (species/10 ha) means, standard errors, and p-values for within-year treatment component contrasts. We surveyed birds during spring in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina 99

Table A.1: Mean percent cover among all years and year of maximum abundance for plant species encountered on our treatments in intensively managed pine plantations in the Coastal Plain of North Carolina, 2002-05 and 2007-09. Blank cells = not encountered, trace = <0.01 % cover. Treatment abbreviations include: W = wide spacing, N = narrow spacing; N = no chemical site preparation, H = chemical site preparation; Ba = banded herbaceous weed control (HWC), Br = broadcast HWC...113

Table A.2: Vegetation percent cover and species richness means, standard errors, and p-values from repeated measures split plot analysis for treatment comparisons among years. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina....124

Table A.3: Vegetation percent cover and species richness means, standard errors, and contrast results from repeated measures split plot analysis for individual treatment component comparisons among years for vegetation types found to differ by treatment in overall repeated measures split plot analysis (Table A.2.). We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina....125

Table A.4: Non-pine and pine woody percent cover and woody richness means and standard errors for within-year ANOVAs. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina....126

Table A.5: Herbaceous plant percent cover means and standard errors for within-year ANOVAs. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina....127

Table A.6: Herbaceous species richness means and standard errors for within-year ANOVAs. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina 128

Table A.7: Shannon H′ and Simpson D diversity means, standard errors, and *p*-values from repeated measures split plot analysis for treatment comparisons among years. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina..129

Table A.8: Total plant Morista community similarity comparisons and standard errors in ascending order by overall average for industrial pine plantation treatments in the Coastal Plain of North Carolina, from 2002-05 and 2007-09 130

LIST OF FIGURES

Figure 2.1: Mean grass, non-pine woody, vine, forb, and pine percent cover by year and treatment in the Coastal Plain of North Carolina. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina. Shaded areas represent missing data. Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC..........................48

Figure 2.2: Mean non-pine woody percent cover and species richness by treatment among years on industrial loblolly pine forests in the Coastal Plain of North Carolina. Data were not recorded in 2006. Asterisks denote differences among treatments within a year ($P \leq 0.05$). Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC 49

Figure 2.3: Mean pine percent cover by treatment among years on industrial loblolly pine forests in the Coastal Plain of North Carolina. Data were not recorded in 2006. Asterisks denote differences among treatments within a year ($P \leq 0.05$). Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical

site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC 50

Figure 2.4: Mean Shannon H′ and Simpson D diversity indices for woody plant species by treatment among years on industrial loblolly pine forests in the Coastal Plain of North Carolina. Data were not recorded in 2006. Asterisks denote differences among treatments within a year ($P \leq 0.05$). Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC..........................51

Figure 3.1: Average capture rates and standard error bars by year and treatment for small mammals with at least one mean treatment capture rate of ≥ 0.5 captures/100 trap nights. We collected data 1-5 and 7 years following site preparation in 6 (2002-04) or 4 (2005-06, 2008) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina. An asterix denotes treatment differences within a year at $\alpha = 0.10$. Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast (HWC)....................74

Figure 4.1: Bird abundance (males/10 ha) by migratory status and habitat association. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina. An asterix denotes treatment differences at $\alpha = 0.05$. Treatment

abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC 100

Figure 4.2: Mean grass, non-pine woody, vine, forb, and pine percent cover by year and treatment in the Coastal Plain of North Carolina. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina 101

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Intensively managed pine forests are a common landscape feature in the southeastern United States, encompassing about 20% of southern forests (Smith et al., 2009). Although the area of planted pine increased during the 1980s and 1990s due to incentive programs that encouraged tree plantings within certain agricultural lands (Smith et al., 2009), this growth has stabilized and increased coverage of pine plantations is not expected to occur during the next 10-15 years (NCSSF, 2005). However, management intensity on existing plantations may increase to raise production and enhance returns on investments (NCSSF, 2005), leading to debates over potential effects of increasing management intensity on plant and animal communities (Guynn et al., 2004; Brockerhoff et al., 2008). Pine plantations are known to host a variety of plant and wildlife species (Wigley et al., 2000; Wilson and Watts, 2000; Miller et al. 2009), and industry-owned lands include large tracts of contiguous forests which are increasingly uncommon as forests become fragmented and urbanized in the southeastern United States (NCSSF, 2005). In addition, sustainable forestry certification programs emphasize the need to manage for plant and wildlife diversity within intensively managed forests (Miller et al., 2009). Understanding how intensive management techniques affect wildlife and habitat is important to maintaining plant and wildlife diversity within these pine forests.

Managers use a variety of mechanical and chemical site preparation techniques when establishing pine plantations to reduce competing vegetation and improve pine productivity (Miller et al., 2009). Mechanical site preparation such as chopping, shearing, disking, and bedding controls competing plants, improves the microsite for each seedling, and removes obstructions prior to planting (Yarrow and Yarrow, 2005). Chemical applications are often used during site preparation to reduce competing vegetation or as releases after pines are planted, and can increase loblolly pine productivity by 10-150% in the southeastern United States (Glover and Zutter, 1993; Borders and Bailey, 2001). Chemical treatments, as compared to mechanical treatments, can be more economical, provide better herbaceous and woody control, and reduce soil disturbance and compaction (Yarrow and Yarrow 2005). Herbicide use within pine stands is increasingly common, and the area treated with herbicides, herbicide tank-mixed combinations, and multiple temporal applications is also increasing (Shepard et al., 2004).

Site preparation techniques can affect wildlife communities by altering the structure and composition of regenerating vegetation, but results vary depending upon the technique used and site-specific differences (Witt, 1991; Miller et al., 1995). Due to the variety of methods available to land managers and differences in regional climate, soils, and ecological communities, multiple studies are required to determine how these methods may affect plant and animal communities (Kilgo et al., 2000). Although several studies have investigated effects of chemical site preparation on wildlife populations and wildlife habitat conditions (Howell et al. 1996), effects of mechanical and chemical site preparation combined with herbaceous weed control are poorly understood. Pine plantations can provide suitable habitat for many wildlife species (Miller et al. 2009), and understanding how site preparation and herbaceous weed control affects plant and wildlife communities within managed pine forests is important in an increasingly fragmented landscape. Therefore, this study examines effects of a gradient of increasing management intensity on plant, small mammal, and bird communities within pine plantations in the Coastal Plain of North Carolina for 8 years (2002-2009) following site preparation. Because the project was a cooperative effort among several graduate students, professors, forest products companies, and wildlife management agencies, in the following chapters I use plural pronouns when describing methods, results, and conclusions of our research.

LITERATURE REVIEW

Intensive management of planted pines is commonly used to increase fiber production in the southeastern United States (NCSSF, 2005). At stand initiation, a variety of mechanical and chemical treatments often are used to reduce competing vegetation and increase pine production, and concerns exist regarding potential impacts of intensive management and herbicides on wildlife communities (Guynn et al., 2004; Brockerhoff et al., 2008). Although studies of common herbicides used in forestry report that these chemicals are quickly eliminated in animals and do not bioaccumulate (Morris et al., 1993; Tatum, 2004), herbicides affect wildlife indirectly through changes in plant species diversity, composition, and abundance.

Site Preparation Effects on Vegetation Communities

Competing woody and herbaceous vegetation can significantly reduce pine growth in the Southeast and elsewhere (Zutter and Miller, 1998; Lautenschlager and Sullivan, 2002). In the Southeast, pines are especially vulnerable to competition in the first 5 years of growth (Miller et al., 1991). To reduce competitors and improve pine productivity, forest managers use a variety of mechanical and chemical treatments during site preparation and often use additional chemical release treatments to reduce herbaceous and woody competition (Miller et al., 2009). Site preparation and release treatments can have short- and long-term effects on vegetative communities, depending upon the intensity of mechanical site preparation, spacing between planted pines, and frequency and type of chemical applications (Nilsson and Allen, 2003; Guynn et al., 2004; Bechard, 2008).

Mechanical site preparation alters plant communities by crushing, removing, or displacing vegetative material, and by altering soil nutrients, moisture, and microtopography (Schultz and Wilhite, 1974; Miller, 1980). Mechanical site preparation such as chopping, shearing, disking, or bedding controls competing plants, improves microsites for pine seedlings, and removes obstructions prior to planting, and techniques vary in their ability to alter plant communities (Yarrow and Yarrow, 2005). For example, chopping can increase abundance of woody vegetation (Miller, 1980; Fredericksen et al., 1991), reduce soil nutrients and moisture (Jobidon, 1990), and reduce erosion and soil loss when compared with treatments that shear, pile, or rake woody vegetation (Pye and Vitousek, 1985). Because mechanical site preparation is often required in pine plantations to prepare land for planting, these treatments are frequently included as controls in studies examining effects of chemicals on competing woody and herbaceous plants (Miller et al., 1991; Miller and Zhijuan, 1995; Nilsson and Allen, 2003). Generally, use of mechanical treatments alone is less effective than combining these with chemical treatments (Cain, 1991).

Several chemicals, including glyphosate, hexazinone, picloram, imazapyr, metsulfuron, triclopyr, and sulfometuron methyl, are labeled for controlling competing vegetation during forest regeneration, but differ in their ability to target plant groups (Miller and Miller, 2004). Hexazinone-treated plots contained more Japanese honeysuckle (*Lonicera japonica*), Carolina jessamine (*Gelsemium sempervirens*), and pokeweed (*Phytolacca americana*) over those treated with imazapyr 2 years post-treatment in a Georgia study, but produced less ragweed (*Ambrosia artemisiifolia*) and grasses (Witt, 1991). In another Georgia study, herbaceous and woody plant diversity was greater in areas treated with imazapyr and lowest on hexazinone treatments, and woody diversity was greatest on sites treated with picloram and triclopyr at 1 year post-treatment

(Brooks et al., 1993). Tank mixes of two or more chemicals are frequently used during site preparation and releases to more broadly control competing plants given selectivity of most individual chemicals (Shepard et al., 2004).

Single chemical applications at stand initiation typically have short-term effects on herbaceous plant communities, but can have longer effects on woody vegetation (Jones et al., 2009b). Miller et al. (1999) found that floristic diversity was not significantly affected 11 years after herbicide site preparation in central Georgia, but composition shifted from pine-hardwood to pine dominance in hexazinone-treated plots due to hexazinone's selectivity against hardwood species. Similarly, Witt (1991) noted that while different herbicides reduced vegetative cover, composition, and diversity during the first 3 years, by year 4 these differences were less pronounced.

Plant communities can respond differently to mechanical and chemical site preparation. In a South Carolina study, herbaceous diversity was greater on mechanically prepared sites at 5 years post treatment than on hexazinone prepared sites, but diversity of woody vegetation was similar (O'Connell 1994, Miller and Chapman 1995). Witt (1991) observed that while mechanically prepared sites had greater abundance of asters, grasses, and legumes than herbicide treatments, mechanical site preparation was less effective in controlling woody vegetation 2-3 years post-treatment.

Chemical releases are also used to improve pine productivity by reducing herbaceous and/or woody competition after site preparation (Borders and Bailey, 2001), although the effects on herbaceous vegetation tend to be short-lived (Wagner et al., 2004). Boyd et al. (1995) noted that there were no differences in plant species richness and diversity 7 years after a broadcast herbicide release to control hardwoods in a 10-year-old pine plantation in central Georgia.

Herbaceous weed control (HWC) release treatments can be broadcast over an entire site or in bands along pine rows, and while both methods yield similar pine growth (Knowe et al., 1985; Nelson et al., 1985; Lauer et al., 1993), banded HWC allow residual vegetation between pine rows that may be beneficial to wildlife (Blake et al., 1987; Jones et al., 2009a).

Site Preparation Effects on Small Mammal Communities

In pine plantations, small mammals are influenced as site preparation treatments reduce competing herbaceous and woody vegetation, encourage pine production, affect the retention of woody snags, and redistribute woody debris within a site (Sparling, 1996; Jones et al., 2009c). Mechanical site preparation redistributes or removes coarse woody debris and affects abundance of trees and shrubs (Miller, 1980; Yarrow and Yarrow, 2005), while chemicals alter plant communities by selectively killing competing herbaceous and woody vegetation (Miller and Wigley, 2004).

Logs, stumps, and other woody debris act as refugia for small mammals, and distance to the nearest log, woody biomass, and stump size are important for many species (Mengak and Guynn, 2003). Increased humidity near woody debris provide suitable growing conditions for plants, provide seed and forage sources for small mammals even during dry periods, and insects living within woody debris are eaten by some small mammal species (Harmon et al., 2004). Increased humidity is particularly important to shrews (*Sorex* spp., *Blarina* spp.), whose metabolic rates make them sensitive to evaporative water loss (Getz, 1961; Bellows et al., 2001) although, in frequently burned or xeric pine habitat forests, woody debris may be less important to small mammals than underground and leaf litter burrows for protection against dry conditions (Ford et al., 1999; Moseley et al., 2008). Mechanical site preparation techniques that retain coarse woody debris are likely beneficial to small mammals (Jones et al., 2009c), particularly in the Southeast where coarse woody debris deposition is low in pine stands and decomposition rates are high (Mattson et al. 1987; McMinn and Hardt, 1996).

Sites prepared mechanically often support lower densities of small mammals than sites chemically prepared, due to less habitat structure and standing woody debris immediately following application, and less herbaceous vegetation in later years due to shading and competition from increased woody shrub cover (Miller and Chapman, 1995; Sparling, 1996). Chemical site preparation allows managers to selectively target competing vegetation, create snags and coarse woody debris, and create openings of early successional habitat within older vegetation types (Wigley et al., 2002). Small mammal abundance tends to be inversely related to management intensity, and combinations of mechanical and chemical site preparation techniques can have additive reductions in small mammal abundance (Edwards, 2004).

In general, effects of site preparation on small mammals are short-lived. Miller and Chapman (1995) observed that small mammal capture rates were greater on mechanically prepared sites than on chemically prepared sites 2 years after stand initiation, but by year 3 treatment differences were no longer apparent. Sparling (1996) observed that mechanical treatments had lower small mammal capture rates than chemical treatments in the first year after stand initiation, but diversity, evenness, and richness were similar among treatments by year 2. Santillo et al. (1989a) noted that differences in small mammal abundance reflected changes in invertebrates and plant food induced by glyphosate applications for at least three years after treatment, probably due to the extended winters and slower recovery rates of northern (Maine) plant communities after a disturbance as compared to southeastern forests.

Small mammal communities follow gradients that mirror the ephemeral, early successional vegetation associations that they inhabit. Atkeson and Johnson (1979) measured small mammals in 1-15 year-old pine plantations in the Georgia Piedmont and observed that seed-eating small mammals such as white-footed mice (*Peromyscus leucopus*) and house mouse (*Mus musculus*) were dominant and abundant in 1-year-old pine plantations due to abundance of seed-producing annual plants. As understory herbaceous communities shifted to perennial herbs and grasses, herbivores such as cotton rats (*Sigmodon hispidus*) became most abundant and persisted until canopy closure at year 7. However, as the herbaceous community declined due to decreased sunlight from a closing canopy, capture rates decreased. By 15 years of age, few small mammals were supported in these closed-canopy pine plantations due to successional changes and canopy closure. Thinning closed-canopy pine plantations creates openings for understory herbaceous plants and may improve habitat conditions for small mammals (Mitchell et al. 1995; Miller et al. 2004).

Site Preparation Effects on Avian Communities

Young pine plantations can host many bird species and generally produce habitat suitable for early successional bird species through at least the first 5 years of growth (Childers et al., 1986; Johnson, 1987; Wigley et al., 2000). Many bird species that use early successional grassland and scrub-shrub habitat types are in nationwide decline due in part to changing land-use practices that often do not incorporate frequent disturbances needed to maintain early successional habitat (Hunter et al., 2001; Brennan and Kuvlesky, 2005). As plantations age, early successional bird species are gradually replaced by those that prefer older, more mature stands. Therefore, stand establishment practices have the potential to indirectly affect bird communities in the short- and long-term by altering distribution of woody debris and understory plant species composition.

Avian diversity is linked to vegetation structural diversity, and the greatest diversity of birds often occurs on sites with the greatest vegetation complexity (MacArthur and MacArthur, 1961; Kilgo et al., 2000). Snags and downed coarse woody debris add important structural components for birds, providing birds with escape cover, nesting substrate, perches, and insect food sources (Hartley, 2002; Lohr et al., 2002). Herbicide treatments often have more structure than mechanical treatments due to the retention of woody debris, and these sites tend to contain a higher abundance of birds. For example, O'Connell and Miller (1994) observed that a chemical treatment had many standing snags while a mechanical treatment had few, and they attributed greater bird diversity in chemical treatments at 2 and 3 years post-treatment to greater vegetation structural diversity in those treatments. However, the effect of site preparation on bird communities was no longer evident by 5 years post-treatment, indicating that differences in habitat structure between mechanical and chemical site preparations are short lived (O'Connell and Miller, 1994).

Removal of snags and coarse woody debris can reduce breeding bird abundance within pine forests. Lohr et al. (2002) observed a 50% reduction of breeding bird abundance and a 40% reduction in bird species richness following complete removal of snags and downed coarse woody debris in 40- to 50-year-old stands. Snag removal reduced abundance of cavity nesters such as red-headed woodpecker (*Melanerpes erythrocephalus*) and great crested flycatcher (*Myiarchus crinitus*), and removal of woody debris reduced abundance of neotropical migrants, secondary cavity nesters, eastern towhees (*Pipilo erythrophthalmus*), great crested flycatchers, and Carolina wrens (*Thyrothorus ludovicianus*). The abundance of standing and fallen woody debris is often the greatest difference between planted and natural forests, and incorporating snag and woody debris retention into pine plantation management could have positive effects on bird communities (Hartley, 2002; Jones et al., 2009c).

Plant species diversity may also be important to bird communities. Santillo et al. (1989b) observed fewer songbirds for 3 years following glyphosate treatment within Maine clearcuts which reduced forb and shrub species richness when compared with untreated clearcuts. However, Miller and Miller (2004) observed no differences in avian diversity and species richness among 3 chemical site-preparation treatments during 4 years post-treatment, indicating that avian communities may respond similarly to a variety of chemical treatments in the southeastern United States. Although Sparling (1996) also noted no differences in breeding bird abundance among different herbicide treatments, she observed that birds used areas with abundant herbaceous plants and woody stems.

Research has clearly demonstrated contributions of intensively managed pine forests to conservation of biological diversity. Controlling competing vegetation through mechanical site preparation and chemical applications allows managers to increase pine production, but also changes habitat conditions for wildlife. Few studies have examined the potential additive effects of combining mechanical and chemical site preparations with additional herbaceous weed control releases, and my research addressed these questions to provide managers with tools to manage for both pine productivity and wildlife habitat.

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CHAPTER 2

PLANT COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA[1]

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ABSTRACT

Intensively managed loblolly pine (*Pinus taeda*) forests are common in the southeastern United States, where combinations of mechanical and chemical site preparation and herbaceous weed control (HWC) treatments are used during stand establishment to manage competing vegetation and increase pine production. However, few long-term studies have described relationships between the intensity of site preparation and effects on plant communities. Understanding potential tradeoffs between increasing pine production and wildlife habitat is important because pine plantations are common and offer conservation opportunities. Therefore, we examined effects of 6 treatments of increasing intensity via combinations of mechanical (wide spacing and strip shear or narrow spacing and roller chop) and chemical (application or no application) site preparation treatments with HWC (broadcast or banded) from 1 to 8 years after site preparation on plant communities in loblolly pine plantations (n = 6) in the Coastal Plain of North Carolina, USA. Mechanical and chemical site preparation techniques had short lived (≤4 yr) effects on grass, vine, and forb percent cover and species richness, but long-term effects on woody plants and pine cover. We observed greatest non-pine woody cover in strip shear/wide spacing treatments in years 1, 3, and 8 following site preparation. Treatments receiving chemical site preparation had lower woody plant cover and richness across all years post-treatment, lower Shannon's H′ and Simpson's D woody diversity for the first 4 years, reduced grass, vine, and forb cover and richness for 2 years post application, and increased pine canopy cover by year 4. Increasing management intensity by including broadcast HWC or roller chop/narrow spacing mechanical site preparation did not result in additive reductions in woody vegetation cover or species richness. However, broadcast HWC reduced grass, vine, and forb cover in the first year post-treatment. Average Morista community similarity values ranged from 0.69-0.89 among

treatments, and plots receiving the same chemical site preparation contained the most similar plant communities. Wide row spacing and banded HWC benefit plant communities within pine plantations. Chemical site preparation can be paired with wide spacing to maximize herbaceous plant growth that may be important for wildlife, particularly in the first few years after site preparation.

INTRODUCTION

Intensively managing pine forests to maximize fiber production is common in the southeastern United States. Pine plantations comprise about 20% of southern forests, and approximately one-third of industrial wood came from planted forests in 2000 (Haynes, 2002; NCSSF, 2005). Social pressures to conserve more forestland for recreational and biodiversity objectives have increased due to growing populations in the South, and many forest products companies have sold large areas of their forests due to global competition, increased land prices due to increasing urbanization, and other financial pressures (NCSSF, 2005; Stein et al. 2005). Because of shifting land use objectives, managers must increase pine productivity on a smaller land base (Wagner et al., 2004). However, tradeoffs may exist between management intensity, timber yields, and conservation of plant and wildlife diversity.

Intensive management through vegetation control can substantially increase timber yields, but can also reduce some aspects of biological diversity (Zutter and Miller, 1998; Borders and Bailey, 2001; Jones et al., 2009b). Various mechanical and chemical treatments are used at stand initiation to reduce competing vegetation and maximize pine growth (Miller et al., 2009). Mechanical site preparation such as chopping, shearing, disking, or bedding controls competing plants, improves the microsite for pine seedlings, and removes obstructions prior to planting (Gent et al., 1986; Glover and Zutter, 1993). Herbicides are often used during site preparation to control woody competition or for release from herbaceous competition during the first growing season. Different herbicides vary in their ability to manipulate plant species, groups, and communities (Boyd et al., 1995; Shepard et al., 2004). Chemically treated sites as compared to mechanically-treated sites can increase wood volume yield gains by 10-150% by reducing competing vegetation, be more economical, provide better herbaceous and woody control, and reduce soil disturbance and compaction (Borders and Bailey 2001; Wagner et al., 2004).

Conservation of plant and animal communities within intensively managed forests is important because plantation forests provide habitat for many species, and because pine forests are a common feature on the landscape (Hartley, 2002; Wigley et al., 2002; Brockerhoff et al., 2008). In addition, sustainable forestry certification programs emphasize the need to manage plant and animal diversity within forest lands (Miller et al., 2009). Managing for biodiversity within intensively managed forests while attempting to meet economic objectives is challenging but increasingly important as remaining rural forests are sold, parcelized, and fragmented (NCSSF, 2005).

Although many studies have examined short-term effects of stand initiation treatments on plants communities, pine growth, and wildlife habitat conditions, few long-term studies describe relationships across a range of intensities of mechanical and chemical site preparation and herbaceous weed control treatments. Because pine plantations can provide habitat for many wildlife species, understanding how site preparation and herbaceous weed control affects plant communities to pine canopy closure is important to managing long-term wildlife habitat within these stands. Therefore, we examined effects of 6 treatments of increasing management intensity on plant communities in loblolly pine (*Pinus taeda*) plantations for 8 years following site preparation.

METHODS

Study Area

We conducted our study on 6 sites managed for loblolly pine (*Pinus taeda*) in the Lower Coastal Plain of North Carolina, USA. Two sites in Craven County were managed by Weyerhaeuser Company and 4 sites in Brunswick County were managed by International Paper, The Nature Conservancy, Resource Management Service, LLC, or North Carolina Wildlife Resources Commission during our study. Two Brunswick County sites were eliminated in 2005 because high pine mortality lowered tree densities below standard forestry practices. In addition, one treatment (narrow spacing, no chemical site preparation, banded herbaceous weed control) was eliminated at one Brunswick County site in 2008 due to high pine mortality. Sites averaged 60.7 ha and were divided into 6 treatment plots of 4.5-12.2 ha each (Mihalco, 2004).

We mechanically (roller-chop or strip shear) or chemically (imazapyr in the form of Chopper™, BASF Corp., Research Triangle Park, North Carolina, at 0.58 L/ha mixed with 11.68 L/ha of oil) prepared in fall 2001−winter 2002 and hand planted with loblolly pine seedlings in late-winter 2002. We planted pines in either narrow (3.0 x 2.4 m) or wide (6.1 x 1.5 m) spacing. We bedded and fertilized all plots with diammonium phosphate (DAP) applied into beds at 280 kg/ha prior to planting. In spring 2002, we applied herbaceous weed control (HWC) with 0.30 L/ha of Arsenal™ (active ingredient imazapyr, BASF Corp., Research Triangle Park, North Carolina) and 0.15 L/ha of Oust™ (active ingredient sulfometuron methyl, E.I. du Pont de Nemours and Company, Inc., Wilmington, Delaware) as either broadcast or 1.5 m bands. We used a randomized complete block design and treatment plots received 1 of 6 treatment combinations that varied in intensity of vegetation control (Table 2.1). Treatment components included mechanical site preparation (strip shear coupled with wide spacing [SSW] or roller-chop coupled with narrow spacing [RCN]), use or lack of chemical site preparation (N = no application, H = application), and banded or broadcast HWC during the first year after planting (Ba = banded, Br = broadcast).

Vegetation Sampling

We sampled vegetation during June-August in 2002-2005 and 2007-2009. Within each treatment plot, we randomly located 10, 30-m line transects. We identified all plants to species or genera depending upon identifiable characteristics. We estimated percent cover of all plant species that intersected these permanent transects on a vertical plane from ground level to canopy by summing intersect lengths by species and dividing by total transect length. We calculated species richness from transect data. We estimated frequency using established 4, 1 m^2 quadrats along each transect (40 per treatment plot). On each transect, we centered 2 quadrats on beds and 2 in the interbed. We randomly located quadrats on each side and 5 m from the transect to avoid trampling vegetation while locating and measuring transects. We calculated frequency of plant occurrence by the presence or absence of a species within a quadrat so that any given species had a maximum frequency of 40 per treatment.

We calculated Shannon's H′ diversity (Shannon and Weaver, 1949), Simpson's D diversity (Simpson, 1949), and Morista community similarity (Spellerberg, 2005) indices using quadrat frequency data. Shannon diversity index values range from 0 where there is no diversity to ~5 for the most diverse communities. Simpson's diversity index ranges from 0-1 with 1 being the most diverse. Shannon's diversity index is strongly influenced by species richness, while Simpson's index gives more weight to common species (Spellerberg, 2005). Although these two indices frequently agree, calculating and examining the results of both increases likelihood that observed differences truly exist and are not a function of each index's slightly different approach

(Boyle et al., 1990). Morista similarity values for comparisons between two communities range from 0-1.0 with 1.0 being most similar. Because our sample sizes were small for some plant groups depending upon year and site, we only report Morista similarity values for the whole plant community.

Statistics

We hypothesized that plant community cover, species richness, diversity, and similarity were inversely related to management intensity. Our main effects included type of mechanical site preparation/spacing, use of chemical site preparation, type of HWC, and we blocked by site. Our response variables included plant cover and richness by taxonomic group, total plant diversity, and Morista Community Similarity Index. Because we were interested in when differences occurred, we examined within-year treatment effects with ANOVA for all parameters. If treatment differed, we used Tukey's means separation tests to identify differences among means. We tested data for normality with the Shapiro-Wilk test. If required, percent cover data were arc-sine square-root transformed and species richness data were log-transformed for analysis (Dowdy et al., 2004: pages 328-333), but we present non-transformed values in results for ease of interpretation.

We examined interactions of chemical site preparation by mechanical site preparation, and chemical site preparation by HWC. We compared vegetation parameters between plots receiving or not receiving chemical site preparation with orthogonal contrasts. Plots receiving different mechanical site preparation and HWC treatments were not orthogonal and were compared with t-tests. We did not include broadcast HWC plots in our mechanical site preparation comparisons or wide spacing plots in our HWC comparisons because these plots were not replicated within all levels of the comparisons. Differences were considered significant at $\alpha = 0.05$.

RESULTS

We identified 40 grass, 62 woody tree and shrub, 18 vine, and 120 forb species or unique genera among all sites, for a total of 240 plant species. Our sites were characterized by a thick understory of switchcane (*Arundinaria gigantea*), broomsedge (*Andropogon virginicus*), and woody shrubs such as white titi (*Cyrilla racemiflora*), fetterbush (*Lyonia lucida*), and pepperbush (*Clethra alnifolia*). Common vines included muscadine (*Vitus rotundifolia*), poison ivy (*Toxicodendron radicans*), greenbrier (*Smilax* spp.), and blackberries (*Rubus* spp.). Forbs such as bracken fern (*Pteridium aqualinum*), meadowbeauties (*Rhexia* spp.), bonesets (*Eupatorium* spp.), goldenrods (S*olidago* spp.), redroot (*Lachnanthes caroliana*), and fireweed (*Erechtites heiracifolia*) were also common, especially in the first 3 years following site preparation.

We detected few interactions of chemical site preparation by spacing or HWC. Therefore, we present results of individual treatment component contrasts (e.g. mechanical site preparation) for within-year analyses.

Effects on Woody Vegetation

Treatments mechanically prepared with strip shear and wide bed spacing (SSW) had greater non-pine woody cover in years 1, 3, and 8 than those prepared via roller chopping and narrow bed spacing (RCN, Table 2.2). Pine cover was greater on RCN treatments in year 8, likely because the RCN treatments had more pines than SSW treatments (approx. 1344 versus 1075 trees/ha).

Non-pine woody percent cover was greater in treatments that did not receive chemical site preparation (Table 2.2). Non-pine woody cover was greatest in the treatment receiving SSW mechanical preparation, no chemical site preparation, and banded HWC treatment (WNBa) and least in the RCN, chemically prepared treatments (NHBa, NHBr, Figure 2.1). By 4 years after site preparation, non-pine woody cover had reached approximately 70% for plots with chemical site preparation and 25% for plots without (Figure 2.2). Conversely, pine cover was greatest in treatments receiving chemical site preparation by year 4 and this difference persisted until our study ended in year 8 (Figure 2.3). We did not detect differences in non-pine woody or pine cover between types of HWC treatments.

Type of mechanical site preparation did not affect woody richness (Table 2.2). As with non-pine woody cover, woody richness was greater in plots not receiving chemical site preparation (Figure 2.2). Woody richness was greatest on the SSW, no chemical site preparation, banded HWC treatment (WNBa) and least on RCN treatments with chemical site preparation (NHBa, NHBr, Figure 2.1). Type of HWC did not affect woody species richness (Table 2.2).

Effects on Herbaceous Vegetation

Low intensity treatments had greater grass, vine, and forb cover than high intensity treatments for up to 2 years following site preparation (Figure 2.1). Treatments with no chemical site preparation and banded HWC (WNBa, NNBa) had greatest grass cover in year 1, and greatest vine cover in years 1-2 (Figure 2.1). The SSW mechanical site preparation treatments had 14% greater grass cover than the RCN treatments in year 1 (Table 2.3). Grass cover was similar between the two mechanical treatments in later years, while vine and forb cover showed no response to mechanical treatments in any year. Chemical site preparation reduced grass, vine, and forb cover in years 1-2 as compared to treatments that received no chemical site preparation (Table 2.3). However, treatments receiving chemical site preparation had greater grass cover in year 4 and forb cover in year 8 than treatments without chemical site preparation (Table 2.3). Broadcast HWC reduced grass, vine, and forb cover by 70, 40, and 44% in year 1, respectively, over banded HWC. By year 2, HWC only affected vine cover; broadcast HWC reduced vine cover by 16% and 30% over banded HWC in years 2 and 3, respectively (Table 2.3).

Differences in grass, vine, forb, and total species richness among treatments also tended to be short-lived, but changed direction over time (Table 2.3). The SSW treatments had more grass species than RCN treatments the first year following site preparation, but fewer forb species in year 3 (Table 2.4). Treatments receiving chemical site preparation had a reduced number of grass and forb species in the first year following treatment, but chemical site preparation increased grass richness by year 7 and forb richness by year 4 when compared to plots not receiving chemical site preparation. Chemical site preparation reduced vine richness in years 1-4 over plots not receiving chemical site preparation. Treatments receiving broadcast HWC had lower grass, vine, and forb species richness versus banded HWC in year 1, but by year 2 treatment differences were no longer consistently apparent. Vine and forb richness were also greater in banded HWC over broadcast HWC in year 4 and 8, respectively, but were similar between HWC types in all other years except year 1.

Species Diversity and Community Similarity

Type of mechanical site preparation did not affect plant diversity in any year. Treatments receiving chemical site preparation when compared with plots not receiving chemical site preparation had lower Shannon H′ and Simpson D woody plant diversity for 4 years following site preparation (Figure 2.4). These plots also had lower forb Shannon H′ diversity in year 1

(0.73 versus 1.04, $F_{1,15}$ = 8.84, P = 0.006), vine Shannon H′ (0.38 versus 0.67, $F_{1,15}$ = 14.60, P <0.001) and vine Simpson D diversity (0.27 versus 0.44, $F_{1,15}$ = 14.60, P = 0.003) in year 2. HWC only affected plant diversity in year 1, when broadcast HWC reduced Shannon H′ forb diversity over banded HWC (0.63 versus 0.96, $F_{1,15}$ = 6.94, P = 0.02).

We detected no differences over time within each Morista community similarity comparison. Therefore, we report overall instead of annual averages for each comparison. Average Morista community similarity values varied from 0.69-0.89 within treatment comparisons among years (Table 2.5). Plots receiving or not receiving chemical site preparation contained more similar plant communities than plots with different chemical preparation. Low to moderate intensity treatments that did not receive chemical site preparation had the most similar plant communities (NNBa x NNBr and WNBa x NNBa). The most dissimilar communities existed between the least intensive treatment (WNBa) and the most intensive treatments (NHBa and NHBr).

DISCUSSION

Effects on Woody Vegetation

Increasing management intensity by changing type of mechanical site preparation or HWC did not significantly impact cover, richness, or diversity of non-pine woody plants beyond effects of the chemical site preparation. Chemical site preparation reduced cover, richness, and diversity of non-pine woody plants and plant community similarity indices when compared to plots not receiving chemical site preparation, and had the most consistent long-term effect on our plant community. Woody cover and richness on chemically prepared plots remained lower than those on plots receiving no chemical site preparation for the duration of our study, and mechanical site preparation and HWC had minor or no impact on woody plant communities. In a mirror study examining the effects of different site preparation techniques for 5 years on vegetation in Mississippi, Jones et al. (2009b) also observed that chemical site preparation primarily affected vegetative communities after the first year, reducing hardwood tree richness for at least 5 years post-treatment over plots receiving mechanical site preparation.

Pine canopy cover was greatest after year 4 on plots receiving chemical site preparation, indicating that pines may have responded favorably to decreased competition from woody species on those plots. Miller et al. (1991) and Borders and Bailey (2001) also reported increased pine growth in response to chemical site preparation. However, Jones (2008) noted a positive relationship between pine cover and increasing management intensity due to release from competing woody and herbaceous plants in Mississippi, while our pine cover apparently responded to woody plant competition altered by the presence or absence of chemical site preparation. Competition from herbaceous vegetation was less prominent in our sites, which were dominated by trees and shrubs typical of North Carolina Coastal Plain pocosins (Richardson, 1983). Therefore, effects of HWC and chemical site preparation may vary depending upon local site conditions and vegetative communities.

Although pine spacing was paired with mechanical site preparation, we observed that pine spacing or mechanical site preparation affected non-pine woody cover in years 1, 3, and 8. While different mechanical site preparation techniques vary in their ability to alter woody plant abundance and diversity (Jobidon, 1990; Fredericksen et al., 1991), we did not observe expected long-term, consistent differences if mechanical site preparation alone had primarily affected woody plant growth. Pearson et al. (1995) noted that tree and shrub canopy cover only differed among site preparation techniques (prescribed burning and selective hardwood removal by herbicide injection versus shear, windrow, and burn) in the first 3 years following site preparation. Therefore, our differences in non-pine woody cover in years 1 and 3 were likely due to the type of mechanical site preparation. However, in young, unthinned pine plantations, sunlight limitations related to pine spacing and canopy closure often limit growth of woody and herbaceous plants (Monk and Gabrielson, 1985), and the differences we observed in non-pine woody cover in year 8 were likely due to differences in pine spacing and not the type of mechanical site preparation.

Deciduous, broad-leaved woody cover for species such as red maple (*Acer rubrum*), devil's walking stick (*Aralia spinosa*), and sweet pepperbush (*Clethra alnifolia*) increased by 24-63% in wide spacing treatments in years 3 and 8, and cover values for other, less common species also increased slightly. Deciduous woody species may have produced fewer leaves in some years perhaps due to variability in precipitation events, which could reduce broadleaf cover to levels where treatment differences were not obvious. In years with adequate precipitation, woody cover was greatest in SSW versus RCN treatments, probably due to greater species diversity in early years and increased sunlight available between wider pine rows in later years.

Although woody species richness differed between plots receiving or not receiving chemical site preparation, no single species was completely excluded by chemical site preparation. Chopper™ targets woody species, although blackberries (*Rubus* spp.) and legumes are resistant (Harper, 2007). Thus, chemical site preparation reduced red maple (*Acer rubrum*), sweet pepperbush, gallberry (*Ilex glabra*), and winged sumac (*Rhus copallinum*) coverage by up to 75% when averaged among years. Woody richness was less in treatments receiving chemical site preparation because species susceptible to the herbicides were not detected in every vegetation transect due to lower abundances.

As expected, type of HWC did not affect woody cover or woody species richness. At the rates applied in our study, herbaceous competition control using Arsenal™ and Oust™ does not further reduce or eliminate woody vegetation, which can provide important structure, cover, and food for a variety of wildlife species (MacArthur and MacArthur, 1961; Warren and Hurst, 1981; Mengak and Guynn, 2003). We also observed no differences in pine cover among banded or broadcast HWC, as has been reported previously (Knowe et al., 1985; Nelson et al., 1985), although effects of broadcast HWC on pine cover may be more distinct in areas with significant herbaceous competition (Jones, 2008). However, increased herbaceous plant richness associated with banded HWC is likely beneficial to many wildlife species, and similar pine yields at maturity may not justify investment in broadcast HWC (Jones, 2008). Therefore, banded HWC appears to be ecologically and economically justified (Blake *et al.*, 1987; Jones *et al.*, 2009a).

Effects on Herbaceous Vegetation

Initial differences among site preparation treatments on herbaceous plant communities were short lived, and grass, vine, and forb cover and richness were similar among treatments by year 4. The initial responses we observed on the herbaceous community were typical to those reported in other studies (Boyd et al., 1995; Miller et al., 1999; Keyser et al., 2003). Early successional, herbaceous plant communities associated with young pine plantations rapidly recover from disturbances, although site preparation techniques can delay maximum abundance of some plant groups and shorten duration of these communities within stands (Miller et al., 1995). Although we observed minor differences among treatments, all treatments within our pine stands contained diverse herbaceous plant communities, especially during the first years following site preparation.

Grass and forb cover and richness were reduced with chemical site preparation in the first 1-2 years following site preparation compared to plots without chemical site preparation. However, in later years grasses and forbs increased in plots receiving chemical site preparation. Although the increase in grass and forb cover and richness in plots with chemical site preparation in later years was statistically significant, error bars overlapped by as much as 56%, indicating variability in this trend. While chemical site preparation may increase grass and forb cover and richness in later years by reducing competing woody vegetation as observed by Miller et al. (1995), benefits to wildlife may be minor if abundance of grasses and forbs is limited due to a closed pine canopy in unthinned plots. Herbaceous growth is important for a variety of wildlife in young pine plantations, such as northern bobwhite (*Colinus virginianus*) and small mammals (Atkeson and Johnson, 1979; Welch et al., 2004). Thus, when using chemical site preparation, managers should weigh the potential impacts on grasses, vines, and forbs that are important to wildlife with potential improvements in pine productivity.

Broadcast HWC reduced grasses, vines, and forbs in the first year following treatment when compared to banded HWC. Because we observed no differences in pine cover among sites receiving broadcast versus banded HWC in any year following site preparation, banded HWC appeared to sufficiently control competing herbaceous vegetation around seedlings at our sites. Banded HWC also increase wildlife food plant availability over broadcast HWC, particularly in the first few years after site preparation (Blake et al., 1987), and provide similar pine growth as broadcast HWC (Lauer et al., 1993). However, Jones (2008) observed increased pine cover, height, and diameter in treatments with broadcast HWC in his mirror study in Mississippi, and although his financial analysis indicated that pine growth and yield projections did not justify more intensive treatments with broadcast HWC, herbaceous plant competition may be more important to pine growth in other areas than in shrub-dominated pocosins found in the Coastal Plain of North Carolina. Banded HWC may be appropriate in pocosins if managers wish to support a more diverse plant community while controlling herbaceous vegetation, but may not be as effective at increasing pine production as broadcast HWC in areas with greater herbaceous plant competition. Managers should consider investment costs of site preparation techniques versus potential returns during harvest, and while more intensive treatments can increase pine yields, lower intensity treatments may provide a greater or equal return on investment depending upon site conditions and local plant communities (Jones, 2008).

Although we found few differences in herbaceous communities among treatments after the first few years following site preparation, a few species were noticeably impacted by chemical site preparation. Switchcane, Virginia creeper (*Parthenocissus quinquefolia*), poison ivy (*Toxicodendron radicans*), muscadine (*Vitis rotundifolia*), and pokeweed (*Phytolacca americana*) percent cover was greatly reduced by chemical site preparation. Although these species provide important soft mast crops for wildlife (Warren and Hurst, 1981), blackberries and other important herbaceous wildlife foods are resistant to chemical control, and imazapyr is frequently used during site preparation to enhance wildlife habitat (Welch et al., 2004). Herbicides vary in their ability to target different plant species, and managers should carefully select herbicides depending upon soil conditions, local plant communities, and wildlife management objectives (Wigley et al., 2002).

Species Diversity and Community Similarity

The various site preparation treatments had short-term effects (≤4 years) on plant species diversity. In Georgia, Miller et al. (1999) observed that chemical site preparation had little effect on plant diversity 11 years following application, and Miller and Chapman (1995) found few treatment differences among 3 chemical site preparation treatments after year 5. However, in Mississippi, Jones et al. (2009b) observed that intensive site preparation treatments (mechanical and chemical site preparation with banded or broadcast HWC) reduced species diversity when compared to lower intensity treatments through 5 years post-treatment. Chemical site preparation had the greatest influence on our plant communities, and our similarity indices primarily reflected changes in woody species richness and abundance. Jones et al. (2009b) also noted that plant communities were most similar among treatments receiving similar site preparation. Therefore, long-term community structure seems primarily driven by presence or absence of chemical site preparation due to impacts on woody species.

CONCLUSION

We found relatively minor vegetation responses to treatments, other than effects of chemical site preparation on woody vegetation. Lower intensity treatments contained greater plant cover and a more diverse plant community in the first few years after site preparation than high intensity treatments. The type of mechanical site preparation had little effect on plant cover, richness, and diversity. Woody plant cover and richness were reduced by chemical site preparation, and these reductions persisted for the duration of our study. Increasing management intensity through the addition of RCN or broadcast HWC did not have additive reductions in woody cover and richness. Broadcast HWC had short-term reductions in herbaceous cover as compared to banded HWC. Although increasing pine growth is a goal of intensive pine management, treatments that encourage establishment of herbaceous vegetation and increase vegetation structure may improve early successional habitat important to small mammal, bird, and other wildlife communities (Atkeson and Johnson, 1979; Langley and Shure, 1980; Childers et al., 1986). While increasing management intensity may increase pine growth and yields depending upon site conditions and local plant communities, return on investment may be greater or equal to lower intensity treatments due to lower initial costs (Jones, 2008). In our study, our mid-intensity treatments (WHBa and NNBa) appeared to provide the best compromise between plant cover, richness, and diversity and pine cover. If chemical site preparation is necessary to reduce competing woody vegetation, pairing chemical site preparation with wide pine spacing and banded HWC may provide greater herbaceous plant coverage in the first few years after site preparation if plant species diversity is a concern. Although we observed differences among site preparation techniques, all treatments resulted in abundant and diverse plant communities within our pine plantations. Site preparation techniques allow managers to alter plant communities to meet pine production and wildlife management goals, and should be tailored to local site conditions and management objectives.

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Table 2.1. Treatments used to evaluate plant community responses to combinations of chemical and mechanical site preparation techniques in the Coastal Plain of North Carolina, 2002-05, 2007-09.

Intensity	Treatment	Abbrev.[a]	MSP[b]	CSP[bc]	Year 1 HWC[d]	Bed Spacing
Low	1	WNBa	Strip Shear	No	Banded	Wide (6.1 x 1.5 m)
	2	WHBa	Strip Shear	Yes	Banded	Wide (6.1 x 1.5 m)
	3	NNBa	Chop	No	Banded	Narrow (3.0 x 2.4 m)
	4	NNBr	Chop	No	Broadcast	Narrow (3.0 x 2.4 m)
	5	NHBa	Chop	Yes	Banded	Narrow (3.0 x 2.4 m)
High	6	NHBr	Chop	Yes	Broadcast	Narrow (3.0 x 2.4 m)

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC
[b] MSP = mechanical site preparation; CSP = chemical site preparation
[c] Chopper™ (0.58 L/ha mixed with 11.68 L/ha of oil)
[d] HWC = herbaceous weed control, Arsenal™ (0.30 L/ha) and Oust™ (0.15 L/ha)

Table 2.2. Pine percent cover, non-pine woody percent cover, and woody species richness means, standard errors, and contrast results for individual treatment component comparisons. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) loblolly pine plantations in the Coastal Plain of North Carolina.

		Mechanical Site Preparation[a]						Chemical Site Preparation						Herbaceous Weed Control					
		RCN[b]		SSW				No		Yes				Banded		Broadcast			
Type	Yr	Mean	SE	Mean	SE	*F*	*P*[c]	Mean	SE	Mean	SE	*F*	*P*	Mean	SE	Mean	SE	*F*	*P*
Pine	1	0.5	0.2	0.9	0.4	0.72	0.41	0.9	0.4	0.5	0.2	0.15	0.71	0.5	0.2	0.04	0.1	0.03	0.87
Cover	2	1.6	0.4	1.7	0.5	0.04	0.84	1.6	0.6	1.5	0.5	0.15	0.70	1.6	0.4	1.1	0.3	1.15	0.30
	3	14.0	1.9	16.0	4.6	0.03	0.88	12.2	2.3	15.1	5.7	1.42	0.25	14.0	1.9	14.7	2.4	0.00	0.98
	4	25.1	3.4	26.6	4.1	0.10	0.76	19.4	4.8	32.1	4.3	14.24	0.001	25.1	3.4	29.2	4.1	1.17	0.31
	6	56.6	7.4	52.4	7.1	0.40	0.54	45.9	8.2	64.1	8.9	14.64	0.001	56.6	7.4	56.1	6.7	0.00	0.98
	7	67.0	3.5	64.1	6.0	0.95	0.36	58.9	7.9	72.9	6.3	10.84	0.005	67.0	3.5	67.6	6.2	0.04	0.85
	8	85.1	4.2	72.6	6.2	11.96	0.009	73.0	8.0	86.6	6.6	9.39	0.008	85.1	4.2	83.3	4.8	0.00	0.94
Non-pine Woody	1	5.4	1.6	10.9	3.1	15.99	0.001	11.6	3.5	1.6	0.7	88.65	<0.001	5.4	1.6	3.6	1.4	2.26	0.15
Cover	2	23.1	7.3	29.2	6.5	3.19	0.10	39.4	10.5	9.6	1.9	52.05	<0.001	23.1	7.3	21.2	7.1	0.00	0.97
	3	27.3	9.9	36.9	8.5	6.53	0.03	43.7	11.4	13.2	5.4	62.04	<0.001	27.3	9.9	21.0	6.3	1.17	0.31
	4	44.5	18.0	49.8	13.9	0.59	0.46	68.0	21.3	22.8	8.4	34.68	<0.001	44.5	18.0	41.8	10.5	0.03	0.87
	6	43.9	13.8	48.0	9.8	1.26	0.29	67.3	15.3	23.7	8.8	74.28	<0.001	43.9	13.8	44.5	12.7	0.04	0.84
	7	39.0	12.0	53.8	12.8	2.45	0.16	68.1	20.4	27.2	9.6	54.37	<0.001	39.0	12.0	46.4	13.5	0.09	0.77
	8	35.9	11.5	60.5	11.2	6.86	0.03	72.5	19.5	30.2	10.0	49.35	<0.001	35.9	11.5	53.0	14.2	2.54	0.15
Non-pine Woody	1	2.8	0.7	3.6	0.5	3.24	0.09	4.2	0.8	1.5	0.3	58.01	<0.001	2.8	0.7	2.2	0.5	1.29	0.27
Richness	2	4.2	0.7	4.7	0.6	0.88	0.36	5.5	0.7	2.9	0.4	54.17	<0.001	4.2	0.7	3.7	0.4	1.59	0.23
	3	4.7	0.8	5.0	0.5	0.98	0.35	5.8	0.7	3.3	0.6	64.63	<0.001	4.7	0.8	4.1	0.6	1.39	0.27
	4	5.6	0.6	6.1	0.8	0.76	0.41	6.7	0.7	4.7	0.7	24.44	<0.001	5.6	0.6	5.3	0.5	0.25	0.63
	6	5.5	0.6	6.4	0.9	1.73	0.22	6.9	0.9	4.8	0.8	21.17	<0.001	5.5	0.6	5.6	0.7	0.08	0.79
	7	5.7	0.8	6.4	1.0	1.78	0.22	7.0	1.3	4.9	0.8	28.24	<0.001	5.7	0.8	5.5	0.7	0.24	0.64
	8	5.9	0.8	6.7	0.9	2.22	0.18	7.3	1.3	5.5	0.8	22.83	<0.001	5.9	0.8	6.4	0.7	1.45	0.26

[a] Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.
[b] RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.
[c] Df: year = 6, site = 5 (2002-2004) or 3 (2005, 2007-2009), comparison = 1, interaction = 1, error 15 (2002-03), 10 (2004), 9 (2005, 07), or 8 (2008-09).

Table 2.3. Herbaceous vegetation percent cover means, standard errors, and contrast results for individual treatment component comparisons. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) loblolly pine plantations in the Coastal Plain of North Carolina.

		Mechanical Site Preparation[a]						Chemical Site Preparation						Herbaceous Weed Control					
		RCN[b]		SSW				No		Yes				Banded		Broadcast			
Type	Yr	Mean	SE	Mean	SE	*F*	*P*[c]	Mean	SE	Mean	SE	*F*	*P*	Mean	SE	Mean	SE	*F*	*P*
Grass	1	19.5	7.3	26.3	7.0	9.96	0.007	24.4	10.6	8.5	6.1	31.63	<0.001	19.5	7.3	3.5	2.1	14.28	0.002
Cover	2	57.1	11.5	53.3	9.9	0.12	0.74	58.7	15.5	46.9	14.3	5.98	0.02	57.1	11.5	48.0	10.9	1.60	0.23
	3	61.6	7.4	67.3	9.1	0.23	0.65	61.3	13.7	65.5	11.1	0.53	0.48	61.6	7.4	60.8	10.3	0.05	0.83
	4	93.7	19.0	90.3	15.5	0.00	0.95	87.4	27.8	103.5	23.1	6.87	0.02	93.7	19.0	102.2	21.0	0.99	0.35
	6	30.2	10.6	30.0	8.2	0.32	0.59	34.8	16.4	27.0	8.9	0.33	0.57	30.2	10.6	32.5	10.1	0.41	0.54
	7	22.4	7.1	21.2	5.5	0.20	0.67	23.0	11.4	19.3	6.9	0.20	0.66	22.4	7.1	19.8	6.3	0.00	0.97
	8	12.2	5.2	14.5	3.9	1.69	0.23	17.9	9.8	9.6	4.0	1.18	0.30	12.2	5.2	13.9	5.9	0.47	0.51
Vine	1[d]	2.3	0.8	3.4	0.9	3.66	0.08	3.3	1.2	1.2	0.8	36.06	<0.001	2.3	0.8	1.0	0.3	9.82	0.007
Cover	2[d]	13.9	3.0	13.0	2.6	0.15	0.70	15.6	4.3	9.1	3.7	22.59	<0.001	13.9	3.0	10.2	3.4	4.88	0.04
	3	30.5	5.6	29.0	7.0	0.26	0.62	28.9	9.3	21.0	6.1	3.38	0.08	30.5	5.6	16.5	3.9	5.37	0.04
	4	53.3	12.0	55.3	16.0	0.21	0.66	58.2	23.2	36.4	10.7	3.77	0.07	53.3	12.0	33.4	11.1	4.48	0.06
	6	25.2	7.0	29.7	9.7	0.21	0.65	28.4	13.6	19.8	6.4	2.07	0.17	25.2	7.0	17.4	5.6	2.89	0.12
	7	20.7	5.3	24.4	8.2	0.60	0.46	26.2	12.7	14.3	4.2	4.20	0.06	20.7	5.3	14.9	4.5	1.23	0.30
	8	24.5	8.9	20.4	7.1	0.05	0.84	27.6	14.4	12.9	3.6	5.93	0.03	24.5	8.9	15.6	5.3	1.70	0.23
Forb	1	11.3	4.8	12.9	4.0	1.57	0.23	12.8	6.4	6.4	4.1	36.06	<0.001	11.3	4.8	4.5	2.0	5.10	0.04
Cover	2	32.1	8.3	27.1	4.7	0.00	0.95	30.8	10.1	27.0	9.6	22.59	<0.001	32.1	8.3	27.6	7.7	0.76	0.40
	3	30.9	3.4	28.7	4.9	0.04	0.84	26.0	5.9	33.3	6.1	3.38	0.08	30.9	3.4	29.6	5.0	0.13	0.73
	4	38.1	8.6	33.6	11.8	0.69	0.43	27.6	11.5	43.7	12.0	3.77	0.07	38.1	8.6	35.3	5.5	0.00	0.98
	6	12.3	4.2	12.2	6.3	0.94	0.36	10.2	6.4	13.9	7.3	2.07	0.17	12.3	4.2	11.5	4.3	0.14	0.72
	7	9.6	4.6	9.0	5.4	1.41	0.27	7.2	6.2	10.9	7.3	4.20	0.06	9.6	4.6	8.7	4.2	0.35	0.57
	8	13.2	7.8	11.4	6.8	1.26	0.29	9.6	8.9	15.2	10.8	5.93	0.03	13.2	7.8	13.1	6.8	0.09	0.78

[a] Mechanical site preparation and herbaceous weed control (HWC) treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.
[b] RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.
[c] Df: year = 6, site = 5 (2002-2004) or 3 (2005, 2007-2009), comparison = 1, interaction = 1, error 15 (2002-03), 10 (2004), 9 (2005, 07), or 8 (2008-09).
[d] Significant chemical site preparation by HWC interaction (narrow spacing only).

Table 2.4. Herbaceous vegetation species richness means, standard errors, and contrast results for individual treatment component comparisons. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) loblolly pine plantations in the Coastal Plain of North Carolina.

		Mechanical Site Prep. and Spacing[ab]						Chemical Site Preparation						Herbaceous Weed Control					
		RCN[c]		SSW				No		Yes				Banded		Broadcast			
Type	Yr	Mean	SE	Mean	SE	*F*	*P*[d]	Mean	SE	Mean	SE	*F*	*P*	Mean	SE	Mean	SE	*F*	*P*
Grass	1	2.1	0.5	2.8	0.5	4.90	0.04	2.4	0.8	1.6	0.6	7.93	0.009	2.1	0.5	1.0	0.3	14.88	0.002
Richness	2	3.1	0.3	3.0	0.3	0.90	0.90	3.1	0.4	3.0	0.4	0.41	0.53	3.1	0.3	3.0	0.3	0.20	0.66
	3	4.9	0.8	3.9	0.7	0.19	0.19	4.2	0.9	4.5	1.0	0.51	0.48	4.9	0.8	4.4	0.7	0.08	0.79
	4	6.5	1.3	6.4	1.1	0.90	0.90	5.8	1.5	6.9	1.6	4.34	0.06	6.5	1.3	6.1	1.1	0.70	0.43
	6	2.7	0.5	2.8	0.5	0.74	0.74	2.6	0.7	3.0	0.6	1.64	0.22	2.7	0.5	2.8	0.4	0.23	0.64
	7	3.2	0.7	3.1	0.7	0.72	0.72	2.8	1.0	3.4	0.9	8.22	0.01	3.2	0.7	3.1	0.6	0.44	0.53
	8	2.9	0.7	2.5	0.6	0.82	0.82	2.4	1.0	2.8	0.8	6.05	0.03	2.9	0.7	2.5	0.6	0.01	0.94
Vine	1	1.0	0.2	1.3	0.2	1.80	0.20	1.4	0.3	0.6	0.2	28.10	<0.001	1.0	0.2	0.7	0.1	8.02	0.01
Richness	2	1.6	0.2	2.0	0.3	2.30	0.15	2.0	0.4	1.3	0.3	18.19	<0.001	1.6	0.2	1.4	0.3	1.70	0.21
	3	2.3	0.4	2.2	0.4	0.01	0.91	2.4	0.7	1.8	0.3	5.31	0.03	2.3	0.4	1.7	0.4	1.32	0.28
	4	3.7	0.6	3.8	0.8	0.02	0.88	3.8	1.1	3.0	0.7	4.94	0.04	3.7	0.6	2.9	0.6	6.54	0.03
	6	3.0	0.4	3.6	0.5	3.12	0.11	3.3	0.8	3.1	0.6	0.84	0.37	3.0	0.4	3.0	0.6	0.03	0.87
	7	3.4	0.4	3.5	0.5	1.80	0.22	3.7	0.8	3.1	0.6	3.39	0.09	3.4	0.4	3.2	0.5	0.01	0.93
	8	3.5	0.4	3.5	0.5	0.39	0.55	3.6	0.8	3.0	0.6	2.36	0.15	3.5	0.4	3.0	0.5	0.32	0.59
Forb	1	2.8	0.9	3.5	1.1	3.71	0.07	2.9	1.3	2.2	1.2	11.78	0.002	2.8	0.9	1.4	0.4	12.56	0.003
Richness	2	5.2	1.2	5.0	1.1	0.01	0.92	5.2	1.6	4.7	1.5	0.94	0.34	5.2	1.2	4.5	1.0	1.40	0.26
	3	4.9	0.7	3.6	0.7	5.81	0.04	4.0	1.0	4.3	0.8	1.55	0.23	4.9	0.7	4.1	0.6	1.00	0.34
	4	7.1	1.6	5.3	1.3	2.78	0.13	5.7	2.1	6.5	1.8	4.83	0.04	7.1	1.6	5.9	1.3	0.83	0.39
	6	3.5	0.9	4.1	1.4	0.00	0.99	3.2	1.5	4.2	1.6	5.75	0.03	3.5	0.9	3.5	1.0	0.01	0.94
	7	2.8	1.1	2.9	1.3	0.26	0.63	2.4	1.7	2.7	1.3	2.90	0.11	2.8	1.1	2.1	0.7	1.35	0.28
	8	2.9	0.9	2.8	1.3	1.08	0.33	2.3	1.8	2.7	1.1	6.33	0.03	2.9	0.9	1.9	0.6	9.34	0.02

[a] Mechanical site preparation and spacing treatments were paired.
[b] Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.
[c] RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.
[d] Df: year = 6, site = 5 (2002-2004) or 3 (2005, 2007-2009), comparison = 1, interaction = 1, error 15 (2002-03), 10 (2004), 9 (2005, 07), or 8 (2008-09).

Table 2.5. Total plant Morista community similarity comparisons and standard errors in descending order by overall average for industrial pine plantation treatments in the Coastal Plain of North Carolina, from 2002-05 and 2007-09.

	Average	
Comparison[a]	Mean	SE
NNBa x NNBr	0.89	0.02
WNBa x NNBa	0.89	0.02
NHBa x NHBr	0.86	0.02
WNBa x NNBr	0.85	0.02
WHBa x NHBa	0.80	0.03
NNBr x NHBr	0.78	0.02
WNBa x WHBa	0.77	0.01
WHBa x NHBr	0.77	0.03
WHBa x NNBr	0.76	0.02
NNBr x NHBa	0.74	0.03
WHBa x NNBa	0.74	0.03
NNBa x NHBa	0.73	0.02
NNBa x NHBr	0.71	0.02
WNBa x NHBa	0.69	0.03
WNBa x NHBr	0.69	0.03

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Morista community similarity values range from 0-1, where 1=most similar.

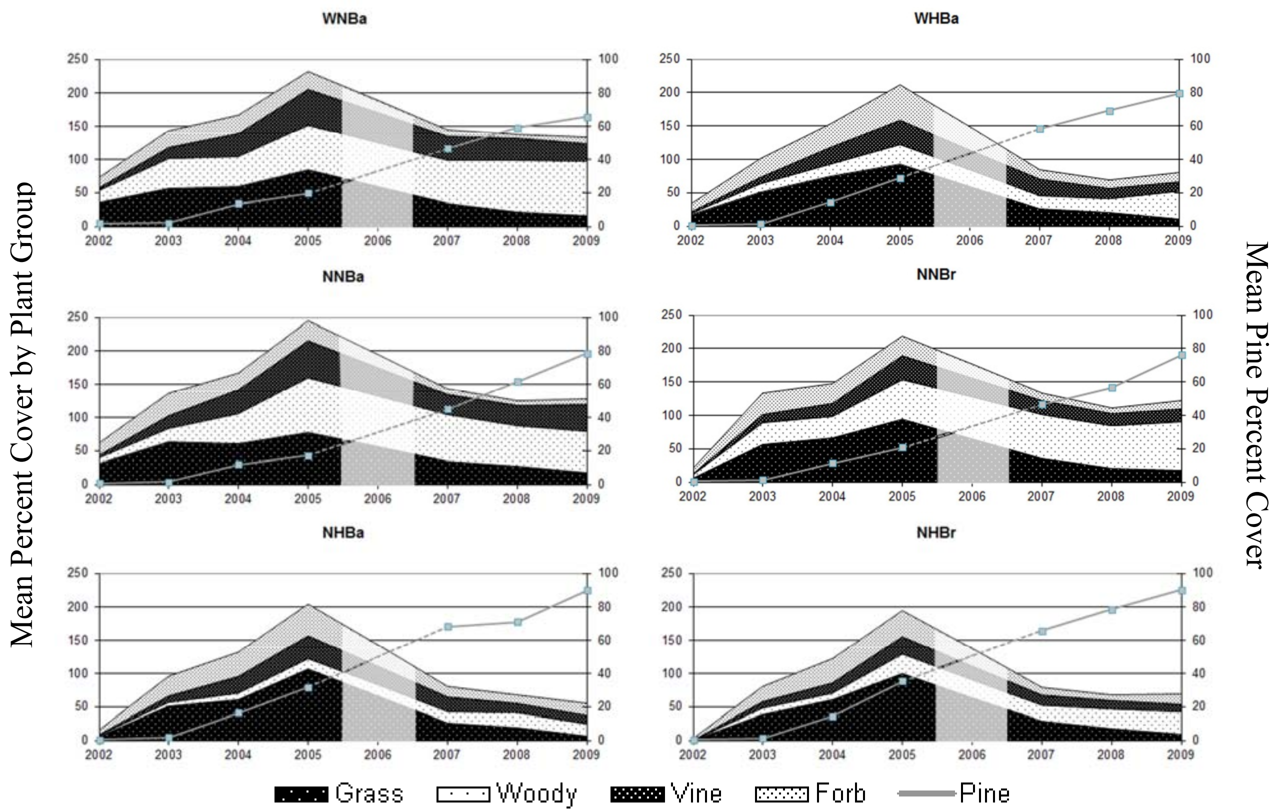

Figure 2.1. Mean grass, non-pine woody, vine, forb, and pine percent cover by year and treatment in the Coastal Plain of North Carolina. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina. Shaded areas represent missing data. Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC.

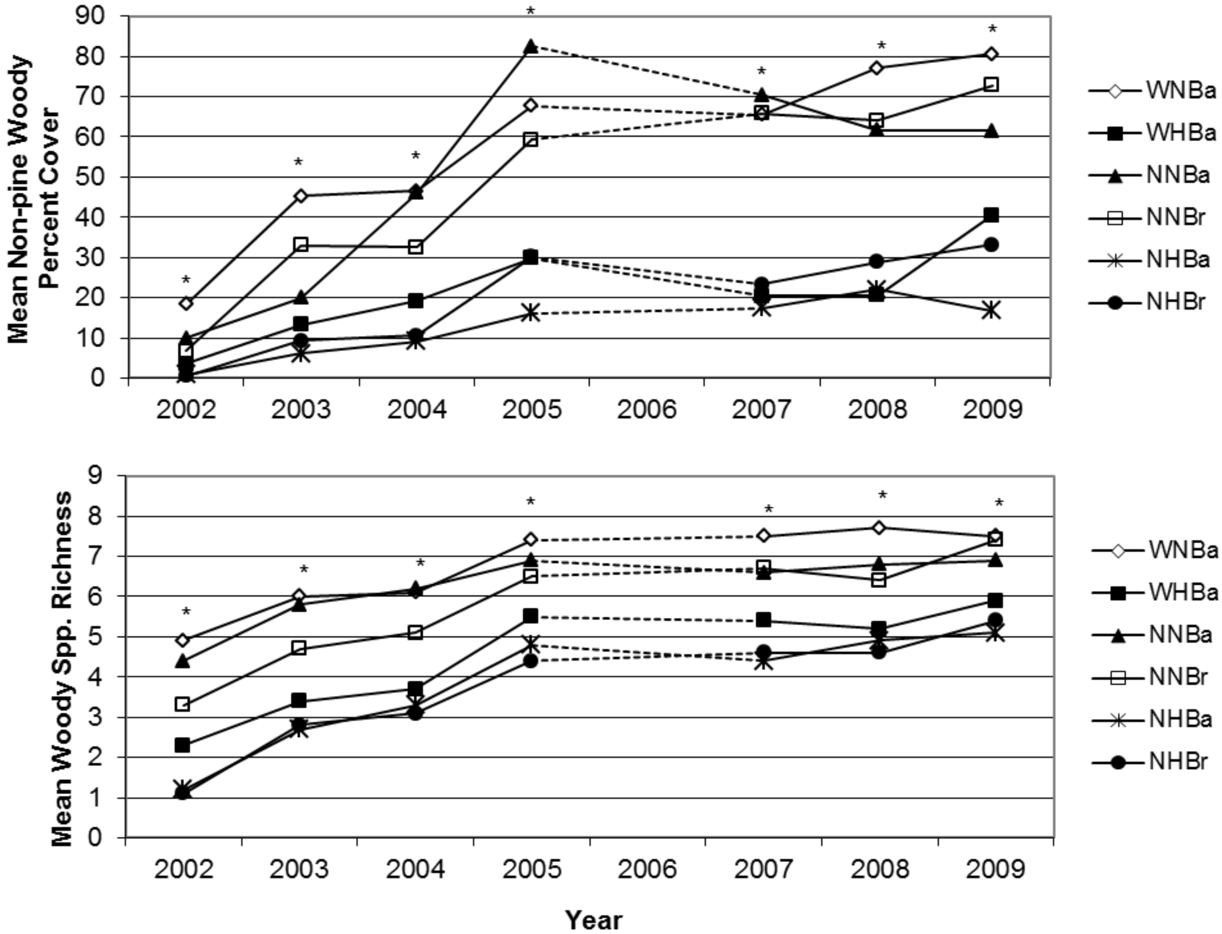

Figure 2.2. Mean non-pine woody percent cover and species richness by treatment among years on industrial loblolly pine forests in the Coastal Plain of North Carolina. Data were not recorded in 2006. Asterisks denote differences among treatments within a year ($P \leq 0.05$). Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC.

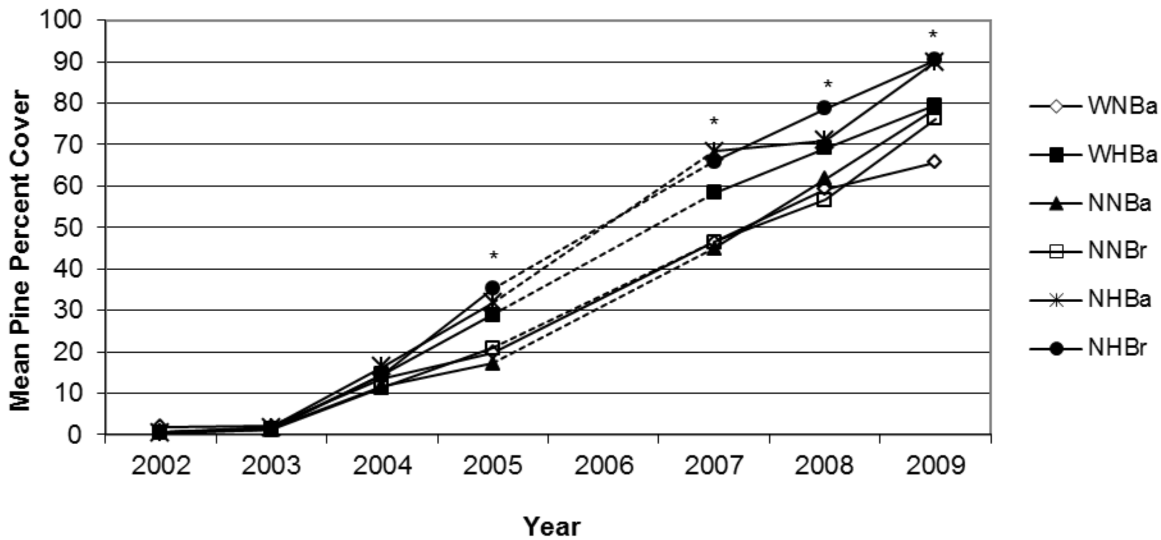

Figure 2.3. Mean pine percent cover by treatment among years on industrial loblolly pine forests in the Coastal Plain of North Carolina. Data were not recorded in 2006. Asterisks denote differences among treatments within a year ($P \leq 0.05$). Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC.

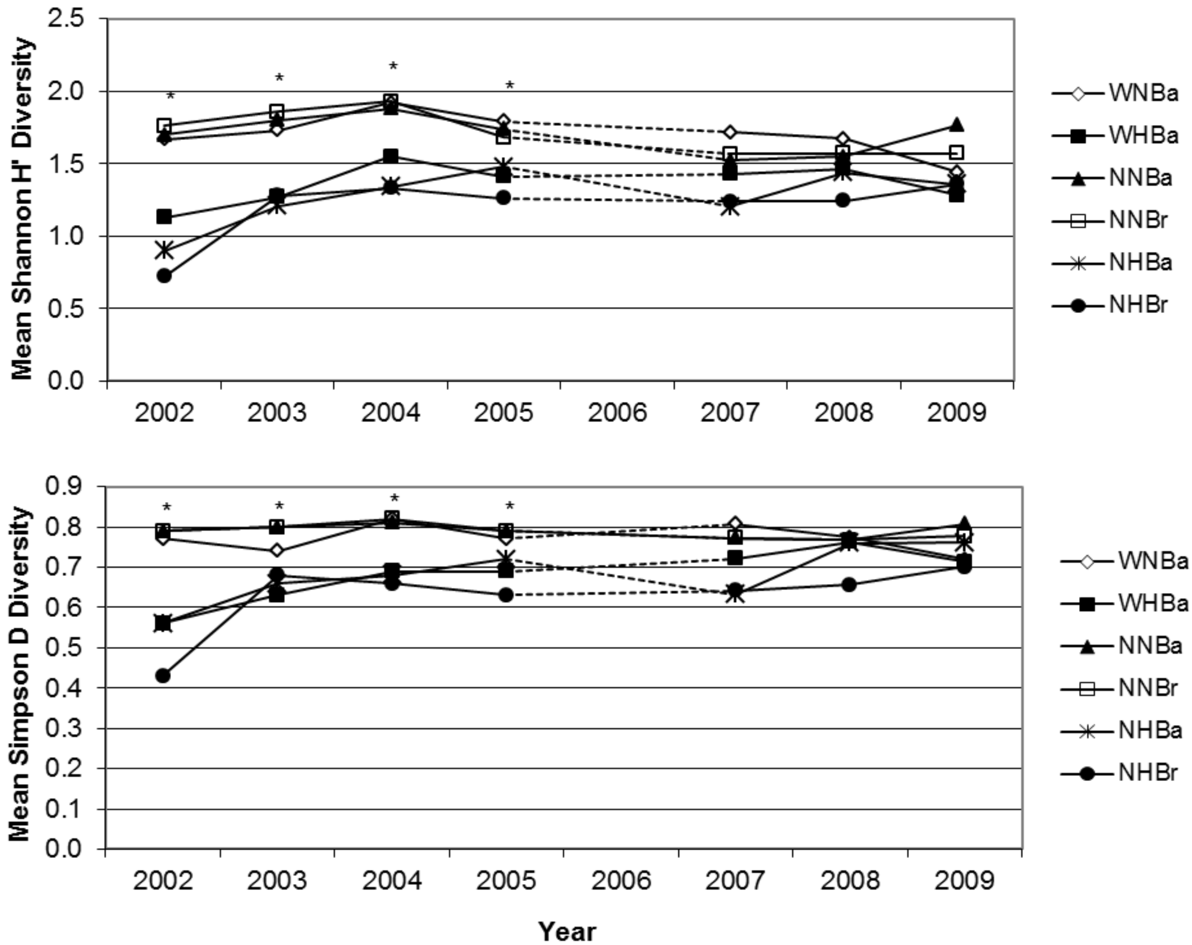

Figure 2.4. Mean Shannon H′ and Simpson D diversity indices for woody plant species by treatment among years on industrial loblolly pine forests in the Coastal Plain of North Carolina. Data were not recorded in 2006. Asterisks denote differences among treatments within a year ($P \leq 0.05$). Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC.

CHAPTER 3

SMALL MAMMAL COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA[2]

[2] Lane, V.R., K.V. Miller, S.B. Castleberry, D.A. Miller, T.B. Wigley, and R.A. Mihalco. To be submitted to *Forest Ecology and Management.*

ABSTRACT

Small mammal communities are an important consideration in sustainable management of pine plantations in the southeastern United States. Few studies, however, describe how combinations of mechanical and chemical site preparation and herbaceous weed control (HWC) techniques in pine plantations affect pocosin small mammal communities. We examined effects of 6 treatments of increasing intensity via combinations of mechanical (strip-shear and wide spacing or roller chop and narrow spacing) and chemical (application or no application) site preparation treatments with banded or broadcast HWC on small mammal communities in 6 loblolly pine (*Pinus taeda*) plantations in the Coastal Plain of North Carolina, USA, for 7 years following site preparation. We removal trapped for 36,000 trap-nights and captured 3,795 small mammals during 2002-06 and 2008. Site preparation techniques had short-term (1-2 year) effects on small mammal abundance, species richness, and diversity, although the timing and magnitude of these effects varied by species. Small mammal capture rates, richness, and diversity were greater in strip-shear plots than chopped plots for 2 years following site preparation, were less in plots receiving chemical site preparation than plots without chemical site preparation for 1-2 years, and were greater on banded HWC than broadcast HWC for 1 year following application. Eastern harvest mice (*Reithrodontomys humulis*) were most abundant in a strip-shear treatment with no chemical site preparation before HWC was applied, and were most abundant in plots with no chemical site preparation and banded herbaceous HWC 1 year post-HWC. House mice (*Mus musculus*) and hispid cotton rats (*Sigmodon hispidus*) were more abundant in plots with no chemical site preparation and banded HWC in 1 year post-HWC, and cotton rats were also most abundant in these plots 2 years post-HWC. Deer mice (*Peromyscus* spp.) were most common in our most intensive treatment 2 years post-HWC. Golden mice

(*Ochrotomys nuttalli*) first appeared 3 years following site preparation (2 years post-HWC), and were most abundant in treatments with no chemical site preparation. Intensity of site preparation did not exclude any species, affected diversity through changes in relative abundance and timing of colonization, and had minor and short-term impacts on small mammal communities.

INTRODUCTION

Recently harvested pine stands provide early successional or edge habitats used by many small mammal species (Kirkland, 1990; Mitchell et al. 1995; Constantine et al., 2004). After harvest, newly planted pine plantations commonly receive one or more mechanical and chemical site preparation treatments paired with herbaceous weed control (HWC) to reduce competing vegetation and increase pine production (Shepard et al., 2004; Miller et al., 2009). Stand establishment techniques can affect small mammal populations in a variety of ways, but typically by altering the structure and composition of plant communities (Langley and Shure, 1980). Mechanical site preparation physically reduces vegetation, and can affect the structure and amount of residual coarse woody debris important to several small mammal species (Jones et al., 2009b). Chemical site preparation and HWC can affect small mammal populations through changes in plant community richness, diversity, structure, and succession due to herbicide specificity (Wigley et al., 2001; Miller and Miller, 2004). Increased management intensity through combinations of mechanical and chemical treatments can substantially increase pine growth and yields (Borders and Bailey, 2001), but rapid pine canopy closure associated with increased pine growth can reduce the duration of early successional habitat important to many small mammal species (Atkeson and Johnson, 1979).

Few studies have examined relationships among combinations of mechanical and chemical site preparation treatments and HWC on small mammal communities in the Southeast (Miller and Chapman, 1995; Edwards, 2004). Although specific site preparation techniques have short-lived effects on small mammal populations (Langley and Shure, 1980; Sparling, 1996), understanding the scope of those effects and when they occur as related to increasing intensity of site preparation is important to understanding small mammal community dynamics in intensively managed, even-aged pine stands.

Responses of small mammal communities to pine management techniques in pocosins are relatively unknown. Pocosins are freshwater wetlands with poorly drained soils and dense stands of evergreen and deciduous vines and shrubs that are common in the Lower Coastal Plain of North Carolina. Many pocosins are now managed for agricultural or forestry uses (Richardson, 1983). Small mammal communities in undisturbed pocosins generally exhibit low densities but high regional diversity (Clark et al., 1985). Although Clark et al. (1985) noted that small mammal densities and diversity increased with natural or man-made openings due to increased plant diversity associated with early successional habitat, Mitchell et al. (1995) hypothesized that some small mammal species associated with pocosins may decline or temporarily disappear following management-related disturbance. However, Mitchell et al. (1995) also hypothesized that small mammal communities may be similar between undisturbed and managed pocosin where structure was similar.

Understanding how small mammal species respond to forest management techniques within different habitat types is important to maintaining small mammal diversity, and can help meet biodiversity objectives encouraged by sustainable forestry programs. In addition, few long-term studies have examined how site preparation techniques affect small mammal communities within the same stands from site preparation to canopy closure, and potential effects on colonization by late-successional small mammal species found within pocosins are not understood. Therefore, we examined effects of 6 treatments of increasing management intensity on small mammal communities in intensively managed loblolly pine plantations in pocosins within the Coastal Plain of North Carolina for 7 years following site preparation. We tested effects of mechanical site preparation, pine spacing, chemical site preparation, and 1 year HWC (banded versus broadcast) on small mammal abundance, species richness, and diversity, and examined how these techniques affected small mammal succession within pocosins.

METHODS

Study Area

We conducted our study on 6 sites managed intensively for loblolly pine (*Pinus taeda*) in the Lower Coastal Plain of North Carolina, USA. Two sites in Craven County were managed by Weyerhaeuser Company and 4 sites in Brunswick County were managed by International Paper, The Nature Conservancy, Resource Management Service, LLC, or North Carolina Wildlife Resources Commission during our study. Two Brunswick County sites were dropped in 2005 because high pine mortality lowered tree densities below standard forestry practices. In addition, one treatment (narrow spacing, no chemical site preparation, banded HWC) was dropped at one Brunswick County site in 2008 due to high pine mortality. Sites averaged 60.7 ha and were divided into 6 treatment plots 4.5-12.2 ha each (Mihalco, 2004) .

We mechanically (roller-chop or strip shear) or chemically (imazapyr in the form of Chopper™, BASF Corp., Research Triangle Park, North Carolina, at 0.58 L/ha mixed with 11.68 L/ha of oil) prepared in fall 2001−winter 2002 and hand planted with loblolly pine seedlings in late-winter 2002. We planted pines in either narrow (3.0 x 2.4 m) or wide (6.1 x 1.5 m) spacing.

We bedded and fertilized all plots with diammonium phosphate (DAP) applied into beds at 280 kg/ha prior to planting. In spring 2002, we applied herbaceous weed control (HWC) with 0.30 L/ha of Arsenal™ (active ingredient imazapyr, BASF Corp., Research Triangle Park, North Carolina) and 0.15 L/ha of Oust™ (active ingredient sulfometuron methyl, E.I. du Pont de Nemours and Company, Inc., Wilmington, Delaware) as either broadcast or 1.5 m bands. We used a randomized complete block design and treatment plots received 1 of 6 treatment combinations that varied in intensity of vegetation control (Table 3.1). Treatment components included mechanical site preparation (strip shear coupled with wide spacing [SSW] or roller-chop coupled with narrow spacing [RCN]), use or lack of chemical site preparation (N = no application, H = application), and banded or broadcast HWC during the first year after planting (Ba = banded, Br = broadcast).

Small Mammal Sampling

We established 6 100 × 100 m small mammal trapping grids on each study site, with one grid per treatment. Each grid contained 100 stations, spaced at 10 × 10 m intervals, and each station contained one Victor® (Woodstream Corporation, Lititz, PA) rat and one Victor® mouse snap-trap (1,200 traps/site). We operated traps for 4 consecutive nights February-April of 2002-06 and 2008. We trapped small mammals following site preparation but before HWC in 2002, and small mammal captures reflect vegetative conditions from the previous growing season. We baited traps with a peanut butter and oats mix and checked traps in the same order at approximately the same time each day. We conducted small mammal trapping under University of Georgia Institutional Animal Welfare Assurance no. A3437-01 and North Carolina Wildlife Resources Commission Wildlife Collecting License no. 0557.

We used analysis of variance (ANOVA) to examine the hypothesis that small mammal capture rates, species richness, and Shannon H′ diversity were inversely related to management intensity. Our main effects included type of mechanical site preparation/spacing, use of chemical site preparation, type of HWC, and we blocked by site. Because we were interested in when differences occurred, we examined within-year treatment effects with ANOVA for all parameters. If treatments differed, we used Tukey's means separation tests to identify differences among means. We tested for normality with Shapiro-Wilk tests using log transformations when necessary (Dowdy et al. 2004: pages 328-333). We examined interactions of chemical site preparation by spacing and chemical site preparation by HWC type. We compared small mammal capture rates, richness, and diversity in plots receiving different chemical site preparation with orthogonal contrasts. Plots receiving different spacing and HWC treatments were not orthogonal and were compared with t-tests. We did not include broadcast HWC plots in our spacing comparisons or wide spacing plots in our HWC comparisons because these treatments were not replicated within all comparison levels. Differences were considered significant at $\alpha = 0.10$.

RESULTS

Each year we trapped for 7,200 total trap-nights in 2002-04 and 4,800 in 2005-06 and 2008, for a total of 36,000 trap-nights. We captured 3,795 individual small mammals representing 11 species. We captured 689 eastern harvest mice (*Reithrodontomys humulis*), 140 golden mice (*Ochrotomys nuttalli*), 998 hispid cotton rats (*Sigmodon hispidus*), 737 house mice (*Mus musculus*), 283 least shrews (*Cryptotis parva*), 4 pine voles (*Microtus pinetorum*), 98 marsh rice rats (*Oryzomys palustris*), 743 deer mice (*Peromyscus leucopus* or *P. gossypinus*), 67 northern short-tailed shrews (*Blarina brevicauda*), 34 southeastern shrews (*Sorex longirostris*), and 2 southern bog lemmings (*Synaptomys cooperi*).

More intensive treatments (narrow spacing with chemical site preparation) reduced small mammal capture rates, richness, and diversity when compared with less intensive treatments before HWC was applied and 1 year post-HWC, but we observed no treatment effects in later years (Table 3.2). No species with >30 captures throughout the entire study were excluded by any treatment. When compared with RCN, SSW had greater capture rates and species richness pre-HWC and 1 year post-HWC, and greater diversity pre-HWC (Table 3.3). When compared to plots not receiving chemical site preparation, chemically prepared plots did not affect small mammal capture rates pre-HWC, but reduced richness and diversity before HWC was applied. Chemical site preparation also reduced small mammal capture rates, species richness, and diversity 1 year post-HWC. When compared to banded HWC, broadcast HWC reduced capture rates, species richness, and diversity 1 year post-HWC (Table 3.3).

Eastern harvest mice, deer mice, house mice, hispid cotton rats, and least shrews were present following site preparation and prior to HWC, but capture rates were low (< 0.6 captures/100 trap-nights, Figure 3.1). Although small mammal capture rates differed among treatments pre-HWC and 1 year post-HWC, only eastern harvest mice differed by treatment during the pre-HWC sampling period ($F_{5,25}$ = 3.57, P = 0.01) while eastern harvest mice ($F_{5,25}$ = 2.11, P = 0.10) and house mice differed by treatment after the first growing season (year 1 post-HWC; $F_{5,25}$ = 5.20, P = 0.002). Eastern harvest mice abundance was inversely related to treatment intensity pre-HWC, but by 1 year post-HWC eastern harvest mice were equally abundant in our 3 lowest intensity treatments. House mice were most frequently captured in plots not receiving chemical site preparation and banded HWC 1 year post-HWC, but were similar among treatments in later years.

Total small mammal capture rates did not differ by treatment after 1 year post-HWC, but golden mouse, hispid cotton rat, and deer mouse abundances differed among treatments in later years. Golden mice were first observed 3 years following site preparation (2 years post-HWC), and first appeared in the low intensity treatments with no chemical site preparation ($F_{5,25} \geq 2.18$, $P \leq 0.09$, Figure 3.1). Golden mice were most abundant in treatments with no chemical site preparation and banded HWC 3-4 years post-HWC ($F_{5,15} \geq 3.56$, $P \leq 0.03$). Hispid cotton rats reached peak abundance 3 years following site preparation. Cotton rats were least abundant in high intensity treatments 2 years post-HWC ($F_{5,25} = 2.54$, $P = 0.05$) but abundance did not differ in other years. Deer mice were our most abundant species after site preparation pre-HWC, but we did not observe treatment differences until 2 years post-HWC when deer mice were most common in our highest intensity treatment ($F_{5,25} = 4.16$, $P = 0.007$).

DISCUSSION

Small mammal capture rates, species richness, and diversity differed among treatments only in the first two years following site preparation, although species-specific capture rates differed in later years. Other studies shown similar ephemeral impacts of site preparation techniques on small mammal communities in the southeastern United States. For example, Miller and Chapman (1995) compared small mammals for 3 years following 3 different chemical treatments. Although they observed that small mammal capture rates declined during the first growing season following site preparation, rates recovered to pre-treatment levels on all treatments after the first year. Similarly, O’Connell and Miller (1994) compared small mammal communities for 5 years following either mechanical or chemical (hexazinone) site preparation and observed no treatment-related differences in capture rates or species composition after 2 years post-treatment. Therefore, small mammal communities in the Southeast are apparently tolerant of various site preparation techniques applied at stand initiation in pine plantations.

We recorded greater capture rates on sites mechanically prepared by shearing and wide row spacing than on those prepared by roller-chopping coupled with narrow bed spacing during the first 2 years following treatment. Mechanical site preparation influences amount of coarse woody debris (CWD) available to small mammals (Carey and Johnson, 1995), and CWD provides travel corridors, escape routes, and sources of invertebrates for small mammals, preserves soil moisture for plants, and is correlated with increased small mammal diversity in managed stands (Barry and Francq, 1980; Carey and Johnson, 1995; Bellows *et al.*, 2001). Pine spacing, however, has little effect on small mammals in early years (Bechard, 2008). Strip-shear treatments move CWD to the area between the beds, whereas roller-chopping crushes CWD, thereby reducing its size and availability. Thus, our results likely are a direct response to the type of mechanical site preparation rather than an effect of spacing.

We captured more eastern harvest mice in SSW than RCN treatments pre-HWC, but no other species differed in any year by mechanical site preparation or spacing. Although wide pine spacing may delay pine canopy closure and extend the period of suitable habitat for small mammals (Atkeson and Johnson, 1979), we did not observe effects of pine spacing on pine canopy cover until 7 years post-HWC (narrow = 85.1% mean pine cover, wide = 72.6%, $F_{1,8}$ = 11.96, P = 0.009), after all species had declined below 0.5 captures/100 trap nights. While pine spacing affected timing of canopy closure, all small mammal species declined sharply once canopy cover reached 50% closure in year 5 post-HWC due to shading that reduced understory herbaceous vegetation.

Chemical site preparation reduced small mammal capture rates and species richness for 2 years following application compared with plots not receiving chemical site preparation. Others have also observed short-term effects (< 2 year) of chemical site preparation on small mammal communities, although few studies have directly compared treated and untreated sites with similar mechanical site preparation in the Southeast (Rodrigue, 1988; Moore, 1993; O'Connell and Miller, 1994). In Maine, Santillo et al. (1989) observed reduced small mammal abundance in chemically (glyphosate) prepared plots relative to plots not receiving chemical site preparation for at least 3 years post-treatment, probably due to extended winters and slower post-disturbance recovery rates of northern plant communities as compared to southeastern forests. In the Southeast, chemical site preparation typically has short-term effects on plant communities, with subsequent short-term effects on small mammal communities (O'Connell and Miller, 1994).

While chemical site preparation did not exclude any species, timing of effects was species-specific. Deer mice were more abundant in chemically prepared plots 3 years following application and most abundant in our most intensive treatment. During that year, woody cover differed among treatments and was 26-68% less in plots receiving chemical site preparation (range = 32.5-46.6% with no chemical site preparation, 9.2-19.2% with chemical site preparation, $F_{5,18} = 14.99$, $P < 0.001$). Although other studies have observed more deer mice in areas with moderate to dense woody vegetation (Mengak et al., 1989; Perry and Thill, 2005), the deer mouse is a generalist and occurs in various vegetation types, including early successional habitats (Wolfe and Linzey, 1977). Clarke et al. (1985) noted that many small mammals, including the deer mouse, use early successional stages in pocosin communities, and intermediate or late succession pocosins typically support very low densities of small mammals.

Decreased woody cover present in our chemically prepared treatments may have extended the availability of early successional habitat important for deer mice in pocosins.

In contrast, eastern harvest mouse captures were lower in chemically prepared plots for 2 years following application, but did not differ by treatments in later years. The eastern harvest mouse is a pioneer species that uses early successional communities rich in grasses and forbs (Bellows et al., 2001). In years 1 and 2 following application, our chemically prepared plots contained on average 28% grass cover versus 42% on unprepared plots, and an average of 17% forb cover versus 22% on unprepared plots ($F_{1,15} \geq 5.98$, $P \leq 0.02$). Eastern harvest mice apparently responded to increases in grass and forb cover available on plots that did not receive chemical site preparation. As grass and forb cover became similar among treatments by year 3 post-application, eastern harvest mice abundances also became similar.

Golden mice were more abundant on plots without chemical site preparation, but were not recorded until 3 years following site preparation. The golden mouse is a semi-arboreal species known to prefer abundant woody shrub and vine cover (Linzey and Packard, 1977; Mengak and Guynn, 2003), and woody shrub cover was greatest on plots without chemical site preparation. The golden mouse is common in pocosin habitats due to its preference for dense woody vegetation, and site preparation methods that allow for woody plant and vine establishment can benefit this species (Clark et al., 1985). We observed peak golden mouse abundance among treatments 4-5 years following chemical site preparation, then captures declined as the pine canopy closed and cover of berry-producing vines such as poison ivy, (*Toxicodendron radicans*), blackberries (*Rubus* spp.), and greenbrier (*Smilax* spp.) gradually decreased.

Hispid cotton rats and house mice were also more abundant on plots that did not receive chemical site preparation at years 2 and 3 post-treatment, likely in response to increased herbaceous vegetation. Hispid cotton rat is common in young pine plantations, and is associated with early successional habitat types (Langley and Shure, 1980; Clark et al., 1985; Constantine et al., 2004). House mice occasionally inhabit young pine plantations, but are typically not encountered in undisturbed pocosins (NCASI, 1992; Mitchell et al., 1995). Perry and Thill (2005) and Mitchell et al. (1995) observed strong associations between cotton rat and house mouse abundance and herbaceous cover. Therefore, site preparation techniques that favor establishment of herbaceous plants would likely benefit both species. Cotton rats and house mice are typically absent from closed-canopy pine forests (NCASI, 1992; Mengak and Laerm, 2007), and we observed a sharp decline in both species once mean pine canopy cover was 14%, non-pine woody cover was ≥ 9%, and vine cover was ≥ 15%.

Broadcast HWC decreased small mammal capture rates in the year immediately following application, but small mammal abundance recovered to levels observed in banded HWC by the second year. Effects of HWC on plant communities are frequently confined to the first few years after application, with corresponding short-term effects on small mammals (Keyser et al., 2003; Edwards, 2004; Jones et al., 2009a). In our study, broadcast HWC reduced grass cover by 70% (19.5% cover in banded, 3.5% in broadcast), vine cover by 40% (2.3% banded, 1.0% broadcast), and forb cover by 44% (11.3% banded, 4.5% broadcast) in the year following application, but vegetation was similar between type of HWC in later years. Early successional small mammal species, such as eastern harvest mouse and house mouse, appeared to benefit from increased vegetation present in banded HWC in the first year following application. Thus, banded HWC increased wildlife food plant availability over broadcast HWC and provided similar pine cover as broadcast HWC (Lauer et al., 1993).

Small mammal succession within our sites resembled old field succession (Atkeson and Johnson, 1979; Langley and Shure, 1980). Pioneering species such as eastern harvest mouse, house mouse, and deer mouse colonized our sites within a few months following site preparation. Species commonly associated with pocosins, such as golden mouse, were not captured on our sites until the sites transitioned to shrub-dominated pocosin-like habitat, supporting the hypothesis of Mitchell et al. (1995) that pocosin small mammal species recolonize sites a few years following disturbance.

CONCLUSION

Although timing and magnitude of site preparation effects differed by species, in general, small mammal communities were affected by treatments during the first 2 years after treatments were applied and increasing intensity of site preparation by combining chemical site preparation with narrow spacing or broadcast HWC had minor additional reductions in small mammal abundance and species richness over other methods we examined. Strip/shear mechanical site preparation increased small mammal abundance and species richness during the first 2 years following treatment, and pine spacing had no observable effect. Chemical site preparation only reduced small mammal abundance and species richness 1-2 years following application, but altered species composition after 3-4 years post-treatment. Banded HWC supported more abundant and diverse small mammal communities immediately following treatment than broadcast HWC, and may be beneficial to small mammals. Small mammal species normally associated with pocosin habitats, such as golden mouse, took several years to recolonize and used treatments with abundant vine and woody cover. Small mammal succession within our converted pocosin, intensively managed pine plantation was similar to old field succession observed in other studies. Small mammal communities are resilient to a variety of treatment effects in industrial forest management and recover quickly following disturbance. Industrial forests provide habitat for many small mammal species, and may play an increasingly important role in wildlife conservation as forested lands are converted and fragmented by urbanization, subdivision, and other development.

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Table 3.1. Treatments used to evaluate small mammal community responses to combinations of chemical and mechanical site preparation techniques in the Coastal Plain of North Carolina, 2002-05, 2007-09.

Intensity	Treatment	Abbrev.[a]	MSP[b]	CSP[bc]	Year 1 HWC[d]	Bed spacing
Low	1	WNBa	Strip Shear	No	Banded	Wide (6.1 x 1.5 m)
↓	2	WHBa	Strip Shear	Yes	Banded	Wide (6.1 x 1.5 m)
	3	NNBa	Chop	No	Banded	Narrow (3.0 x 2.4 m)
	4	NNBr	Chop	No	Broadcast	Narrow (3.0 x 2.4 m)
	5	NHBa	Chop	Yes	Banded	Narrow (3.0 x 2.4 m)
High	6	NHBr	Chop	Yes	Broadcast	Narrow (3.0 x 2.4 m)

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC
[b] MSP = mechanical site preparation; CSP = chemical site preparation
[c] Chopper™ (0.58 L/ha mixed with 11.68 L/ha of oil)
[d] HWC = herbaceous weed control, Arsenal™ (0.30 L/ha) and Oust™ (0.15 L/ha)

Table 3.2. Small mammal capture rates (captures/100 trap nights), species richness, and Shannon H′ diversity index means, standard errors, and p-values for within-year treatment comparisons. We removal trapped small mammals for 4 consecutive days in winter in 6 (2002-04) or 4 (2005-06, 2008) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina.

		Treatment														
		WNBa[a]		WHBa		NNBa		NNBr		NHBa		NHBr				
Index	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	DF	*F*	*P*[b]
Capture rate	Pre-HWC[c]	1.73A	0.44	1.23AB	0.45	0.98AB	0.36	0.88AB	0.21	0.63B	0.21	0.90AB	0.23	5,25	2.91	0.03
	1	6.25A	1.99	3.35AB	1.20	5.33AB	1.46	1.92AB	0.86	2.06AB	0.79	1.27B	0.29	5,25	3.54	0.02
	2	5.54	3.48	6.33	2.81	8.06	3.96	5.77	3.45	5.13	2.94	5.17	2.50	5,25	0.99	0.45
	3	2.44	0.77	2.41	0.79	3.28	0.46	1.75	0.38	2.31	0.72	2.41	0.26	5,15	1.64	0.21
	4	1.69	0.71	1.28	0.19	1.59	0.38	1.13	0.33	1.16	0.44	1.09	0.53	5,15	0.39	0.85
	6	0.50	0.18	0.53	0.31	0.44	0.17	0.41	0.2	0.34	0.13	0.22	0.06	5,15	0.64	0.67
Spp. richness	Pre-HWC	2.83A	0.48	2.00AB	0.52	2.00AB	0.37	1.67AB	0.33	1.17B	0.40	1.67AB	0.33	5,25	2.64	0.05
	1	4.50A	0.56	3.17AB	0.65	3.67AB	0.56	2.17AB	0.31	2.33B	0.71	1.83B	0.40	5,25	4.29	0.006
	2	5.00	0.52	4.17	0.48	4.33	0.49	4.00	0.63	3.83	0.83	4.17	0.40	5,25	0.83	0.54
	3	4.75	1.03	4.50	0.87	4.00	0.82	3.75	0.48	4.50	0.87	4.25	1.03	5,15	0.24	0.94
	4	4.25	1.11	4.50	0.50	4.00	0.71	4.00	0.82	3.25	0.63	3.25	1.44	5,15	0.52	0.76
	6	2.25	0.48	2.25	1.03	2.25	0.48	1.25	0.48	1.75	0.48	1.50	0.29	5,15	0.90	0.50
Shannon H′	Pre-HWC	0.79A	0.18	0.43AB	0.20	0.39AB	0.15	0.37AB	0.18	0.13B	0.13	0.26B	0.13	5,25	3.50	0.02
	1	1.07A	0.05	0.82AB	0.24	0.93AB	0.10	0.48AB	0.13	0.50AB	0.24	0.32B	0.18	5,25	3.36	0.02
	2	1.27	0.12	1.06	0.08	1.11	0.10	1.07	0.17	0.92	0.25	1.20	0.07	5,25	0.68	0.64
	3	1.17	0.19	1.16	0.10	0.99	0.27	1.17	0.13	1.16	0.12	1.15	0.20	5,15	0.25	0.93
	4	1.24	0.26	1.25	0.09	1.12	0.15	1.13	0.18	0.99	0.16	0.74	0.44	5,15	0.57	0.72
	6	0.59	0.20	0.59	0.35	0.68	0.24	0.27	0.16	0.39	0.25	0.33	0.19	5,15	0.77	0.59

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Sites differed within all years ($P \leq 0.05$).

[c] Small mammals trapped after mechanical and chemical site preparation and pine planting but before HWC in 2002.

[d] Different letters within a row indicate differences among treatments among years.

Table 3.3. Small mammal capture rates (captures/100 trap nights) and species richness means, standard errors, and p-values[a] for within-year treatment component contrasts for years with significant treatment effects. We removal trapped small mammals for 4 consecutive days in winter in 6 (2002-04) or 4 (2005-06, 2008) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina.

	Mechanical Site Prep. and Spacing[a]						Chemical Site Prep.[b]						Herbaceous Weed Control					
	RCN[c]		SSW				No		Yes				Banded		Broadcast			
Year	Mean	SE	Mean	SE	*F*	*P*[d]	Mean	SE	Mean	SE	*F*	*P*	Mean	SE	Mean	SE	*F*	*P*
Capture Rate																		
Pre-HWC[e]	0.84	0.12	1.48	0.31	9.94	0.004	1.19	0.21	0.92	0.18	2.63	0.12						
1	2.65	0.55	4.80	1.19	5.05	0.04	4.50	0.94	2.23	0.50	5.52	0.03	4.25	0.75	1.59	0.44	5.45	0.03
Spp. Richness																		
Pre-HWC	1.6	0.2	2.4	0.4	5.84	0.02	2.2	0.2	1.6	0.2	4.59	0.04						
1	2.5	0.3	3.8	0.5	9.21	0.006	3.4	0.4	2.4	0.4	7.54	0.01	3.4	0.3	2.0	0.2	3.64	0.07
Shannon H′																		
Pre-HWC	0.26	0.10	0.61	0.14	6.76	0.02	0.52	0.10	0.27	0.09	6.32	0.02						
1	0.72	0.14	0.95	0.12	1.96	0.18	0.83	0.08	0.55	0.13	4.59	0.04	0.72	0.14	0.40	0.11	3.83	0.07

[a] Mechanical site preparation and spacing treatments were paired.
[b] Chemical site preparation compared with orthogonal contrasts. Spacing and herbaceous weed control (HWC) treatments compared with t-tests.
[c] RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.
[d] Degrees of freedom: year = 6, site = 5, comparison = 1, prep x HWC = 1, error = 25. Chemical prep x HWC and prep x spacing not significant in any year. Sites differed within years ($P \leq 0.05$).
[e] Small mammals trapped after mechanical and chemical site preparation and pine planting but before HWC in 2002.

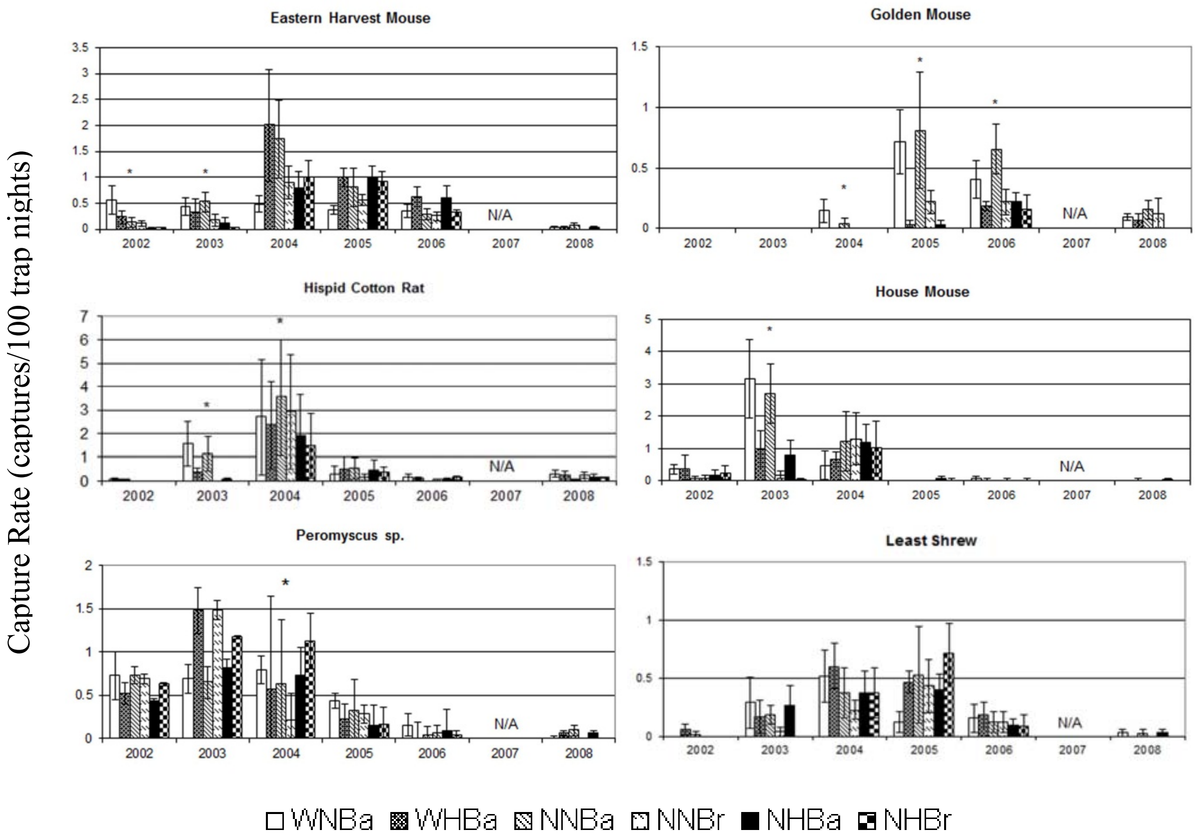

Figure 3.1. Average capture rates and standard error bars by year and treatment for small mammals with at least one mean treatment capture rate of ≥ 0.5 captures/100 trap nights. We collected data 1-5 and 7 years following site preparation in 6 (2002-04) or 4 (2005-06, 2008) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina. An asterix denotes treatment differences within a year at α = 0.10. Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC.

CHAPTER 4

BIRD COMMUNITY RESPONSES TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE COASTAL PLAIN OF NORTH CAROLINA[3]

[3] Lane, V.R., K.V. Miller, S.B. Castleberry, D.A. Miller, T.B. Wigley, R.J. Cooper, G.M. Marsh, and R.A. Mihalco. To be submitted to the *Wildlife Society Bulletin.*

ABSTRACT

Although intensively managed pine forests are common in the southeastern U.S. and are known to support many bird species, few studies describe how combinations of mechanical (MSP) and chemical site preparation (CSP) and herbaceous weed control (HWC) techniques affect bird communities. Understanding how site preparation techniques affect bird communities is important to sustainable forest management and bird conservation, particularly for declining bird species that use early successional habitats present within young pine forests. Therefore, we examined effects of 6 treatments of increasing intensity via combinations of MSP (strip-shear and wide spacing or roller chop and narrow spacing) and CSP (application or no application) treatments with banded or broadcast HWC on bird communities in 6 loblolly pine (*Pinus taeda*) plantations in the Coastal Plain of North Carolina, USA, for 8 years following site preparation. We detected 76 species, including 13 resident, 32 neotropical migrants, and 31 short distance migrants. Of these species, 24 were associated with forest interior, 29 with forest edge, 12 with pine-grassland, and 11 were incidental encounters. Wide pine spacing and strip-shear MSP increased bird abundance and species richness over narrow spacing and chopped MSP for 6 years after planting. Chemical SP reduced bird abundance in year 2, increased bird abundance in year 6, had no effect on abundance after year 7, and did not affect species richness in any year. Total bird abundance and species richness were similar between banded and broadcast HWC. Site preparation and HWC had no effect on bird diversity and bird communities were most similar in treatments of similar intensity. Site preparation and HWC had few effects on bird guilds based upon migratory status and habitat association, and did not delay or accelerate timing of colonization by birds that use late-successional forests. Wide pine spacing and strip-shear MSP may improve habitat structure for birds in the first few years after site preparation over

narrow spacing and chopping. The addition of chemical site preparation or HWC had little effect on birds beyond pine spacing, and bird abundance was not proportional to management intensity. Although we observed treatment effects, all treatments provided habitat used by a variety of bird species, and pine plantations may play an increasingly important role in bird conservation as forests become fragmented and urbanized and natural processes that create early successional habitat, such as fire, are suppressed.

INTRODUCTION

Intensively managed pine forests are common in the southeastern U.S. and are known to support many bird species (Childers et al., 1986; Wilson and Watts, 2000; NCSSF, 2005). Wildlife conservation within managed forests is of great interest and importance to foresters and biologists, in part because industry-owned forests consist of large, contiguous blocks of land that are increasingly uncommon in the Southeast (Wigley et al., 2001). Conservation opportunities exist due to the diverse array of habitats present on privately owned and managed forest landscapes, and conservation efforts that consider such landscapes may be more effective than those that focus solely on public land (Wigley et al., 2000).

In recently established pine plantations, habitat changes and succession can be directed using a variety of mechanical and chemical applications that allow managers to selectively control vegetation to enhance pine productivity and wildlife habitat (Miller et al., 2009). Mechanical site preparation affects the amount and distribution of coarse woody debris and snags used by many bird species, particularly woodpeckers, flycatchers, and cavity-nesting birds (Hartley, 2002; Lohr et al., 2002; Jones et al., 2009). Chemical site preparation and chemical releases, such as herbaceous weed control (HWC), can affect bird communities through changes in plant community richness, diversity, structure, and succession due to herbicide specificity

(Boyd et al., 1995; Miller and Miller, 2004). Increased management intensity through combinations of mechanical and chemical treatments can substantially increase pine growth and yields (Borders and Bailey, 2001; Wagner et al., 2004), but understanding tradeoffs between pine growth and bird habitat is important to conserving bird species in managed forests.

Many bird species that use early successional grassland and scrub-shrub vegetation associations are in nationwide decline due in part to changing land-use practices that often do not incorporate frequent disturbances needed to maintain early successional habitat (Brennan and Kuvlesky, 2005). In the southeastern U.S., industrial forest lands provide early-successional habitat through clearcutting, site preparation, and thinning (Krementz and Christie, 2000). Because mechanical and chemical site preparation techniques applied after clearcutting can alter plant communities, the interaction of various site preparation techniques and HWC may reduce or lengthen duration of early successional avian communities within pine plantations (Atkeson and Johnson, 1979; Miller et al., 1995; Zutter and Miller, 1998).

Although other studies have examined bird communities across multiple pine stands of varying ages (Wilson and Watts, 2000), few studies have assessed long-term effects of site preparation techniques on bird communities within the same stands over time. In addition, combinations of site preparation and HWC techniques are becoming increasingly popular to control vegetation competing with pines, and few studies have examined the effects of these combinations on bird communities (Shepard et al., 2004). Understanding how site preparation and HWC combinations affect bird communities is important because intensively managed pine forests can provide early successional vegetation communities known to be used by a variety of declining bird species, yet potential short- and long-term effects of these combinations on bird communities remain poorly understood. Therefore, we examined effects of mechanical site preparation, pine spacing, chemical site preparation, and HWC on bird communities for 8 years following site preparation.

METHODS

Study Area

We conducted our study on 6 sites managed intensively for loblolly pine (*Pinus taeda*) in the Lower Coastal Plain of North Carolina, USA. Two sites in Craven County were managed by Weyerhaeuser Company and 4 sites in Brunswick County were managed by International Paper, The Nature Conservancy, Resource Management Service, LLC, or North Carolina Wildlife Resources Commission during our study. Two Brunswick County sites were eliminated in 2005 because high pine mortality lowered tree densities below standard forestry practices. In addition, one treatment (narrow spacing, no chemical site preparation, banded HWC) was dropped at one Brunswick County site in 2008 due to high pine mortality. Sites averaged 60.7 ha and were divided into 6 treatment plots 4.5-12.2 ha each (Mihalco, 2004) .

We mechanically (roller-chop or strip shear) or chemically (imazapyr in the form of Chopper™, BASF Corp., Research Triangle Park, North Carolina, at 0.58 L/ha mixed with 11.68 L/ha of oil) prepared in fall 2001−winter 2002 and hand planted with loblolly pine seedlings in late-winter 2002. We planted pines in either narrow (3.0 x 2.4 m) or wide (6.1 x 1.5 m) spacing. We bedded and fertilized all plots with diammonium phosphate (DAP) applied into beds at 280 kg/ha prior to planting. In spring 2002, we applied herbaceous weed control (HWC) with 0.30 L/ha of Arsenal™ (active ingredient imazapyr, BASF Corp., Research Triangle Park, North Carolina) and 0.15 L/ha of Oust™ (active ingredient sulfometuron methyl, E.I. du Pont de Nemours and Company, Inc., Wilmington, Delaware) as either broadcast or 1.5 m bands. We used a randomized complete block design and treatment plots received 1 of 6 treatments that varied in intensity of vegetation control (Table 4.1). Treatment components included mechanical site preparation (strip shear coupled with wide spacing [SSW] or roller-chop coupled with narrow spacing [RCN]), use or lack of chemical site preparation (N = no application, H = application), and banded or broadcast HWC during the first year after planting (Ba = banded, Br = broadcast).

Bird Surveys

We surveyed birds from 2002-05 and 2007-09 using a modified spot mapping technique derived from protocol established by Robbins (1970) and Wunderle (1994). Six surveys were completed for each treatment plot at all sites during the breeding season (May-June), and all treatments within a site were surveyed during the same morning. We surveyed birds between sunrise and 1000 hours on days with winds ≤ 32 km/hr and no precipitation (Hamel 1992). We placed multiple transects 100 m apart and in each treatment plot noted all birds singing or seen within 50 m of each transect. Transects were arranged so we could survey all area within a treatment plot during each visit and calculate bird abundance per unit area. Observers walked all transects in each treatment and recorded all birds heard or seen. Observers were assigned different treatments among sites so all observers surveyed a treatment at least once to reduce possible bias due to observer skill, but the same treatment within a site was surveyed by a single observer throughout a season because dense vegetation made navigation difficult in some years. Observers reversed their walking direction every survey to avoid timing effects.

We hypothesized that bird abundance, species richness, and diversity were inversely related to management intensity. Our main effects included type of mechanical site preparation/spacing, use of chemical site preparation, type of HWC, and we blocked by site. Because we were interested in when differences occurred, we examined within-year treatment effects with ANOVA for all parameters. If treatments differed, we used Tukey's means separation tests to identify differences among means. We tested for normality with Shapiro-Wilk tests and used log transformations when necessary (Dowdy et al. 2004: pages 328-333). We examined interactions of chemical site preparation by spacing and chemical site preparation by HWC. We compared bird abundance, species richness, and diversity between plots receiving or not receiving chemical site preparation with orthogonal contrasts. Plots receiving different spacing and HWC were not orthogonal and were compared with t-tests. We did not include broadcast HWC plots in our spacing comparisons or wide spacing plots in our HWC comparisons because these treatments were not replicated within all levels of the comparisons. Differences were considered significant at $\alpha = 0.05$.

We used number of territorial singing males as our response variable because dense vegetation made it difficult to reliably count birds by sight in some years. We tested for differences in bird abundance (males/10 ha), bird species richness (species/10 ha), and Shannon H′ diversity (Shannon and Weaver, 1949) among treatments. Bird migratory status (resident, neotropical migrant, or short-distance migrant determined from Poole 2010) and general habitat preferences (forest interior, forest edge, and pine-grassland adapted from Wilson et al. 1995) were also compared among treatments. We used the Morista community similarity index to determine treatments that contained the most similar bird communities (Spellerberg, 2005). Morista similarity values for comparisons between two communities range from 0-1.0, with 1.0 being most similar.

RESULTS

We detected 76 bird species over 8 years following site preparation (Table 4.2). Of these species, 13 were resident, 32 were neotropical migrants, and 31 were short-distance migrants. In addition, 24 species were classified as forest interior, 29 forest edge, and 12 pine-grassland species. We also encountered 11 incidental species, such as great egret (*Ardea alba*) and killdeer (*Charadrius vociferus*), we excluded from our analysis because they were detected only once or did not fit into the three main habitat categories. Our most common species included blue grosbeak (*Passerina cerulea*), Carolina wren (*Thryothorus ludovicianus*), common yellowthroat (*Geothlypis trichas*), eastern towhee (*Pipilo erythrophthalmus*), gray catbird (*Dumetella carolinensis*), indigo bunting (*Passerina cyanea*), northern cardinal (*Cardinalis cardinalis*), prairie warbler (*Dendroica discolor*), white-eyed vireo (*Vireo griseus*), and yellow-breasted chat (*Icteria virens*).

Total bird abundance and species richness differed among treatments up to 6 years following site preparation (Table 4.3). In general, bird abundance, species richness, and bird diversity did not change with increasing management intensity. We detected no interactions of chemical site preparation with spacing or herbaceous HWC. Pine spacing had the greatest effect on bird abundance and species richness, and SSW had greater bird abundance and species richness than RCN in years 1-6 (Table 4.4). Chemical site preparation reduced bird abundance in year 2, but in year 6 chemically prepared plots supported more species and greater abundance than mechanically treated plots. However, chemical site preparation did not affect bird communities after year 6. Total bird abundance, species richness, and diversity were similar in all years between banded and broadcast herbaceous HWC.

Of species with abundance greater than 0.1 males/10 ha within a year, only blue grosbeak and common yellowthroat differed by treatment, and these differences were short-lived. In year 2, blue grosbeak abundance was greatest in treatments with no chemical site preparation (CSP mean = 0.56 males/10 ha, no CSP mean = 1.17, $F_{1,15} = 17.47$, $P < 0.001$). By year 3, blue grosbeak abundance was greatest in all intermediate treatments (WHBa mean = 1.80, standard error = 0.32; NHBa mean = 1.88, SE = 0.31) and lowest in our least and most intensive treatments (WNBa mean = 1.03, SE = 0.25; NHBr mean = 0.96, SE = 0.22, $F_{5,25} = 3.11$, $P = 0.03$), but was similar among all treatments in later years. Common yellowthroat abundance was greatest on treatments not receiving chemical site preparation in year 2 only (CSP mean = 0.74 males/10 ha, no CSP mean = 1.77, $F_{1,15} = 10.92$, $P = 0.002$).

Neotropical migrants were the most common migratory group present on our sites, followed by short-distance migrants and resident species (Figure 4.1). Bird densities were lowest in all migratory groups in the first 2 years following site preparation, peaked in years 3-5, and slowly declined until near pine canopy closure in year 8. In year 4, resident bird abundance was greatest on wide spacing treatments, intermediate in narrow spacing treatments with no chemical site preparation, and least in narrow spacing, chemically prepared treatments. In year 2, neotropical migrant abundance was greatest in our wide spacing treatment with no chemical site preparation and decreased with increasing management intensity, but these differences were not evident in following years. Short-distance migrants differed by treatment in years 1, 3, and 8, and were most abundant in wide spacing treatments in year 1. By year 3, short-distance migrant abundance was greatest in our most intensive treatment (NHBr) and wide spacing treatments, and least in intermediate treatments. By year 8, abundance of short-distance migrants increased with increasing management intensity, and was lowest in wide spacing treatments.

Birds that used forest edges were the most common guild present in our study, while forest interior birds were the least common (Figure 4.1). We observed no treatment differences for forest interior birds in any year. Forest edge birds differed among treatments in years 1, 2, 3, and 6. In years 1-3, forest edge bird abundance was greatest in wide spacing treatments. In year

6, forest edge bird abundance was greatest in low and high intensity treatments, and least in intermediate treatments. Pine-grassland bird abundance only differed in year 2, when abundance decreased with increasing management intensity.

Morista similarity values averaged 0.78-0.85 among years, and were greatest for sites receiving similar treatment intensities. Overall, the most similar bird communities were shared by treatments with identical pine spacing (0.82-0.85), and least similar between our least and most intensive treatments (0.78).

DISCUSSION

We observed a bird community in young pine plantations in the North Carolina Coastal Plain similar to that reported by Karriker (1993) and Wilson and Watts (2000). In the first two years following site preparation, swallows (Hirundinidae) were occasionally seen foraging over low vegetation, and killdeer used bare ground for nesting. In years 3-6, shrub-nesting birds such as common yellowthroat, blue grosbeak, and indigo bunting were abundant. By year 7, late succession, forest interior birds such as wood thrush (*Hylocichla mustelina*) and ovenbird (*Seiurus aurocapillus*) were observed regularly in low abundance. We first observed worm-eating warbler (*Helmitheros vermivorum*) within our most densely vegetated sites in year 8, although Wilson and Watts (2000) first detected this species in plantations entering their 10th growing season. Prairie warbler was most abundant at our sites in years 4-7, and began to decline in year 8.

Our site preparation and HWC treatments had few effects on individual bird species abundance, but minor differences within species accumulated to a significant community effect on density when all species were considered. Pine spacing or mechanical site preparation was particularly important to total bird abundance and richness. Wide pine spacing/strip-shear supported more individual birds and bird species than RCN in the first 6 years following site preparation. Other studies have observed differences in bird communities due to subtle changes in structure and composition of vegetation (O'Connell and Miller, 1994). Pine spacing may affect birds by changing vegetation characteristics by delaying canopy closure and increasing sunlight availability to the forest floor (Bechard, 2008), but we observed few differences in vegetation cover among MSP treatments after year 1 (see Chapter 2). Birds, therefore, may be responding to structure of the pines themselves, perhaps as physical boundaries or perches for delineating or defending territories (Michener and Michener, 1935).

Although chemical site preparation had the greatest effect on plant communities in our study, particularly by reducing woody plant cover by over 50% (Figure 4.2), chemical site preparation had minor impacts on bird communities. In the second year following site preparation, birds were more abundant on plots not receiving chemical site preparation, likely due to greater woody plant, forb, and grass cover. As time progressed and woody vegetation became dense within mechanically prepared plots, birds gradually became more abundant in chemically prepared plots until year 7 when pine canopy cover reached an average of 65%. Many bird species present in young pine plantations use ephemeral early-successional habitat present in the first few years following site preparation, and bird densities tend to be lowest in stands with dense woody midstories and sparse herbaceous ground cover (NCASI, 1992; Wilson et al., 1995). Chemical site preparation may initially reduce vegetation structure important to birds, but also reduces woody plant encroachment that may lengthen the availability of early successional habitats within pine stands, and approximate the structure of historical pine-grassland communities (Miller et al., 1995; Wigley et al. 2002). Herbaceous growth is important for a variety of wildlife in young pine plantations, such as northern bobwhite (*Colinus* *virginianus*), white-tail deer (*Odocoileus virginianus*), and small mammals (Atkeson and Johnson, 1979; Welch et al., 2004; Jones et al. 2009a). Chemical site preparation is often necessary to give pines a competitive advantage over woody and herbaceous vegetation (Zutter and Miller, 1998; Miller et al., 2009), but can be paired with wide pine spacing to provide greater herbaceous plant coverage in the first few years after site preparation.

The type of HWC did not appear to affect bird communities. Despite broadcast HWC reducing grasses, vines, and forbs in the first year following treatment when compared to banded HWC, these reductions had little effect on bird density and richness. Although type of HWC did not affect birds in our study, banded HWC are known to increase wildlife food plant availability over broadcast HWC in the first few years after site preparation (Blake et al., 1987), and provide similar pine growth as broadcast HWC (Lauer et al., 1993), therefore banded HWC may be beneficial to other wildlife while potentially meeting pine growth objectives.

As with total bird density and richness, SSW site preparation supported greater densities within bird migratory and habitat groups. Resident birds were least common on our sites because many residents, such as woodpeckers, use mid- to late-successional habitat not present in young pine plantations (Wilson et al., 1995). Carolina wrens, in combination with northern cardinals and northern mockingbirds (*Mimus polyglottos*), accounted for 63% of all resident bird detections in year 4 when treatment differences were detected. Although we observed no vegetation differences between wide and narrow spacing in year 4, resident birds may have selected areas with wider pine spacing because of greater distance between tree trunks.

Neotropical migrants were the most common migratory group in our study, but we only observed treatment differences in the second year following site preparation. The most common neotropical migrants in year 2 included blue grosbeak, common yellowthroat, indigo bunting, and yellow-breasted chat. Together, these species accounted for 80% of all neotropical migrant detections in year 2. Our SSW plots contained greater vertical vegetation cover, which likely provided more nesting sites and adequate foraging opportunities to neotropical birds breeding in early successional forests (Sparling, 1996).

In years 1 and 3, short-distance migrants were most common in low-intensity wide spacing treatments. Sparling (1996) noted that breeding bird abundance was positively correlated with vertical cover at 0.5-1.0 m in the first 2 years following site preparation, and we observed greater vegetation cover among low-intensity treatments that short-distance migrants possibly preferred (Figure 4.2). By year 8, low-intensity treatments supported a much denser understory of woody trees and shrubs than high-intensity treatments, and we observed more short-distance migrants within high-intensity treatments. Many of the short-distance migrants we encountered were species that use forest edges or pine-grasslands, such as eastern phoebe (*Sayornis phoebe*), eastern towhee, mourning dove (*Zenaida macroura*), and field sparrow (*Spizella pusilla*). Childers et al. (1986) observed that species that use forest-edge and pine-grasslands increase in abundance until year 5, and then gradually decline as pine canopies close. Although short-distance migrants were more abundant in our low intensity treatments in the few years following site preparation, short-distance migrants may select high intensity treatments in later years because of reduced understory woody cover and vertical vegetation cover that more closely mimic edge or pine-grassland habitats.

Forest interior birds were least common within our study sites, which was expected of young pine plantations characterized by early-successional vegetation structure (Krementz and Christie, 2000). Carolina chickadee and tufted titmouse were our most common forest interior birds, and both regularly ventured into our young stands. Wilson and Watts (2000) also observed low numbers of Carolina chickadees (*Poecile carolinensis*) and tufted titmice (*Baeolophus bicolor*) within pine plantations <9 years old, although these two species reached peak abundance in older, mature, thinned stands. Other forest interior species, such as ovenbird (*Seiurus aurocapillus*), wood thrush (*Hylocichla mustelina*), Acadian flycatcher (*Empidonax virescens*), and woodpeckers (Picidae) did not appear on our treatments until after year 4, and were not regularly encountered until year 7. Although densities were low, our treatments had no effect on forest interior species.

Bird species associated with forest edge, including shrub/scrub species, were most common in our study, perhaps due to our relatively small treatment areas (≤ 12.2 ha), ditches that provided more edges than expected, and tendency of our study areas to quickly become pocosin-like, shrub-dominated systems (Richardson, 1983; Childers et al., 1986; Mihalco, 2004). Forest edge birds were more abundant in SSW treatments the first 3 years following site preparation, perhaps in response to increased vertical vegetation cover. By year 6, forest edge birds were beginning to decline as pine canopies were approximately 50% closed and treatment differences in herbaceous vegetation gradually vanished.

CONCLUSION

Pine spacing had the greatest influence on bird communities, indicating that habitat structure and not plant diversity is what primarily influenced bird communities in our study (MacArthur and MacArthur, 1961). Plots with similar spacing contained similar numbers of individual birds and bird species regardless of presence or absence of chemical site preparation, indicating that birds may be responding to structure of the pines themselves. Chemical site preparation had minor effects on birds, and although chemical site preparation initially reduced bird abundance, bird abundance increased on chemically prepared plots in later years. The type of HWC had no effect on bird communities, but banded HWC may be more beneficial to other wildlife, provide similar pine cover, and be less expensive than broadcast HWC. Increasing management intensity by including chemical site preparation and broadcast herbaceous HWC had few additional effects on bird communities beyond effects of pine spacing.

Intensively managed pine forests can support many species of birds and other wildlife (Wigley et al., 2000). We detected 76 bird species, including many of regional and continental concern, such as northern bobwhite (*Colinus virginianus*), prairie warbler (*Dendroica discolor*), worm-eating warbler (*Helmitheros vermivorus*), and wood thrush (Donovan et al., 2002). Pine stands have the potential to be important habitat for many bird species, particularly through site preparation techniques that extend availability of early successional habitat.

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Table 4.1. Treatments used to evaluate bird community responses to combinations of chemical and mechanical site preparation techniques in the Coastal Plain of North Carolina, 2002-05, 2007-09.

Intensity	Treatment	Abbrev.[a]	MSP[b]	CSP[bc]	Year 1 HWC[d]	Bed Spacing
Low	1	WNBa	Strip Shear	No	Banded	Wide (6.1 x 1.5 m)
	2	WHBa	Strip Shear	Yes	Banded	Wide (6.1 x 1.5 m)
	3	NNBa	Chop	No	Banded	Narrow (3.0 x 2.4 m)
	4	NNBr	Chop	No	Broadcast	Narrow (3.0 x 2.4 m)
	5	NHBa	Chop	Yes	Banded	Narrow (3.0 x 2.4 m)
High	6	NHBr	Chop	Yes	Broadcast	Narrow (3.0 x 2.4 m)

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC
[b] MSP = mechanical site preparation; CSP = chemical site preparation
[c] Chopper™ (0.58 L/ha mixed with 11.68 L/ha of oil)
[d] HWC = herbaceous weed control, Arsenal™ (0.30 L/ha) and Oust™ (0.15 L/ha)

Table 4.2. Bird species detected 1-4 and 6-8 years following site preparation in intensively managed loblolly pine plantations in the Coastal Plain of North Carolina, and associated Partners in Flight regional combined score, migratory status, and habitat preferences.

Common Name	Scientific Name	PIF Score[a]	Migratory Status[b]	Habitat Preference[c]
Acadian flycatcher	*Empidonax virescens*	15	NTM	FI
American crow	*Corvus brachyrhynchos*	11	SDM	FE
American goldfinch	*Spinus tristis*	8	SDM	FE
American robin	*Turdus migratorius*	6	SDM	FE
American woodcock	*Scolopax minor*	-	SDM	I
Barn swallow	*Hirundo rustica*	9	NTM	I
Black-and-white warbler	*Mniotitla varia*	11	NTM	FI
Blue-gray gnatcatcher	*Polioptila caerulea*	11	NTM	FE
Brown-headed cowbird	*Molothrus ater*	8	SDM	FE
Brown-headed nuthatch	*Sitta pusilla*	20	R	PG
Blue grosbeak	*Passerina caerulea*	12	NTM	PG
Blue jay	*Cyanocitta cristata*	14	SDM	FE
Brown thrasher	*Toxostoma rufum*	15	SDM	FI
Boat-tailed grackle	*Quiscalus major*	11	R	FE
Carolina chickadee	*Poecile carolinensis*	16	R	FI
Carolina wren	*Thryothorus ludovicianus*	13	R	FE
Chipping sparrow	*Spizella passerina*	9	NTM	PG
Common grackle	*Quiscalus quiscula*	11	SDM	FE
Cooper's hawk	*Accipiter cooperii*	13	SDM	FI
Common nighthawk	*Chordeiles minor*	13	NTM	I
Common yellowthroat	*Geothlypis trichas*	13	NTM	FE
Cedar waxwing	*Bombycilla cedrorum*	-	SDM	I
Downy woodpecker	*Picoides pubescens*	14	R	FI
Eastern bluebird	*Sialia sialis*	11	SDM	FE
Eastern kingbird	*Tyrannus tyrannus*	15	NTM	PG
Eastern meadowlark	*Sturnella magna*	14	SDM	PG
Eastern phoebe	*Sayornis phoebe*	9	SDM	FE
Eastern towhee	*Pipilo erythrophthalmus*	16	SDM	FE
Eastern wood-pewee	*Contopus virens*	14	NTM	PG
Field sparrow	*Spizella pusilla*	15	SDM	PG
Great crested flycatcher	*Myiarchus crinitus*	12	NTM	FI
Gray catbird	*Dumetella carolinensis*	11	NTM	FE
Great egret	*Ardea alba*	-	SDM	I
Hairy woodpecker	*Picoides villosus*	13	R	FI
House finch	*Carpodacus mexicanus*	7	SDM	FE
Hooded warbler	*Wilsonia citrina*	14	NTM	FI
House wren	*Troglodytes aedon*	8	SDM	FE
Indigo bunting	*Passerina cyanea*	14	NTM	PG
Kentucky warbler	*Oporornis formosus*	16	NTM	FI
Killdeer	*Charadrius vociferus*	-	SDM	I
Mourning dove	*Zenaida macroura*	11	SDM	FE
Northern bobwhite	*Colinus virginianus*	16	R	PG
Northern cardinal	*Cardinalis cardinalis*	12	R	FE
Northern flicker	*Colaptes auratus*	15	SDM	FE

Table 4.2 continued.

Common Name	Scientific Name	PIF Score[a]	Migratory Status[b]	Habitat Preference[c]
Northern mockingbird	*Mimus polyglottos*	12	R	FE
Northern parula	*Parula americana*	15	NTM	FI
Northern rough-wing swallow	*Stelgidopteryx serripennis*	15	NTM	I
Orchard oriole	*Icterus spurius*	16	NTM	FE
Ovenbird	*Seiurus aurocapillus*	10	NTM	FI
Pine warbler	*Dendroica pinus*	14	SDM	PG
Pileated woodpecker	*Dryocopus pileatus*	14	R	FI
Prairie warbler	*Dendroica discolor*	18	NTM	PG
Red-bellied woodpecker	*Melanerpes carolinus*	13	R	FI
Red-eyed vireo	*Vireo olivaceus*	11	NTM	FI
Red-headed woodpecker	*Melanerpes erythrocephalus*	15	SDM	PG
Red-tailed hawk	*Buteo jamaicensis*	9	SDM	FE
Ruby-throated hummingbird	*Archilochus colubris*	12	NTM	FE
Red-winged blackbird	*Agelaius phoeniceus*	11	SDM	I
Scarlet tanager	*Piranga olivacea*	12	NTM	FI
Sharp-shinned hawk	*Accipiter striatus*	12	SDM	FI
Song sparrow	*Melospiza melodia*	8	SDM	FE
Spotted sandpiper	*Actitis macularius*	-	SDM	I
Summer tanager	*Piranga rubra*	16	NTM	FI
Swainson's warbler	*Limnothlypis swainsonii*	18	NTM	FI
Tree swallow	*Tachycineta bicolor*	9	SDM	I
Tufted titmouse	*Baeolophus bicolor*	13	R	FI
Turkey vulture	*Cathartes aura*	9	SDM	FE
White-breasted nuthatch	*Sitta carolinensis*	9	SDM	FE
White-eyed vireo	*Vireo griseus*	14	NTM	FE
Worm-eating warbler	*Helmitheros vermivorum*	14	NTM	FI
Wild turkey	*Meleagris gallopavo*	11	R	FE
Wood thrush	*Hylocichla mustelina*	15	NTM	FI
Yellow-breasted chat	*Icteria virens*	13	NTM	FE
Yellow-billed cuckoo	*Coccyzus americanus*	15	NTM	FI
Yellow warbler	*Dendroica petechia*	9	NTM	FE
Yellow-throated warbler	*Dendroica dominica*	16	NTM	FI

[a] Regional combined score for the breeding season in Region 27, Southeastern Coastal Plain. Larger numbers indicate greater conservation concern.
[b] R = resident, NTM = neotropical migrant, SDM = short-distance migrant.
[c] FI = forest interior, FE = forest edge, PG = pine-grassland, I = incidental.

Table 4.3. Means, standard errors, and *P*-values for total bird abundance (males/10 ha), species richness (species/10 ha), and Shannon H′ diversity. We surveyed birds during spring in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina.

		Treatment														
		WNBa		WHBa		NNBa		NNBr		NHBa		NHBr				
Index	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	DF	*F*	*P*[b]
Total abundance	1	7.1A[c]	1.0	6.5AB	2.2	4.2AB	1.5	3.6AB	1.4	3.0B	1.0	3.4B	1.1	5,25	4.40	0.005
	2	12.7A	1.2	7.8B	1.6	9.0B	1.7	8.3B	1.9	6.2B	1.6	6.4B	1.6	5,25	9.66	<0.001
	3	33.6	3.0	32.2	1.3	30.3	3.0	25.8	2.6	26.5	2.2	28.4	4.3	5,25	2.02	0.11
	4	37.2AB	6.5	46.3A	9.2	32.5B	5.8	32.4B	5.9	34.9AB	7.8	32.7AB	5.1	5,15	3.26	0.03
	6	30.9	5.0	32.9	5.2	23.5	4.5	25.4	5.1	26.4	3.9	32.7	5.8	5,15	3.09	0.04
	7	24.1	3.0	24.2	1.9	28.9	6.9	23.7	2.5	26.1	3.9	24.4	4.5	5,14	0.41	0.83
	8	15.4	2.5	16.3	2.7	18.6	3.7	20.2	2.9	16.3	2.1	15.5	2.3	5,14	1.03	0.44
Species richness	1	4.1A	0.7	3.6AB	1.1	2.6AB	0.7	2.3B	0.7	2.2B	0.7	2.2B	0.6	5,25	4.94	0.003
	2	6.1	0.6	4.3	0.7	4.3	0.8	3.8	0.6	3.7	0.7	3.8	0.7	5,25	2.71	0.04
	3	12.2	0.8	12.8	0.6	11.2	1.1	9.7	0.8	10.2	0.6	11.7	0.9	5,25	2.74	0.04
	4	11.6AB	2.2	15.0A	1.5	9.7AB	1.4	9.2	1.6	8.8B	2.3	9.1B	0.8	5,15	4.07	0.02
	6	8.3	1.1	10.1	0.5	7.1	0.8	7.1	1.6	7.4	0.9	9.1	1.1	5,15	3.13	0.04
	7	7.5	0.6	8.9	0.7	9.5	1.2	7.7	0.5	8.7	1.1	8.9	1.4	5,14	0.86	0.53
	8	7.1	1.0	8.2	0.9	7.7	0.9	7.0	0.6	7.0	1.1	7.5	0.7	5,14	0.56	0.73
Shannon H′	1	1.94	0.26	1.61	0.36	1.50	0.22	1.62	0.20	1.62	0.18	1.38	0.25	5,25	1.35	0.28
	2	2.01	0.21	1.81	0.11	1.69	0.15	1.61	0.16	1.81	0.07	1.80	0.10	5,25	1.15	0.36
	3	2.46	0.08	2.46	0.06	2.48	0.13	2.31	0.11	2.39	0.06	2.41	0.07	5,25	1.13	0.37
	4	2.30	0.24	2.43	0.06	2.24	0.16	2.15	0.19	1.96	0.21	2.05	0.14	5,15	1.18	0.36
	6	2.02	0.06	2.01	0.10	1.96	0.10	1.86	0.18	1.86	0.14	1.99	0.05	5,15	0.80	0.57
	7	2.10	0.05	2.19	0.12	2.18	0.01	1.99	0.06	2.06	0.07	2.07	0.08	5,14	0.78	0.58
	8	2.04	0.08	2.03	0.03	2.10	0.08	2.01	0.03	1.97	0.14	2.01	0.07	5,14	0.20	0.97

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Sites differed within all years ($P \leq 0.05$).

[c] Different letters within a row indicate differences among treatments among years.

Table 4.4. Total bird abundance (males/10 ha) and species richness (species/10 ha) means, standard errors, and p-values for within-year treatment component contrasts. We surveyed birds during spring in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina.

	Mechanical Site Prep. and Spacing[a]						Chemical Site Preparation[b]						Herbaceous Weed Control					
	RCN[c]		SSW				No		Yes				Banded		Broadcast			
Year	Mean	SE	Mean	SE	*F*	*P*[c]	Mean	SE	Mean	SE	*F*	*P*	Mean	SE	Mean	SE	*F*	*P*
Total abundance																		
1	3.6	0.9	6.8	1.2	12.94	0.003	5.0	0.8	4.3	0.9	1.02	0.32	3.6	0.9	3.5	0.8	0.02	0.88
2	7.6	1.2	10.2	1.2	16.16	0.001	10.0	1.0	6.8	0.9	26.49	<0.001	7.6	1.2	7.4	1.2	0.10	0.76
3	28.4	1.9	32.9	1.6	4.22	0.06	29.9	1.7	29.0	1.7	0.24	0.63	28.4	1.9	27.1	2.4	0.73	0.41
4	33.7	4.5	41.8	5.5	14.42	0.004	34.0	3.2	38.0	4.3	2.59	0.13	33.7	4.5	32.5	3.6	0.13	0.73
6	24.9	2.8	31.9	3.4	14.88	0.004	26.6	2.7	30.6	2.8	4.61	0.05	24.9	2.8	29.0	3.8	1.44	0.26
7	27.3	3.4	24.2	1.6	1.01	0.34	25.3	2.2	24.9	1.9	0.11	0.75	27.3	3.4	24.1	2.4	0.87	0.38
8	17.3	1.8	15.8	1.7	0.62	0.45	18.0	1.7	16.0	1.2	1.79	0.20	17.3	1.8	17.8	1.9	0.00	0.95
Species richness																		
1	2.4	0.5	3.9	0.6	16.32	0.001	3.0	0.4	2.7	0.5	0.96	0.34	2.4	0.5	2.2	0.4	0.23	0.64
2	4.0	0.5	5.2	0.5	4.87	0.04	4.7	0.4	3.9	0.4	3.17	0.09	4.0	0.5	3.8	0.4	0.27	0.61
3	10.7	0.6	12.5	0.5	5.54	0.03	11.0	0.5	11.5	0.5	0.82	0.38	10.7	0.6	10.7	0.7	0.01	0.94
4	9.2	1.2	13.3	1.4	17.83	0.002	10.2	1.0	11.0	1.2	0.67	0.43	9.2	1.2	9.2	0.8	0.00	0.96
6	7.3	0.6	9.2	0.6	11.90	0.007	7.5	0.7	8.9	0.6	5.84	0.03	7.3	0.6	8.1	1.0	1.17	0.31
7	9.0	0.8	8.2	0.5	1.21	0.30	8.1	0.5	8.8	0.6	0.44	0.52	9.0	0.8	8.3	0.7	1.13	0.32
8	7.3	0.7	7.6	0.6	0.05	0.83	7.2	0.4	7.6	0.5	0.14	0.72	7.3	0.7	7.3	0.4	0.04	0.86

[a] Mechanical site preparation and spacing treatments were paired.

[b] Chemical site preparation compared with orthogonal contrasts. Spacing and HWC treatments compared with t-tests.

[c] RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

[d] Degrees of freedom: year = 6, site = 5, comparison = 1, prep x HWC = 1, error = 25. Chemical prep x HWC and chemical prep x spacing not significant in any year. Sites differed within years ($P \leq 0.05$).

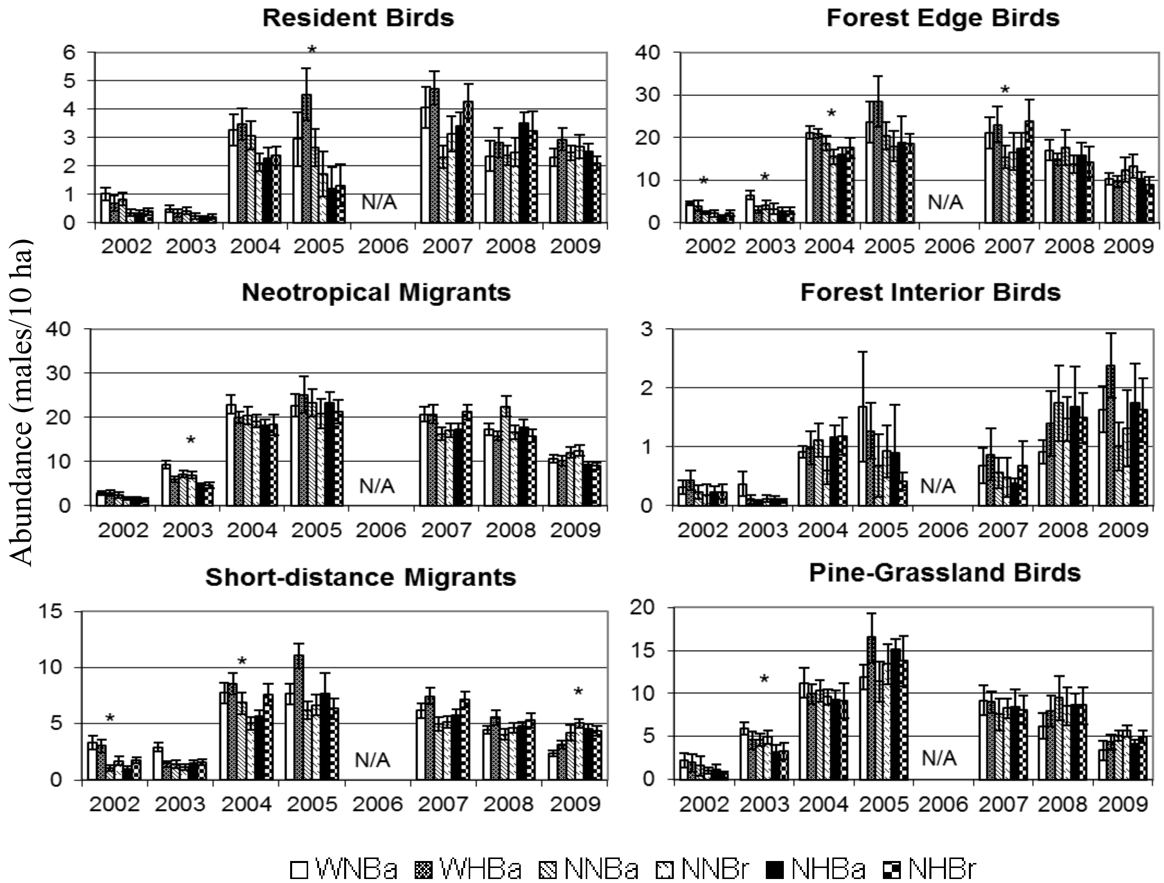

Figure 4.1. Bird abundance (males/10 ha) by migratory status and habitat association. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina. An asterix denotes treatment differences at $\alpha = 0.05$. Treatment abbreviations are: W = wide spacing, N = narrow spacing; N = no chemical site prep, H = chemical site prep; Ba = banded herbaceous weed control (HWC), and Br = broadcast HWC.

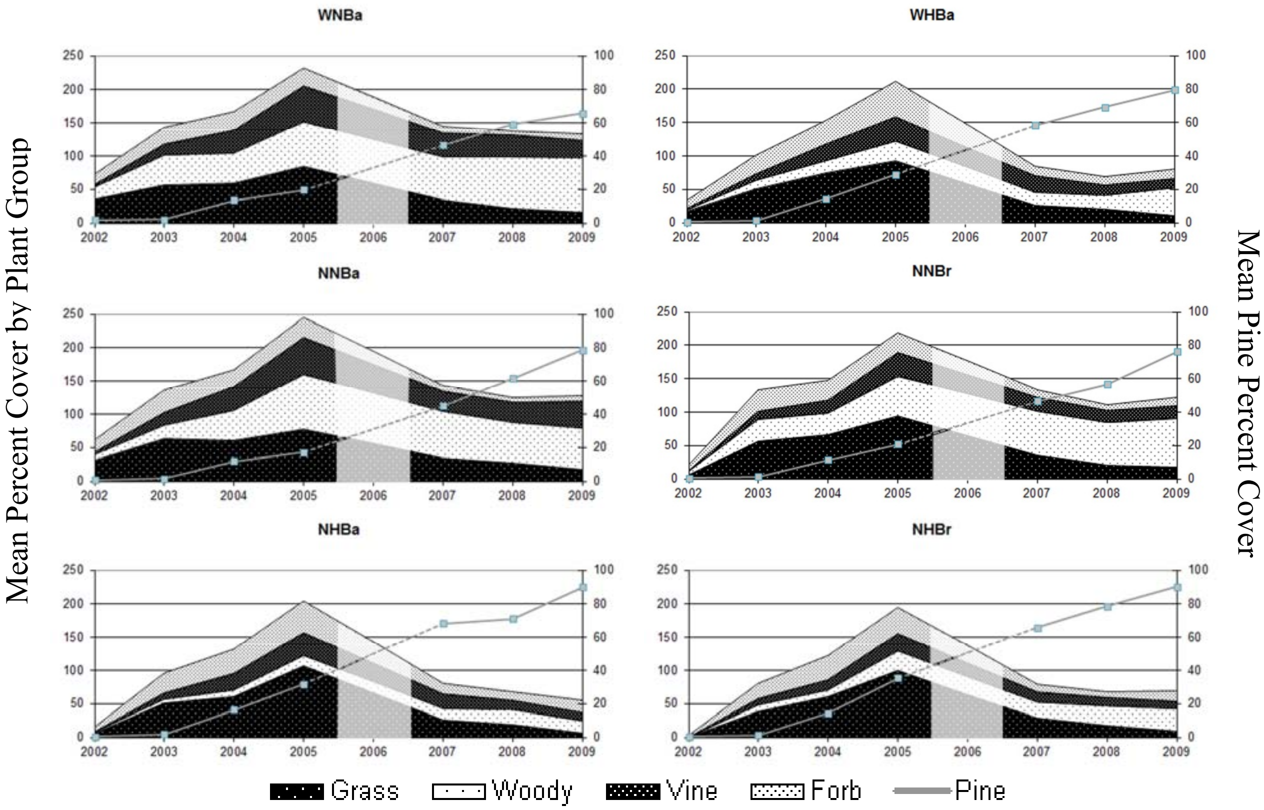

Figure 4.2. Mean grass, non-pine woody, vine, forb, and pine percent cover by year and treatment in the Coastal Plain of North Carolina. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) intensively managed loblolly pine plantations in the Coastal Plain of North Carolina.

CHAPTER 5

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Intensively managed pine forests are common in the Southeast, and various methods are available to reduce competing vegetation and promote pine growth (NCSSF, 2005; Miller et al., 2009). Mechanical site preparation removes, piles, or incorporates post-harvest residual vegetation, including coarse woody debris (CWD), into the soil (Yarrow and Yarrow, 2005). Chemical site preparation is frequently used to selectively inhibit growth of competing vegetation (Boyd et al., 1995) and tank mixes of multiple herbicides are often used to broaden vegetation control (Shepard et al., 2004). Chemical releases in the form of herbaceous weed control (HWC) can be used to reduce herbaceous vegetation shortly after planting or later in stand development (Cain, 1991). Although other studies have examined effects of stand initiation treatments on plants, pine growth, and wildlife (Brooks et al., 1993; Miller and Chapman, 1995; Edwards et al., 2006), few long-term studies exist that describe relationships between combinations of pine spacing, mechanical and chemical site preparation, and herbaceous weed control, and how they affect plant and wildlife communities. We determined how plants, small mammals, and birds responded to combinations of common site preparation techniques, including mechanical site preparation/pine spacing combinations, the use or lack of chemical site preparation, and 1 year broadcast or banded HWC.

We observed that site preparation and HWC techniques generally had short-term effects on plant, small mammal, and bird communities. Others have observed similar short-term effects (O'Connell and Miller, 1994; Boyd et al., 1995; Miller and Chapman, 1995), indicating that plant and wildlife communities are robust to intensive management techniques. Our site preparation techniques did not interact and appeared to have minor or no cumulative effects on plant, small mammal, and bird communities, although others have observed interactions among herbaceous and woody plant control and pine cover (Pearson et al., 1995; Zutter and Miller, 1998). Because a variety of site preparation and release treatments are available to forest managers, effects on plant and wildlife communities may vary and long-term studies can be challenging because management regimes change over time (Kilgo et al., 2000). Thus, by the time a study concludes, the management regimes selected for study may no longer be used by managers or new regimes may have emerged. However, long-term studies can provide valuable information about the timing of colonization of mid- to late-successional species altered by management practices within pine plantations, and should focus on commonly used management techniques.

We observed that either pine spacing or mechanical site preparation had short term, 1-4 year effects on plants and small mammals, but affected bird abundance up to 6 years following site preparation. Although our pine spacing treatments were paired with mechanical site preparation techniques, we attributed first- and second-year differences in plant, small mammal, and bird communities to effects of mechanical site preparation because pines were too young to alter communities through shading or changes in vegetation structure (Atkeson and Johnson, 1979; Miller et al., 1995). Mechanical site preparation influences amount of CWD available to small mammals (Carey and Johnson, 1995), while pine spacing appears to have minimal effect on small mammal communities (Bechard, 2008). Our strip-shear treatments had greater small mammal abundance and species richness over roller-chopped plots, likely due to more CWD typically associated with strip-shear mechanical site preparation (Yarrow and Yarrow, 2005). Wide pine spacing/strip-shear treatments supported more individual birds and bird species than narrow spacing/roller chop in the first 6 years following site preparation, but birds may have responded to structure of the pines themselves rather than distribution of CWD, perhaps as physical boundaries or perches for delineating or defending territories (Michener and Michener, 1935). Mechanical site preparation techniques that maximize CWD will likely benefit small mammals in the first few years following site preparation (Jones et al., 2009c), and wide pine spacing may improve habitat conditions for birds and other wildlife in later years by delaying pine canopy closure (Atkeson and Johnson, 1979).

Chemical site preparation had short-term, relatively minor effects on small mammal and bird communities, but changed plant communities by reducing woody cover and species richness in all years and increasing pine cover by year 4. Miller et al. (1991) and Borders and Bailey (2001) also noted increased pine growth with chemical woody control, and Jones et al. (2009b) also observed that chemical site preparation primarily affected vegetative communities after the first year in a mirror study within Mississippi. Decreased woody cover in our chemically prepared treatments may have extended availability of early successional habitat important for deer mice, eastern harvest mice, cotton rats, and house mice (Clark *et al.*, 1985; Bellows et al., 2001), but delayed golden mouse colonization in later years. Although Wilson et al. (1995) noted that bird densities were lowest on sites with dense woody midstories and sparse herbaceous ground cover, we observed greater bird densities on plots not receiving chemical preparation in the first 2 years following site preparation, likely due to increased vertical structure and woody and herbaceous cover. However, as woody vegetation became dense on our plots not receiving chemical preparation in later years, birds gradually became more abundant in chemically prepared plots. If chemical site preparation is used to give pines a competitive advantage over woody and herbaceous vegetation (Zutter and Miller, 1998; Miller et al., 2009), wide pine spacing would provide greater herbaceous plant coverage in the first few years after site preparation and improve habitat structure for birds in later years.

Relative to banded HWC, broadcast HWC reduced herbaceous plant cover, herbaceous species richness, and small mammal species richness in the first year following application, but the type of chemical HWC had no effect on bird communities. Herbaceous weed control treatments often have short-term effects on plant communities that are frequently confined to the first few years after application, with corresponding short-term effects on small mammals (Keyser et al., 2003; Edwards, 2004; Jones et al., 2009a). We observed no differences in pine cover between banded or broadcast HWC and other studies have shown similar pine growth between these HWC types (Knowe et al., 1985; Nelson et al., 1985). However, Jones (2008) observed greater pine growth and yield projections in broadcast HWC projections, but financial returns may only offset initial costs associated with more expensive and intensive broadcast HWC under optimal conditions. Although bird community measures did not differ between banded and broadcast HWC, banded HWC have less effects for small mammals and important wildlife food plants than broadcast HWC (Blake et al., 1987; Keyser et al., 2003; Edwards, 2004). Thus, banded HWC appears to support a more diverse plant community which can be beneficial to many wildlife species and may provide greater or equal returns on investment over broadcast HWC.

Intensive pine forest management through vegetation control can substantially increase timber yields (Borders and Bailey, 2001), but can also reduce plant and wildlife diversity which are increasingly important as forested habitats are fragmented, sold, and urbanized (Zutter and Miller, 1998; NCSSF, 2005; Jones et al., 2009b). Young pine plantations provide early successional habitat important for many wildlife species, and factors that delay canopy closure may extend availability of early successional habitat important for certain small mammal, bird, and other wildlife communities (Atkeson and Johnson, 1979; Langley and Shure, 1980; Childers et al., 1986). Therefore, managers should consider potential tradeoffs between wildlife habitat, pine production, and potential benefits versus costs of increasing management intensity when deciding upon site preparation techniques. In addition, effects of site preparation techniques on pine production and on plant, small mammal, and bird communities may vary depending upon local site conditions and plant communities. In our study, herbaceous competition appeared less important to pines, small mammals, and birds, but in a mirror study conducted in Mississippi, Jones (2008) observed an inverse relationship between herbaceous cover and pine growth. Therefore, understanding local site conditions is vital before implementing site preparation methods.

Pine plantations can support a variety of wildlife and plant species, particularly in the first few years after site preparation when early successional habitat is present (Wigley et al., 2000). We observed 40 grass, 62 woody tree and shrub, 18 vine, and 120 forb species or unique genera among all sites, for a total of 240 plant species across our study sites. We detected 11 small mammal species, including 2 southern bog-lemmings in Brunswick County, which is a range extension for this uncommon species (NCASI, 1982; Richardson, 1983; Clark et al., 1985). We also detected 76 bird species, including several that are in nationwide decline due in part to changing land-use practices that often do not incorporate frequent disturbances that are needed to maintain early successional habitat (Brennan and Kuvlesky, 2005). Although the role of pine plantations in the conservation of plant and wildlife diversity is a topic of debate (Brockerhoff et al., 2008), our study sites supported plants and animals typical of pocosin communities common in the Coastal Plain of North Carolina (Richardson, 1983), and may provide increasingly important wildlife habitat as areas in this heavily populated region are sold, parcelized, cleared, and drained for urban and suburban uses.

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APPENDIX A

SUMMARY DATA FOR PLANT SPECIES RECORDED ON STUDY SITES 2002-05 AND 2007-09 BY COMPOSITIONAL GROUP

Table A.1. Mean percent cover among all years and year of maximum abundance for plant species encountered on our treatments in intensively managed pine plantations in the Coastal Plain of North Carolina, 2002-05 and 2007-09. Blank cells = not encountered, trace = <0.01 % cover. Treatment abbreviations include: W = wide spacing, N = narrow spacing; N = no chemical site preparation, H = chemical site preparation; Ba = banded herbaceous weed control (HWC), Br = broadcast HWC.

	Treatment													
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr		Overall	
Grasses and Sedges	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Andropogon capillipes	4.42	3	10.80	3	5.74	3	7.58	2	9.76	4	9.14	4	7.94	3
Andropogon virginicus	4.31	4	2.51	4	4.73	4	5.99	3	5.62	4	5.82	4	4.84	4
Andropogon glomeratus			trace	8									trace	8
Andropogon sp.	0.12	3	0.68	4	0.10	8	0.06	3	0.13	6	0.10	4	0.20	5
Aristida stricta	1.04	4	0.22	4	0.72	7	1.30	3	0.37	7	0.45	4	0.68	5
Arundinaria gigantea	12.02	6	3.89	6	10.39	6	10.31	3	1.23	4	2.13	6	6.62	5
Carex glaucescens	0.90	3	0.49	4	0.41	4	0.50	4	0.58	4	0.40	4	0.55	4
Carex sp.	0.35	4	0.34	4	0.32	4	0.22	3	0.09	4	0.27	4	0.26	4
Chasmanthium laxum	0.22	4	0.91	4	0.45	4	0.55	3	0.33	4	0.08	4	0.42	4
Cyperus echinatus									trace	2			trace	2
Cyperus retrorsus	0.09	1	0.16	1	0.10	1	trace	1	0.05	1	0.01	1	0.07	1
Cyperus sp.	0.22	1	0.08	1	0.07	1	0.02	2	0.01	8	trace	1	0.07	2
Danthonia sericea	0.11	2	trace	2	0.17	2	0.14	1	0.44	2	0.45	2	0.22	2
Dichanthelium commutatum	0.05	2	0.10	2	0.07	2	0.03	1	0.19	2	0.21	2	0.11	2
Dichanthelium laxiflorum	trace	6	trace	6					0.01	6			trace	6
Dichanthelium sp.	0.74	4	1.42	4	0.63	4	0.58	4	0.75	4	0.58	4	0.79	4
Digitaria spp.	0.13	1	0.54	1	0.09	1	trace	1	0.05	1			0.14	1
Eleocharis sp.					0.01	6							trace	6
Eragrostis spectabilis			0.01	3					0.02	3			trace	3
Erianthus giganteus	0.12	4	0.10	4	0.16	4	0.43	4	0.25	4	0.26	3	0.22	4
Eriophorum virginicum	0.23	2	0.48	2	0.49	2	0.24	2	1.40	2	0.61	2	0.57	2
Fuirena squarrosa	0.01	3					trace	3					trace	3
Juncus coriaceus							0.06	2					0.01	2
Juncus diffusissimus	0.05	2											0.01	2

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr			
Grasses and Sedges	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Juncus effusus	0.09	3	0.13	6	0.25	6	0.05	6	0.08	3	0.16	3	0.12	5
Juncus marginatus	0.04	3	0.01	3	0.01	3	0.03	6	0.02	3	0.23	4	0.06	4
Juncus sp.	1.61	1	1.55	2	1.03	2	1.28	2	1.94	2	2.49	2	1.66	2
Microstegium vimineum	0.08	7	0.03	7	0.05	7	0.01	7	0.04	7	0.01	7	0.03	7
Muhlenbergia schreberi	0.12	7	0.53	7	0.25	8	0.20	3	0.32	7	0.07	3	0.25	6
Panicum dichotomiflorum	0.42	3	0.01	3	0.08	3	0.01	3	0.08	3	0.03	3	0.10	3
Panicum sp.	9.52	2	8.93	1	12.36	2	5.42	1	5.60	2	2.58	2	7.31	2
Paspalum notatum							trace	1					trace	1
Paspalum urvillei					0.03	3							trace	3
Piptochaetium avenaceum	0.07	1	0.01	1	0.04	1	0.24	2	0.04	3	0.02	1	0.07	2
Rhychospora cephalantha	0.02	3	0.17	3	0.03	3	0.10	3	0.17	3	0.01	2	0.08	3
Rhychospora chalarocephala					0.05	3	0.27	3	0.10	3	trace	3	0.07	3
Rhychospora filifolia							0.01	3			0.01	3	trace	3
Rhychospora glomerata									0.02	3			trace	3
Rhychospora microcarpa	trace	3			0.05	3	0.02	3	0.19	3	0.11	3	0.06	3
Rhychospora inexpansa					0.15	3	0.06	3	0.27	3	0.10	3	0.10	3
Rhynchospora nitens			0.01	3									trace	3
Rhychospora rariflora									0.03	3	0.06	3	0.02	3
Rhynchospora sp.	1.80	4	1.36	3	1.98	4	1.23	4	1.80	4	2.26	4	1.73	4
Scirpus cyperinus	1.86	4	0.97	4	1.45	4	1.43	3	2.56	4	3.31	4	1.93	4
Scirpus sp.	0.05	2	0.11	2	0.21	2	0.06	2	0.17	2	0.18	2	0.13	2
Scleria sp.	0.07	4	trace	6	0.10	4	0.02	4	0.03	4	0.05	4	0.04	4
Sorghum halepense	0.02	6	0.07	6	0.03	6	0.11	6	0.10	6	0.05	6	0.06	6
Sporobolus sp.			0.01	4			0.06	3	0.01	3			0.01	3
Typha sp.			0.01	4									trace	4
Unknown grass	1.98	2	2.67	2	1.84	2	2.25	2	1.03	2	1.45	2	1.87	2

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr			
Woody Trees and Shrubs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Acer rubrum	5.12	8	1.93	7	3.30	8	1.58	7	0.76	8	0.25	8	2.13	8
Aralia spinosa	0.33	3	0.53	8	0.54	7	0.16	3	0.27	6	0.13	7	0.32	6
Aronia arbutifolia	0.38	2	0.12	2	0.59	2	0.12	2	0.01	8	trace	7	0.20	4
Baccharis halimifolia	0.32	7	0.30	8	0.19	7	0.08	6	0.10	7	0.22	8	0.20	7
Callicarpa americana	0.01	4	0.01	2,4	0.02	2	trace	8	trace	7	0.01	8	0.01	6
Chamaecyparis thyoides	0.05	7							0.14	8	0.16	8	0.06	8
Clethra alnifolia	9.10	8	1.70	8	9.60	4	4.10	8	0.74	7	0.33	7	4.17	7
Cyrilla racemiflora	9.38	7	8.22	4	9.14	4	15.28	4	3.07	4	5.83	4	8.53	5
Diospyros virginiana	0.15	2	0.05	8	0.29	2	0.14	2	trace	8	0.03	8	0.11	4
Gaylussacia dumosa			0.07	8	trace	1	0.01	2			0.02	8	0.02	5
Gaylussacia frondosa	0.38	7	0.54	8	0.73	6	0.93	8	0.06	4	0.06	4	0.45	6
Gordonia lasianthus	0.40	2			0.16	2	0.04	2					0.10	2
Hypericum canadensis	0.02	6							trace	6			trace	6
Hypericum cistifolium	0.02	6	0.01	6	0.02	6	trace	6	0.01	6	0.01	6	0.01	6
Hypericum densiflorum			0.01	3	trace	3						2	trace	3
Hypericum gentianoides	0.04	1	0.03	2	0.06	1	0.26	1	0.18	1	0.11	3	0.11	2
Hypericum hypericoides	0.02	7	0.04	7	0.05	8	0.05	8	0.02	8	0.10		0.05	8
Hypericum reductum			trace	3									trace	3
Hypericum stans	0.02	8	0.04	3	0.02	3	0.05	4	0.04	8	0.06	3	0.04	5
Hypericum sp.	0.22	4	0.21	4	0.30	3	0.22	2	0.15	2	0.22	2	0.22	3
Ilex cassine var. *myrtifolia*	0.09	7	0.01	7	0.03	6	0.01	7	0.02	6	0.02	7	0.03	7
Ilex coriacea	1.01	2	0.10	3	0.25	2	0.12	2	0.10	3	0.03	3	0.27	3
Ilex glabra	7.35	7	1.48	8	5.00	3	4.52	8	1.13	7	3.46	8	3.81	7
Ilex opaca	0.01	4	0.02	7			trace	4,7	0.01	8	0.01	7,8	0.01	6
Ilex vomitoria			0.02	8			trace	1					trace	5
Ilex sp.	trace	3	trace	3	trace	3	0.01	3					trace	3
Juniperus virginiana	0.01	8							0.01	2	0.01	2	trace	4
Kalmia angustifolia									trace	2	0.01	6	trace	4
Lingustrum sinense			trace	7							trace	7	trace	7

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr			
Woody Trees and Shrubs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Liquidambar styraciflua	2.21	6	0.45	3	1.46	8	0.83	8	0.13	8	0.25	8	0.87	7
Liriodendron tulipifera	0.02	4			trace	7	trace	2	trace	4	0.01	4	0.01	4
Lyonia lucida	2.02	3	0.63	3	1.17	3	2.36	7	0.22	3	0.47	3	1.15	4
Malus spp.							0.02	8					trace	8
Magnolia grandiflora									0.01	8			trace	8
Magnolia virginiana	1.44	7	0.24	8	0.73	3	0.81	6	0.12	8	0.19	3	0.59	6
Mitchella repens	trace	6	trace	6									trace	6
Morella caroliniensis	0.06	6	0.06	6	0.16	8	0.17	6	0.02	6	0.03	6	0.08	6
Morella cerifera	0.93	8	0.82	4	1.29	8	0.64	4	0.29	7	0.50	8	0.74	7
Nyssa sylvatica	0.49	7	0.07	8	0.20	7	0.20	6	0.14	7	0.05	7	0.19	7
Persea borbonia	1.98	8	0.19	8	1.05	4	1.22	7	0.17	4	0.23	8	0.80	7
Pinus palustris			0.01	7									trace	7
Pinus taeda	27.37	8	31.57	8	25.59	8	27.20	8	35.36	8	37.05	8	30.78	8
Pinus sp.	0.73	2	0.69	2	0.29	2	0.21	2	0.38	2	0.51	2	0.47	2
Potentilla simplex			trace	6									trace	6
Prunus serotina	0.03	4	0.01	6	0.08	4					0.11	8	0.04	6
Prunus sp.			0.02	2									trace	2
Quercus alba					trace	2							trace	2
Quercus laurifolia							0.04	8					0.01	8
Quercus nigra	0.28	8	0.07	6	0.04	8	0.17	8	0.01	4	0.04	6	0.10	7
Quercus phellos	0.12	8	0.05	8	0.16	8	0.38	6	0.05	8	0.18	7	0.16	8
Quercus virginiana	trace	2											trace	2
Quercus sp.	trace	2			0.03	2	trace	1,2	trace	1			0.01	2
Rhododendron viscosum			trace	7	0.08	6	0.06	7	trace	7			0.02	7
Rhus copallinum	4.54	4	1.85	4	5.83	6	4.90	6	1.73	6	2.27	7	3.49	6
Rhus glabra			trace	1									trace	1
Salix sp.	trace	6	0.02	4									trace	5
Sambucus canadensis			0.02	6	0.01	6							trace	6
Sassafras albidum	0.01	7			0.04	6	0.08	8					0.02	7

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr		Overall	
Woody Trees and Shrubs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Stewartia malacodendron	0.09	7	0.12	7	0.06	7	0.03	7	0.03	8	trace	8	0.05	7
Symplocos tinctoria	0.71	8	0.18	6	1.22	7	1.06	8	0.14	8	0.19	4	0.58	7
Vaccinium arboreum	0.16	1	0.05	7	0.17	1	0.08	1	0.01	3,4	0.01	7	0.08	3
Vaccinium corymbosum	0.40	8	0.06	6	0.52	6	0.20	8	0.16	7	0.06	7	0.23	7
Vaccinium crassifolium	2.01	4	0.27	8	1.21	4	1.53	4	0.74	6	0.99	3	1.12	5
Vaccinium elliottii	0.02	4	trace	8	0.02	4	0.06	8	trace	6	0.01	8	0.02	6
Vaccinium stamineum	0.47	3	0.09	3	0.26	4	0.35	8	0.06	4	0.07	3	0.21	4
Vaccinium sp.	0.42	2	0.20	7	0.57	2	0.31	1	0.08	3	0.06	3	0.27	3
Zenobia pulverulenta	0.05	3					0.04	3	0.01	3	0.03	3	0.02	3
Unknown shrub	0.03	3	0.07	4	0.20	4	0.04	8	0.02	3	0.04	3,8	0.06	4

Vines														
Bignonia capreolata					trace	7							trace	7
Campsis radicans					0.02	8	0.02	4					0.01	6
Gelsemium sempervirens	2.17	4	1.54	4	1.32	7	0.85	4	2.38	4	0.45	6	1.44	5
Ipomoea quamoclit	trace	1											trace	1
Lonicera japonica	0.02	7	0.38	7	trace	4	0.01	6,7	0.10	8	0.04	7	0.09	7
Mikania scandens	0.03	3	0.06	4	0.02	4			0.01	1,4			0.02	4
Parthenocissus quinquefolia	1.58	7	0.27	8	1.26	8	1.31	4	0.19	6	0.16	8	0.79	7
Rubus argutus	4.38	3	4.60	6	5.04	3	3.03	3	5.58	3	4.14	4	4.44	4
Rubus cuneifolius	1.44	4	4.10	4	2.36	4	2.08	4	2.10	4	1.48	4	2.26	4
Rubus trivialis	0.02	3	0.07	3	0.04	3	0.09	3	0.29	3	0.12	3	0.11	3
Rubus sp.	1.56	2	1.74	2	1.87	2	1.00	2	1.62	2	1.47	2	1.53	2
Smilax bona-nox	0.05	3	0.03	6	0.05	6	0.09	3	0.04	4	0.04	6	0.05	5
Smilax glauca	1.12	6	0.25	8	0.37	7	0.38	8	0.15	8	0.13	8	0.40	8
Smilax laurifolia	1.60	3	1.14	3	3.68	3	1.48	3	0.86	4	2.00	4	1.77	3
Smilax rotundifolia	0.45	7	0.03	2	0.10	6	0.18	6	0.03	7	0.01	7	0.13	6
Smilax sp.	0.28	2	0.08	2	0.37	2	0.30	2	0.03	2	0.12	2	0.20	2

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr			
Vines	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Toxicodendron radicans	8.65	4	0.65	8	7.59	8	3.57	4	0.27	4	0.44	8	3.46	6
Vitis aestivalis	trace	1			0.01	1	0.01	2					trace	1
Vitis labrusca	0.02	6			0.05	8	0.04	6	0.01	7	trace	6	0.02	7
Vitis rotundifolia	2.17	6	1.60	6	2.27	8	1.62	4	0.47	7	0.71	8	1.46	7
Vitis sp.	0.01	4	0.01	3	0.01	8			0.01	3	0.01	4	0.01	4
Unknown vine					trace	4	0.15	3	0.01	3	0.01	3	0.03	3

Forbs														
Acalypha virginica	0.01	1	0.01	1	0.01	1							trace	1
Agalinus sp.							trace	2	trace	2	0.02	2	trace	2
Aletris farinosa	0.01	6	0.01	2	0.01	4	trace	8	0.01	7,8	trace	8	0.01	6
Ambrosia artemisiifolia	trace	4	0.03	4	0.01	4	trace	4	0.01	4	0.01	4	0.01	4
Amorpha herbacea	0.03	8	0.24	1	0.10	7	0.02	6	0.02	4	0.03	8	0.07	6
Asplenium platyneuron			0.01	6			trace	7			0.01	7	trace	7
Aster dumosus	0.03	4			0.02	3			0.05	3			0.02	3
Aster patens	trace	1											trace	1
Aster squarrosa	0.04	2	0.01	2									0.01	2
Aster sp.	0.17	4	0.11	1	0.20	4	0.02	3	0.19	4	0.11	4	0.13	3
Astilbe biternata			0.01	1					trace	2			trace	2
Baptista bracteata			trace	8					trace	8			trace	8
Baptisia cinerea	trace	2											trace	2
Baptisia tinctoria	0.01	8					trace	8					trace	8
Baptisia sp.									trace	1			trace	1
Boehmeria cylindrica			0.02	6									trace	6
Centella asiatica	trace	8	trace	6	0.04	3					trace	6	0.01	6
Chamaecrista fasciculata	0.04	2	0.31	1	0.09	4	0.13	2	0.10	1	0.05	2	0.12	2
Chrysopsis mariana	trace	2	trace	2	trace	1							trace	2
Cirsium sp.	0.01	4	0.01	4,7,8	0.03	4			0.03	4	trace	4,8	0.01	4

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr		Overall	
Forbs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Clitoria mariana	0.01	6	0.01	6									trace	6
Collinsonia serotina			trace	6					0.04	6	trace	6	0.01	6
Conyza canadensis	0.04	2	0.22	2	0.02	2	0.01	2	0.02	2	0.04	2	0.06	2
Croptilon divaricatum	trace	1	trace	2	0.01	1	trace	1	trace	1	trace	1	trace	1
Croton glandulosus							trace	1					trace	1
Desmodium obtusum			trace	2									trace	2
Desmodium rotundifolium	0.03	8	0.05	8	0.04	7	0.01	1	0.01	6,7			0.02	6
Desmodium strictum	trace	7			trace	8	trace	2	trace	6			trace	6
Desmodium sp.	0.02	4	0.10	4	0.08	4	0.03	4	0.01	4	0.03	4	0.05	4
Diodia teres			trace	1	0.02	1			trace	1	trace	1	trace	1
Diodia virginia			trace	7	trace	7							trace	7
Drosera rotundifolia			trace	2									trace	2
Drosera sp.	trace	2			trace	2					trace	4	trace	3
Dryopteris ludoviciana	0.01	7	0.08	7									0.02	7
Elephantopus tomentosus	0.01	4	trace	1	0.02	4	trace	4					0.01	3
Erechtites hieracifolia	0.69	2	1.05	2	1.04	2	0.93	3	1.27	2	0.57	2	0.92	2
Erigeron strigosus									trace	1			trace	1
Erigeron vernus	0.02	8	0.01	8	0.03	6	trace	7	0.03	6	0.15	7	0.04	7
Erigeron sp.	0.01	1,2	0.02	3	0.02	3	trace	3	0.01	2	0.02	8	0.01	4
Eriocaulon compressum	trace	6	0.01	7							0.01	8	trace	7
Eriocaulon decangulare	0.07	6	0.02	6			0.02	4	trace	3	0.07	3,4	0.03	5
Eryngium integrifolium									trace	3			trace	3
Eupatorium capillifolium	2.15	2	3.05	3	3.59	2	4.07	2	5.47	3	6.50	3	4.15	3
Eupatorium compositifolium							trace	3					trace	3
Eupatorium dubium	trace	6	0.01	6	0.01	6							trace	6
Eupatorium mohrii	0.01	3	trace	3			0.01	3	0.01	3	trace	3	0.01	3
Eupatorium perfoliatum	trace	1											trace	1
Eupatorium pilosum	0.03	4	0.15	4	0.17	3	0.23	3	0.61	4	0.05	4	0.20	4
Eupatorium rotundifolium	0.14	7	0.15	7	0.39	4	0.19	4	0.48	4	0.21	4	0.26	5

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr		Overall	
Forbs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Eupatorium rugosum	trace	3			0.01	3	0.01	3	0.01	3	0.03	3	0.01	3
Eupatorium serotinum	0.07	8	0.01	3	0.06	8	0.04	2	0.07	8	0.04	2	0.05	5
Eupatorium sp.	0.19	4	0.33	4	0.08	4	0.17	4	0.12	2	0.26	4	0.19	4
Euphorbia pubentissima			0.02	2			trace	1					trace	2
Euphorbia sp.											trace	2	trace	2
Euthamia tenuifolia	0.73	4	0.92	4	0.67	3	0.55	4	1.57	4	0.91	4	0.89	4
Galactia volubilis					trace	7	0.01	3					trace	5
Galium tinctorium			0.01	8	trace	6							trace	7
Galax urceolata	0.03	1			0.10	2							0.02	2
Gamochaeta purpureum			trace	4,6	trace	6	trace	4					trace	5
Gratiola pilosa			trace	1			trace	3					trace	2
Helenium amarum	0.33	2	0.17	2	0.23	2	0.05	2	0.18	2	0.07	2	0.17	2
Heterotheca subaxillaris	0.02	7	trace	1	0.01	7	trace	7	0.01	7	0.01	7	0.01	6
Iris tridentata	0.12	8	trace	8									0.02	8
Iris sp.	trace	2											trace	2
Kuhnia eupatoioides	trace	2					trace	2	trace	2			trace	2
Kummerowia stipulacea	trace	1			trace	1					trace	3	trace	2
Lachnanthes caroliana	2.53	3	3.09	4	0.93	2,3	2.21	3	1.04	3	0.93	3	1.80	3
Latuca sp.							0.00	3					trace	3
Lespedeza angustifolia	0.01	1											trace	1
Lespedeza cuneata	0.02	6	0.15	4	0.02	1,3	0.04	3	0.10	3	0.05	4	0.06	4
Lespedeza hirta			0.01	8									trace	8
Lespedeza procubens	trace	6			0.01	6							trace	6
Lespedeza repens		7			trace	8	trace	7	0.05	7	trace	7	0.01	7
Lespedeza virginica	0.01	4	0.02	7	0.01	2	0.02	7	0.03	6	0.01	2	0.02	5
Lespedeza sp.	0.02	2	0.09	4	0.04	4	0.03	4	0.05	4	0.04	4	0.04	4
Liatris graminifolia	trace	2			0.03	2			trace	2			0.01	2
Liatris sp.			trace	2	0.01	2	0.01	2	trace	3	0.01	2	0.01	2
Lobelia brevifolia					trace	1							trace	1

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr		Overall	
Forbs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Lobelia cardinalis			trace	1									trace	1
Lobelia nuttallii			trace	4					trace	3,8			trace	4
Lobelia puberula	0.02	2	0.02	2	0.02	2	0.01	2	0.01	2	0.01	2	0.02	2
Ludwigia alternifolia	0.01	1	0.01	2	0.07	2	trace	2	0.03	2	trace	3	0.02	2
Ludwigia hirtella					0.01	3							trace	3
Ludwigia linearis	0.01	8			trace	4	0.01	4	0.05	3	trace	3	0.01	4
Ludwigia pilosa	0.01	3			0.01	3							trace	3
Ludwigia sp.	0.12	4	0.08	3	0.17	4	0.03	3	0.02	4	0.01	4	0.07	4
Mimosa quadrivalvis			0.06	4									0.01	4
Micranthemum umbrosum					trace	2							trace	2
Nuttallanthus canadensis	trace	1											trace	1
Oenethera sp.					trace	7			trace	7			trace	7
Opuntia sp.			trace	4									trace	4
Osmunda cinnamomea	0.28	2	0.52	3	0.19	6	0.17	8	0.05	8	0.09	3	0.22	5
Osmunda regalis	0.03	6	0.18	2	0.03	8			0.02	3	0.03	8	0.05	5
Oxalis sp.			trace	7									trace	7
Phytolacca americana	1.45	1	0.71	1	2.99	1	1.92	2	0.76	2	0.51	2	1.37	2
Pityopsis graminifolia	0.39	2	0.16	2	0.39	2	0.27	2	0.28	2	0.10	2,4	0.26	2
Pluchea faotida	0.01	3	0.03	4	0.01	4	trace	4					0.01	4
Polygala curtissii	trace	2			0.01	2	trace	2	trace	2	trace	2	trace	2
Polygala incarnata			trace	2			trace	2	trace	2	trace	2	trace	2
Polygala lutea	0.04	2	0.04	3	0.04	2	0.04	4	0.04	2,4	0.02	4	0.04	3
Polygala mariana	trace	1	trace	1					trace	1			trace	1
Polygala ramosa	trace	6	trace	3	trace	3	trace	6	trace	6	trace	2,4,6	trace	5
Polygala sp.	0.01	4	0.01	4	trace	4			0.01	4			trace	4
Polygonum hydropiperoides	0.01	6			0.02	8	0.05	6	trace	6			0.01	7
Polygonum sp.	0.11	1	0.15	2	0.49	2	0.01	4	0.01	1	trace	2	0.12	2
Polypremum procumbens			trace	1									trace	1
Prosperpinaca pectinata	0.06	2	0.01	6	0.03	4	0.03	3	0.06	2	0.08	4	0.05	4

	Treatment													
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr		Overall	
Forbs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Pseudognaphalium obtusifolium	0.15	2	0.07	2	0.20	2	trace	1,2	0.01	2	trace	2	0.07	2
Pteridium aquilinum	1.47	8	6.03	8	2.33	4	4.32	8	5.85	8	2.87	8	3.84	7
Ptilimnium capillaceum	0.01	2			trace	2							trace	2
Pycnanthemum flexuosum	0.01	7	0.02	7	trace	7	0.02	2	trace	7	trace	6	0.01	6
Rhexia alifanus	0.01	4	0.02	6	0.02	4	0.01	4	0.01	4	0.02	4	0.01	4
Rhexia lutea	0.02	6	trace	7			trace	7			trace	6	trace	7
Rhexia mariana	0.15	4	0.19	3	0.25	3	0.23	3	0.21	4	0.38	4	0.23	4
Rhexia virginica	0.17	2	0.10	2	0.25	2	0.07	2	0.10	2	0.05	6	0.12	3
Rhexia sp.	0.05	7	0.08	7	0.05	2	0.04	4	0.06	4	0.01	3	0.05	5
Rhynchosia tomentosa	trace	7							trace	2,7	trace	7	trace	7
Rhynchosia sp.	trace	7	0.01	7									trace	7
Sabatia campanulata	0.06	4	0.01	4	0.05	4			0.02	7	0.07	4	0.03	5
Sabatia difformis	0.01	7	0.01	6	trace	7					0.01	4	0.01	6
Sabatia stellaris	trace	2											trace	2
Sabatia sp.	trace	7			trace	1			trace	7			trace	5
Sarracenia alata	trace	8											trace	8
Scutellaria integrifolia			trace	1									trace	1
Scutellaria nervosa	0.01	6	0.02	6	trace	6	0.02	6	0.04	6	0.01	6	0.02	6
Solanum carolinense	trace	8	0.04	2	0.01	1	0.02	1	trace	8	0.01	4	0.01	4
Solidago fistulosa	0.31	3	0.11	3	0.14	3	0.12	3	0.11	3	0.06	3	0.14	3
Solidago sp.	0.70	4	0.36	4	0.77	4	0.09	4	0.88	4	0.49	4	0.54	4
Sonchus asper			trace	1	0.01	1			0.01	1	trace	1	trace	1
Strophostyles sp.	0.09	7	0.06	7	0.07	7	0.02	7	0.19	7	0.01	7	0.07	7
Stylosanthes biflora	0.01	2,8	trace	1	trace	8	0.01	1	0.01	1	trace		trace	3
Taraxacum sp.	trace	2											trace	2
Tephrosia spicata	0.02	6	0.02	1	0.02	8	0.04	8	0.04	1	0.04	1	0.03	4
Tephrosia virginica	trace	7	0.01	7					0.01	7	0.00	7	trace	7
Viola blanda	0.09	1	0.09	2	0.06	2	0.05	2	0.07	2	0.06	2	0.07	2
Viola lanceolata	0.01	6	0.01	6	0.01	8	trace	6			trace	6	0.01	6

	Treatment												Overall	
	WNBa		WHBa		NNBa		NNBr		NHBa		NHBr			
Forbs	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Cover	Yr Max	Mean	Yr Max
Viola primulifolia	trace	2											trace	2
Viola septemloba	trace	7	0.02	7	0.01	7	trace	7	0.02	6	0.01	2,7	0.01	7
Viola sp.	0.10	2,6	0.06	2,4	0.37	4	0.06	2	0.05	8	0.05	6	0.11	5
Woodwardia areolata	0.17	4	0.10	6	0.15	4	0.05	4	0.22	4	0.48	4	0.19	4
Woodwardia virginica	2.20	3	2.14	4	1.45	2	2.10	4	0.50	8	1.86	8	1.72	5
Xyris ambigua	0.03	7	trace	7	0.07	3	0.01	7	0.07	7	0.01	7	0.03	6
Xyris sp.	0.23	4	0.04	4	0.14	4	0.06	4	0.07	4	trace	4	0.09	4
Unknown forb	0.50	6	0.71	4	0.51	4	0.21	4	0.36	4	0.26	4	0.42	4

Table A.2. Vegetation percent cover and species richness means, standard errors, and p-values from repeated measures split plot analysis for treatment comparisons among years. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina.

Vegetation	Treatment													
	WNBa[a]		WHBa		NNBa		NNBr		NHBa		NHBr		*P*-values[b]	
type	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Trt	Yr x trt
Percent cover														
Grasses	42.9[c]	7.0	39.3	6.7	44.6	7.5	40.8	8.0	35.9	7.3	33.7	7.4	0.41	0.07
Pine	25.9AB	4.7	32.2AC	5.8	24.6B	5.1	26.5B	5.1	34.9C	6.2	35.8C	6.2	0.03	0.02
Woody	53.6A	7.0	21.7B	4.0	47.2C	7.6	43.5C	7.3	11.3D	2.4	17.4D	4.2	<0.001	0.64
Vines	25.6A	5.9	16.6B	3.8	26.4A	5.2	16.2B	4.6	14.1B	3.1	11.3B	2.5	0.008	0.99
Forbs	16.9	3.8	22.9	4.8	19.6	4.4	18.9	4.2	21.9	4.7	17.9	3.9	0.69	0.85
Total	139.0A	11.2	100.5BC	11.9	137.8A	11.7	119.4AB	12.9	83.2C	12.0	80.4C	11.7	<0.001	0.99
Species richness														
Grasses	3.2	0.4	3.4	0.4	3.3	0.4	3.0	0.4	3.3	0.4	3.1	0.5	0.82	0.66
Woody	6.5A	0.5	4.2B	0.5	6.0AC	0.5	5.5C	0.5	3.5D	0.4	3.5D	0.4	<0.001	0.99
Vines	3.0	0.3	2.2	0.3	2.7	0.3	2.2	0.3	2.0C	0.3	1.9	0.2	0.06	0.97
Forbs	3.8	0.7	4.2	0.7	4.2	0.7	3.3	0.5	4.0	0.6	3.3	0.6	0.66	0.16
Total	16.5A	1.3	14.0B	1.3	16.2A	1.3	13.9B	1.2	12.8B	1.2	11.8C	1.2	<0.001	<0.001

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Degrees of freedom: yr = 6, site = 5, trt = 5, yr x trt = 30, error = 122. Effects of site and year were significant ($P \leq 0.05$). We used a treatment x site interaction as our error term in repeated measures analyses.

[c] Different letters within a row indicate differences among treatments among years.

Table A.3. Vegetation percent cover and species richness means, standard errors, and contrast results from repeated measures split plot analysis for individual treatment component comparisons among years for vegetation types found to differ by treatment in overall repeated measures split plot analysis (Table A.2.). We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina.

	Spacing[ab]						Chemical Site Preparation						Herbaceous Weed Control					
Vegetation	Narrow		Wide				No		Yes				Banded		Broadcast			
Type	Mean	SE	Mean	SE	*F*	*P*[c]	Mean	SE	Mean	SE	*F*	*P*	Mean	SE	Mean	SE	*F*	*P*
Percent cover																		
Pine	29.9	4.1	29.0	3.7	0.23	0.65	25.7	2.9	34.3	3.5	11.75	0.002	29.9	4.1	31.1	4.0	0.00	0.96
Woody[de]	28.9	4.1	38.6	3.8	55.72	<0.001	49.0	3.6	16.7	1.7	115.48	<0.001	28.9	4.1	30.2	3.9	0.08	0.79
Vine[de]	22.3	2.9	23.1	3.3	0.02	0.88	24.8	2.9	15.1	1.5	12.14	0.002	22.3	2.9	14.4	2.1	8.48	0.03
Total[de]	115.3	9.1	124.9	8.1	15.66	0.01	136.8	6.7	92.0	6.8	99.76	<0.001	115.3	9.1	102.2	8.7	4.39	0.09
Species richness																		
Woody[de]	4.7	0.3	5.4	0.3	2.53	0.17	6.0	0.2	3.7	0.2	61.16	<0.001	4.7	0.3	4.5	0.3	2.51	0.17
Total[de]	14.8	0.9	15.4	0.8	2.34	0.19	15.7	0.7	13.1	0.7	36.63	<0.001	14.8	0.9	13.0	0.8	9.11	0.03

[a] Degrees of freedom: year = 6, site = 5, comparison = 1, interactions = 1, error = 174 for chemical site preparation, 108 for spacing and herbaceous weed control (HWC).

[b] Spacing and HWC treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

[c] Sites differed among years ($P \leq 0.05$). We used a treatment x site interaction as our error term in repeated measures analyses.

[d] Significant chemical site preparation by spacing interaction (banded HWC only).

[e] Significant chemical site preparation by HWC (narrow spacing only).

Table A.4. Non-pine and pine woody percent cover and woody richness means and standard errors for within-year ANOVAs. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina.

		Treatment														
Vegetation		WNBa[a]		WHBa		NNBa		NNBr		NHBa		NHBr				
type	Yr	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	DF	*F*	*P*[b]
Woody	1	18.3A	4.4	3.5CD	0.5	9.9AB	1.8	6.7BC	2.2	0.8DE	0.5	0.5E	0.1	5,25	24.45	<0.001
Cover	2	45.2A	8.9	13.2BC	2.4	40.0A	10.9	33.0AB	12.7	6.1C	1.1	9.3C	0.9	5,25	11.55	<0.001
	3	46.6A	12.6	19.2BC	5.8	46.0A	12.7	32.5AB	9.5	9.2C	4.4	10.5C	5.0	5,18	14.99	<0.001
	4	67.7A	21.8	29.8BCD	7.2	82.5AB	30.2	59.3ABC	14.7	16.1D	4.8	30.1CD	12.4	5,15	7.45	0.001
	6	65.5A	12.6	30.4B	9.2	70.4A	19.9	65.8A	17.4	17.4B	5.3	23.3B	12.1	5,15	15.64	<0.001
	7	77.0A	17.8	30.6BC	9.1	61.7ABD	21.7	64.0AB	21.2	22.0C	6.4	28.9CD	14.0	5,14	11.46	<0.001
	8	80.6A	14.9	40.4BC	9.5	61.4ABD	18.2	72.7AB	22.6	16.8C	3.1	33.2CD	13.0	5,14	11.85	<0.001
Pine	1	1.9	0.7	0.5	0.1	0.7	0.2	0.4	0.1	0.5	0.2	0.4	0.2	5,25	0.46	0.81
Cover	2	2.1	0.9	1.2	0.4	1.5	0.4	1.2	0.4	1.7	0.7	1.4	0.4	5,25	0.65	0.66
	3	13.6	3.8	14.5	8.8	11.8	1.4	11.4	0.8	16.4	3.0	14.4	4.4	5,18	0.37	0.86
	4	19.8A	2.9	28.9A	7.0	17.1A	5.3	20.8A	6.7	31.8A	2.8	35.2A	2.9	5,15	3.07	0.04
	6	46.4A	8.5	58.3A	11.7	44.9A	8.2	46.4A	10.4	68.3A	9.8	65.8A	6.2	5,15	3.28	0.03
	7	59.2A	7.0	69.1A	10.2	61.6A	6.6	56.6A	9.1	71.0A	2.8	78.7A	3.9	5,14	2.93	0.05
	8	65.7A	7.0	79.4A	9.9	78.6A	6.1	76.2A	7.9	90.0B	5.0	90.4B	3.6	5,14	3.48	0.03
Woody	1	4.9A	0.6	2.3BC	0.4	4.4A	0.9	3.3AB	0.7	1.2C	0.2	1.1C	0.1	5,25	13.82	<0.001
Richness	2	6.0A	0.6	3.4BC	0.6	5.8A	1.0	4.7AB	0.6	2.7C	0.5	2.8C	0.2	5,25	12.28	<0.001
	3	6.1A	0.5	3.7BC	0.4	6.2A	1.0	5.1AB	0.7	3.3C	0.7	3.1C	0.7	5,18	14.33	<0.001
	4	7.4A	0.7	5.5AB	1.2	6.9AB	0.9	6.5AB	0.7	4.8B	0.2	4.4B	0.4	5,15	5.37	0.005
	6	7.5A	1.0	5.4AB	1.3	6.6AB	0.9	6.7AB	1.0	4.4B	0.4	4.6B	0.6	5,15	4.84	0.008
	7	7.7A	1.3	5.2B	1.2	6.8AB	1.6	6.4AB	1.0	4.9B	0.6	4.6B	0.7	5,14	6.75	0.002
	8	7.5A	1.3	5.9AB	1.3	6.9AB	1.6	7.4AC	1.0	5.1B	0.5	5.4BC	0.7	5,14	5.29	0.006

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC) Br=broadcast HWC

[b] Sites differed within all years ($P \leq 0.05$).

[c] Different letters within a row indicate differences among treatments among years.

[d] Differences present within all years, therefore values taken from repeated measures split plot analysis among years.

Table A.5. Herbaceous plant percent cover means and standard errors for within-year ANOVAs. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina.

		Treatment														
Vegetation		WNBa[a]		WHBa		NNBa		NNBr		NHBa		NHBr				
type	Yr	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	DF	*F*	*P*[b]
Grasses	1	36.0A[c]	10.6	16.7BC	8.3	31.0AB	12.4	6.3CD	4.0	8.1CD	5.5	0.8D	0.4	5,25	17.78	<0.001
	2	56.2	16.3	50.5	12.9	63.3	15.1	56.8	17.8	50.9	18.3	39.3	13.3	5,25	1.94	0.12
	3	58.7	13.1	73.6	11.9	59.9	12.4	66.3	17.8	61.3	7.2	60.7	12.2	5,18	0.63	0.68
	4	84.4	26.3	92.6	20.6	77.4	30.8	94.9	33.6	106.8	24.2	100.2	30.1	5,15	2.14	0.12
	6	34.2	15.8	25.7	7.1	34.2	19.8	36.0	18.6	26.3	10.9	29.1	11.1	5,15	0.20	0.96
	7	21.9	10.6	20.4	5.4	26.8	12.9	21.1	11.2	19.1	9.2	18.4	7.8	5,14	0.17	0.97
	8	17.3	7.6	11.7	3.6	18.2	11.4	18.2	10.9	7.6	3.9	9.6	5.4	5,14	0.72	0.62
Vines	1	4.7A	1.3	2.2BC	1.2	3.9AB	1.2	1.3C	0.5	0.8C	0.6	0.6C	0.4	5,25	12.18	<0.001
	2	16.1AB	3.7	10.0BC	3.6	19.2A	3.7	11.7ABC	5.4	8.6C	3.6	8.7C	4.5	5,25	6.10	<0.001
	3	34.1	12.6	25.9	7.6	36.6	6.7	19.8	7.5	24.1	6.8	14.7	2.3	5,18	2.20	0.10
	4	53.9	28.5	37.0	17.2	55.7	22.0	35.6	23.0	34.1	7.8	25.3	2.8	5,15	1.82	0.17
	6	35.0	18.0	24.4	9.8	30.0	13.5	20.2	11.6	20.4	5.7	14.7	2.9	5,15	1.47	0.26
	7	32.3	15.7	16.4	5.4	29.4	9.1	17.6	8.9	14.1	5.0	12.2	3.0	5,14	1.38	0.29
	8	26.2	13.9	14.6	4.7	40.2	17.4	19.7	10.7	12.7	4.0	11.5	2.5	5,14	1.57	0.23
Forbs	1	13.8A	5.7	12.1BC	6.1	16.9AB	9.2	7.7C	3.6	5.7C	2.6	1.3C	0.7	5,25	12.18	<0.001
	2	25.4AB	6.1	28.7BC	7.7	33.9A	11.6	32.9ABC	12.9	30.2C	12.8	22.2C	9.2	5,25	6.10	<0.001
	3	27.5	7.9	34.3	6.3	24.6	3.9	28.5	6.1	37.0	2.4	36.4	8.6	5,18	2.20	0.10
	4	27.2	13.1	53.4	20.2	30.3	14.5	29.8	9.4	48.0	8.4	39.8	6.3	5,15	1.82	0.17
	6	10.3	8.7	14.2	10.2	8.8	4.4	11.5	7.3	15.9	7.4	11.6	5.8	5,15	1.47	0.26
	7	5.9	5.2	12.1	10.1	6.6	5.2	8.9	7.3	12.0	7.6	8.6	5.5	5,14	1.38	0.29
	8	8.6	8.0	14.1	12.1	7.9	5.7	11.8	10.7	17.1	13.5	14.4	10.0	5,14	1.57	0.23

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Sites differed within all years ($P \leq 0.05$).

[c] Different letters within a row indicate differences among treatments among years.

[d] Differences present within all years, therefore values taken from repeated measures split plot analysis among years.

Table A.6. Herbaceous species richness means and standard errors for within-year ANOVAs. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina.

		Treatment														
Vegetation		WNBa[a]		WHBa		NNBa		NNBr		NHBa		NHBr				
type	Yr	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	DF	*F*	*P*[b]
Grasses	1	3.2A[c]	0.9	2.4AB	0.6	2.5AB	0.8	1.4BC	0.5	1.7BC	0.7	0.7C	0.3	5,25	7.49	<0.001
	2	3.0	0.4	3.1	0.4	3.1	0.4	3.2	0.4	3.1	0.4	2.8	0.3	5,25	0.32	0.90
	3	4.2	1.0	3.8	1.0	4.4	0.9	4.4	0.9	5.2	1.2	5.0	1.0	5,18	0.83	0.55
	4	5.7	1.6	6.3	1.6	5.5	1.9	5.1	1.6	6.0	2.0	6.4	1.8	5,15	1.02	0.44
	6	2.5	0.8	3.1	0.8	2.7	0.9	2.7	0.6	2.8	0.7	3.0	0.6	5,15	0.47	0.79
	7	2.5	1.1	3.6	0.8	3.2	1.2	2.7	0.8	3.2	1.0	3.5	1.1	5,14	1.80	0.18
	8	2.0	1.1	3.0	0.8	2.8	1.2	2.4	0.8	2.9	1.0	2.6	0.9	5,14	1.59	0.23
Vines	1	1.6A	0.3	0.9AB	0.3	1.5A	0.3	1.0AB	0.2	0.5B	0.2	0.4B	0.1	5,25	8.15	<0.001
	2	2.5A	0.5	1.4B	0.3	2.0AB	0.4	1.7AB	0.4	1.3B	0.2	1.1B	0.3	5,25	5.27	0.001
	3	2.7	0.7	1.9	0.3	2.6	0.6	2.0	0.8	2.0	0.3	1.5	0.4	5,18	1.60	0.21
	4	3.7	1.3	2.5	1.1	3.5	1.0	2.7	1.1	2.9	0.7	2.6	0.5	5,15	2.38	0.09
	6	3.9	0.7	3.3	0.8	3.0	0.9	3.1	1.0	3.1	0.4	2.8	0.6	5,15	1.06	0.42
	7	3.9	0.7	3.1	0.8	4.1	0.3	3.2	0.9	2.9	0.4	3.2	0.6	5,14	1.60	0.22
	8	3.8	0.6	3.3	0.7	4.3	0.6	3.0	0.9	2.9	0.4	2.9	0.6	5,14	1.03	0.44
Forbs	1	3.6A	1.7	3.4A	1.7	3.4A	1.5	1.8A	0.6	2.2AB	1.2	0.9B	0.5	5,25	9.28	<0.001
	2	4.9	1.8	5.2	1.5	5.6	1.8	4.9	1.6	4.8	1.8	4.1	1.4	5,25	1.18	0.35
	3	3.6A	1.2	4.4A	1.0	4.8B	1.0	4.4B	0.9	5.0B	0.9	4.3A	0.7	5,18	3.07	0.04
	4	5.7	2.3	6.0	1.6	7.0	2.7	5.3	1.7	8.2	2.1	6.7	2.0	5,15	1.83	0.17
	6	3.5	2.4	4.6	2.0	3.1	1.3	3.0	1.0	3.8	1.4	4.0	1.7	5,15	1.32	0.31
	7	2.6	2.1	3.3	1.7	3.0	2.1	1.9	0.7	2.7	1.3	2.3	1.2	5,14	1.22	0.35
	8	2.8	2.3	2.8	1.5	2.6	1.8	1.7	0.9	3.1	1.1	2.2	1.1	5,14	2.19	0.11

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Sites differed within all years ($P \leq 0.05$).

[c] Different letters within a row indicate differences among treatments among years.

[d] Differences present within all years, therefore values taken from repeated measures split plot analysis among years.

Table A.7. Shannon H′ and Simpson D diversity means, standard errors, and *p*-values from repeated measures split plot analysis for treatment comparisons among years. We collected data 1-4 and 6-8 years following site preparation in 6 (2002-04) or 4 (2005, 2007-09) industrial loblolly pine plantations in the Coastal Plain of North Carolina.

	Treatment													
Vegetation	WNBa[a]		WHBa		NNBa		NNBr		NHBa		NHBr		*P*-values[b]	
type	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Trt	Yr x trt
Shannon H′														
Grasses	1.01	0.11	1.03	0.11	1.01	0.11	1.01	0.11	1.07	0.13	0.99	0.13	0.91	0.74
Woody	1.71A[c]	0.08	1.35B	0.10	1.72A	0.08	1.73A	0.08	1.25BC	0.06	1.18C	0.08	<0.001	<0.001
Vines	1.06	0.09	0.80	0.09	0.96	0.09	0.86	0.10	0.73	0.08	0.70	0.08	0.17	0.87
Forbs	1.15	0.16	1.28	0.15	1.34	0.15	1.11	0.13	1.17	0.14	1.10	0.14	0.70	0.44
Total	2.65A	0.10	2.50BC	0.11	2.69A	0.10	2.57AB	0.10	2.42CD	0.10	2.35D	0.11	0.03	0.03
Simpson D														
Grasses	0.49	0.04	0.52	0.03	0.49	0.02	0.50	0.03	0.50	0.03	0.49	0.03	0.74	0.76
Woody	0.77A	0.01	0.68B	0.01	0.79A	0.00	0.79A	0.00	0.68B	0.01	0.63B	0.02	0.04	0.004
Vines	0.65	0.02	0.51	0.03	0.58	0.02	0.52	0.01	0.47	0.02	0.44	0.02	0.19	0.95
Forbs	0.55	0.03	0.59	0.03	0.62	0.03	0.53	0.03	0.54	0.03	0.52	0.05	0.22	0.44
Total	0.90	0.01	0.88	0.01	0.90	0.00	0.89	0.01	0.89	0.01	0.86	0.01	0.17	0.48

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Degrees of freedom: yr = 6, site = 5, trt = 5, yr x trt = 30, error = 124. Effects of site and year were significant ($P \leq 0.05$). We used a treatment x site interaction as our error term in repeated measures analyses.

[c] Different letters within a row indicate differences among treatments among years.

Table A.8. Total plant Morista community similarity comparisons and standard errors in ascending order by overall average for industrial pine plantation treatments in the Coastal Plain of North Carolina, from 2002-05 and 2007-09.

	Year															
	2002		2003		2004		2005		2007		2008		2009		Average	
Comparison[a]	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
NNBa x NNBr	0.82[b]	0.06	0.93	0.02	0.87	0.07	0.88	0.05	0.89	0.03	0.93	0.04	0.92	0.04	0.89	0.02
WNBa x NNBa	0.81	0.07	0.87	0.05	0.91	0.04	0.90	0.06	0.91	0.02	0.94	0.04	0.93	0.03	0.89	0.02
NHBa x NHBr	0.80	0.09	0.87	0.08	0.94	0.02	0.93	0.01	0.89	0.02	0.83	0.03	0.79	0.06	0.86	0.02
WNBa x NNBr	0.81	0.07	0.86	0.03	0.85	0.06	0.86	0.05	0.88	0.03	0.86	0.05	0.85	0.04	0.85	0.02
WHBa x NHBa	0.74	0.07	0.81	0.11	0.88	0.03	0.79	0.05	0.84	0.05	0.78	0.06	0.75	0.09	0.80	0.03
NNBr x NHBr	0.72	0.05	0.82	0.04	0.84	0.04	0.82	0.02	0.82	0.06	0.73	0.02	0.71	0.06	0.78	0.02
WNBa x WHBa	0.74	0.03	0.84	0.02	0.82	0.02	0.78	0.04	0.74	0.03	0.72	0.04	0.71	0.04	0.77	0.01
WHBa x NHBr	0.76	0.10	0.70	0.11	0.86	0.04	0.78	0.06	0.82	0.04	0.69	0.08	0.77	0.07	0.77	0.03
WHBa x NNBr	0.66	0.06	0.80	0.05	0.82	0.08	0.78	0.02	0.79	0.07	0.74	0.10	0.74	0.04	0.76	0.02
NNBr x NHBa	0.69	0.06	0.82	0.06	0.88	0.04	0.82	0.04	0.73	0.05	0.64	0.04	0.54	0.09	0.74	0.03
WHBa x NNBa	0.63	0.06	0.77	0.09	0.88	0.03	0.70	0.07	0.72	0.06	0.74	0.11	0.73	0.07	0.74	0.03
NNBa x NHBa	0.69	0.05	0.82	0.05	0.81	0.04	0.79	0.04	0.66	0.06	0.70	0.06	0.56	0.11	0.73	0.02
NNBa x NHBr	0.62	0.06	0.75	0.05	0.79	0.02	0.76	0.06	0.76	0.06	0.69	0.06	0.60	0.09	0.71	0.02
WNBa x NHBa	0.67	0.07	0.79	0.06	0.81	0.04	0.78	0.02	0.64	0.06	0.60	0.02	0.47	0.07	0.69	0.03
WNBa x NHBr	0.64	0.07	0.70	0.07	0.76	0.05	0.75	0.07	0.75	0.06	0.63	0.05	0.59	0.10	0.69	0.03

[a] Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded herbaceous weed control (HWC), Br=broadcast HWC

[b] Morista community similarity values range from 0-1, where 1=most similar.