

EFFECTS OF A GRADIENT OF SITE PREPARATION INTENSITIES ON WILDLIFE  
HABITAT AND LOBLOLLY PINE PRODUCTIVITY IN THE LOWER COASTAL PLAIN  
OF NORTH CAROLINA

by

GRAHAM M. MARSH

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

ABSTRACT

Intensively managed loblolly pine (*Pinus taeda*) forests are commonly established using combinations of mechanical and chemical site preparation and herbaceous weed control (HWC) treatments to manage competing vegetation and increase pine production. However, few long-term studies have described relationships between intensity of site preparation and effects on plant communities important for white-tailed deer (*Odocoileus virginianus*) and northern bobwhite quail (*Colinus virginianus*). Understanding potential tradeoffs between increasing pine productivity and wildlife habitat is important because pine plantations encompass considerable hectrage in the southeastern U.S. and offer conservation opportunities. Therefore, I examined the 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) on food plants from 1 to 8 years

after site preparation in loblolly pine plantations (n = 6) in the Lower Coastal Plain of North Carolina. Changes in cover of woody shrubs and vines through use of chemical site preparation were the major driver of differences in food plants for white-tailed deer and northern bobwhites. The edaphic conditions of the region produce a low abundance of quality herbaceous food plants beneficial to deer and quail following disturbance. Instead, deer browse was limited to woody shrubs and vines, even from an early age. Grasses dominated total herbaceous cover and quail food plant cover for the first 3-4 years on all treatments. Legumes and other forbs important for deer and quail were sparse regardless of site preparation intensity. Mechanical and chemical site preparation techniques had short lived ( $\leq 4$  yrs) effects on grass, forb percent cover and species richness, but long-term effects on woody and vine forages. Increasing management intensity by including broadcast HWC or roller chop/narrow spacing mechanical site preparation did not result in additive reductions in cover or richness of woody food plants. However, broadcast HWC reduced grass and forb cover in the first year post-treatment. Wide row spacing and banded HWC benefited forages 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.

INDEX WORDS: Chemical site preparation, *Colinus virginianus*, Forest regeneration, Herbaceous weed control, Intensive forest management, Lower Coastal Plain, Mechanical site preparation, northern bobwhite quail, North Carolina, *Odocoileus virginianus*, Pine plantations, Pine spacing, *Pinus* spp., Plant communities, Release treatments, White-tailed deer

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## CHAPTER 1

### INTRODUCTION AND LITERATURE REVIEW

#### INTRODUCTION

Managed pine (*Pinus* spp.) plantations of the southeastern United States produce a significant percentage of the world's wood fiber (Wear and Greis, 2002), are among the most intensively managed forests in the world (Schultz, 1997), and comprise some of the largest remaining privately owned contiguous woodlands in the region. Timber productivity is the primary driver for decision-making in managed forests although other considerations also influence management. Wildlife associated with commercial forests are an important secondary value for commercial forest landowners (Marsinko *et al.*, 1998). Hunt-lease programs on industry lands generate millions of dollars annually and create beneficial public relations opportunities. Such programs also provide benefits to industry through increased security from lessee policing that protects against trespass and property damage (Stroh *et al.*, 2001).

Stewardship programs, such as the Sustainable Forest Initiative<sup>®</sup> (SFI<sup>®</sup>), help the forest industry maintain environmental and social standards valued by consumers by promoting responsible forest management. SFI standards focus on sustainable timber harvest while protecting water quality, biodiversity, wildlife habitat, species at risk, and forests with exceptional conservation value (Sustainable Forestry Initiative<sup>®</sup>, 2010). Managed forests contribute to terrestrial biodiversity because varied silvicultural practices result in diverse plant communities, stands in multiple successional states, and reduction of pressure on unmanaged forests for wood products (Miller *et al.* 2009). However, because timber management can affect

wildlife through changes in vegetation composition and structure, intensification of forest management through multiple site preparation treatments has generated concerns on the effects of these practices to wildlife in intensively managed stands (Miller and Miller, 2004).

Reducing competing vegetation is a primary goal in the establishment of pine plantations to maximize initial pine growth and survival, and promote stand uniformity (Miller, 1991; Knowe, 1992). Site preparation achieves this through silvicultural treatments that alter the vegetative composition and structure of new plant communities which in turn directly affects wildlife use. Typical stand establishment techniques include chemical site preparation, mechanical site preparation, fertilization, planting density (spacing), herbaceous weed control, and/or release treatments. Interactions among treatments can produce growth gains that are additive or even more than additive many cases (Jokela *et al.*, 2000; Allen *et al.*, 2005).

Site preparation techniques set the stage for the future productivity of each stand and consequently are the most important and most intensive silvicultural treatments (Miller, 1991; Allen *et al.*, 2005). Habitat alterations due to site preparation treatments are primarily related to the abundance and diversity of available wildlife food plants and the vertical structure, or cover, provided by vegetation (Miller and Miller, 2004). The degree and types of changes vary with intensity and timing of the selected treatments, as well as site-specific factors, such as soil type, soil moisture, past management, and existing vegetation (Lauer and Glover, 1999; Miller and Miller, 2004). Similar treatments may produce different results across sites. For example, roller chopping before planting slash pine (*Pinus elliottii*) was detrimental to game food plants in northwestern Florida (Hebb, 1971), while it improved food plants in loblolly pine (*Pinus taeda*) stands in South Carolina (Cushwa and Jones, 1969). Knowledge of local conditions and

interactions with these factors allow forest managers to choose the appropriate treatment to achieve specific management goals.

Early successional habitats typically associated with regenerating pine plantations provide habitat for game species, such as white-tailed deer (*Odocoileus virginianus*) (Hazel *et al.*, 1976; Hurst and Warren, 1981b) and northern bobwhite (*Colinus virginianus*) (Brunswick and Johnson, 1972; Hurst and Warren, 1981a). Deer and quail are important game animals in the southeastern United States, and much of their diet is composed of plants associated with early successional habitats resulting from disturbances such as the clearcuts created as part of forest management (Stoddard, 1931; Halls, 1984). Therefore, understanding effects of site preparation techniques is important to managing white-tailed deer and northern bobwhite populations within intensively managed forests.

Young plantations generally provide the highest quality and greatest abundance of wildlife foods in the form of tender browse (Wolters, 1975), annual and perennial herbaceous plants, and soft mast (Felix *et al.*, 1986). However, early successional, shade-intolerant species gradually are replaced by shade-tolerant shrubs and woody vegetation until the canopy closes, after which the abundance of many important wildlife food plants declines drastically (Miller and Miller, 2004). Intensive management of pine plantations accelerates growth of crop trees and decreases the amount of time to canopy closure, although timing of this process varies due to a number of factors including site index, row spacing width, and stocking density.

Site preparation treatments that reduce or delay establishment of woody species can extend the duration of early successional herbaceous plants in young stands (Jones *et al.*, 2009b). Therefore, young plantations can be important contributors to wildlife habitat in commercial forest landscapes. Studying fine scale changes in the vegetative composition of young stands in

response to various establishment regimes and examining how responses vary to site-specific conditions is important to understand effects of site preparation techniques on wildlife communities.

Although numerous studies have examined various aspects of intensive forest management, few have examined the long-term effects of combinations of mechanical site preparation (MSP) and chemical site preparation (CSP) treatments followed by herbaceous weed control (HWC) (Guynn *et al.*, 2004). Additionally, rapidly changing management regimes, such as new combinations of herbicides and improved mechanical treatments such as one pass combination plows, open the door for new studies. Because of the importance of Southeastern pine plantations to wildlife, I examined six combinations of stand regeneration treatments tailored to the North Carolina Lower Coastal Plain. The treatments received fertilization and combined CSP, MSP, varied spacing, and HWC to reflect an intensity gradient that includes currently applied site preparation treatments in the region's managed pine stands. I examined responses of pine growth and important food plants for white-tailed deer and northern bobwhite for eight years post-establishment.

## LITERATURE REVIEW

### Pine Growth and Yield

Current site preparation technologies provide a variety of options that are selected to match site specific characteristics and the landowner's management goals. Intensively managed forests of the southeastern United States have not met their full potential (Borders and Bailey, 2001). Therefore, efforts are being made to select site specific management regimes that maximize financial returns and provide sufficient growth for forest products. Naturally regenerated, unmanaged southern pine stands typically grow at rates averaging less than 5 to

13.5Mg/ha/yr. (Allen *et al.*, 2005). Currently, intensively managed non-thinned pine plantations on the same sites may yield 16-18 Mg/ha/yr. and have the biological potential to reach 34 Mg/ha/yr. (Stanturf *et al.*, 2003; Allen *et al.*, 2005).

Intensive silviculture increases productivity by improving growth efficiency and alleviating resource limitations (Fox *et al.*, 2007b). Basic limitations of sunlight, water, and nutrients are addressed with silvicultural treatments adapted for specific conditions and management goals, and often combined into integrated management regimes that span the length of the growing cycle (Allen *et al.*, 2005).

Forest fertilization is a common means to increase forest yields as importance of meeting resource limitations related to soil nutrients is evident. In the South, the land area receiving fertilization has increased significantly over the past 20 years (Fox *et al.*, 2007a). On Southern Lower Coastal Plain sites, correcting phosphorus deficiencies at planting can result in growth gains of 2.8-3.5 m<sup>3</sup>/ha /yr. throughout the rotation (Fox *et al.*, 2007a). Most pine stands also respond well to nitrogen fertilization as nitrogen tends to become limiting near the time of canopy closure on southern sites (Allen *et al.*, 1990). Repeated nitrogen applications every 8-10 years may be needed to maintain the highest productivity. However, most managers use fewer applications depending upon current fertilizer prices and market conditions.

Current site preparation treatments in the Lower Coastal Plain typically rely on a combination of mechanical site preparation, such as bedding, shearing, and/or chopping, and chemical site preparation. Mechanical treatments have multiple objectives, which include breaking up hardpans to improve rooting conditions, removing and/or redistributing slash and debris within a site, raising seedbeds above elevated water tables, among others (Allen *et al.*, 2005). While more intensive mechanical site preparation treatments such as subsoiling, ripping,

disking, and windrowing have been used in the past, results have been inconsistent and their potential benefits often do not outweigh the high cost on most sites (Fox *et al.*, 2007b). For example, in an 18-year Plantation Management Research Cooperative (PMRC) site preparation comparison in the Georgia Piedmont, Borders (2004) found that an intensive MSP treatment of shear-pile-disk did not result in volume gains great enough to offset the excessive cost (\$494/ha) when compared to a less expensive (\$304.87/ha) herbicide-burn treatment resulting in internal rates of return of 6.7% vs. 9.3% respectively.

Modern chemical treatments have advantages over more expensive mechanical treatments because of their ease of application, ability to target specific plant groups, and reduced soil disturbance and compaction (Allen *et al.*, 2005; Rousseau and Kaczmarek, 2005). Effectiveness and intensity of chemical treatments may be increased by using tank mixes of more than one herbicide to obtain broad spectrum control of competing plants, and by additional follow-up herbaceous weed control treatments (Shepard *et al.*, 2004). Early control of competing vegetation has repeatedly demonstrated significant gains in loblolly pine height and diameter growth (Knowe, 1992; Borders and Bailey, 2001; Miller *et al.*, 2003). More intensive treatments produce early growth gains for crop trees that are carried for several years (Nilsson and Allen, 2003).

In a 4-year site preparation study in the Georgia Piedmont, Knowe (1992) compared operational and experimental site preparation treatments using various chemical combinations and intensive mechanical operations ranging from an untreated control to complete vegetation control using repeated herbicide applications. Mechanical treatments were expensive, but resulted in increased seedling survival. An operational CSP treatment, Picloram + triclopyr,

provided the best control of woody competition, produced some of the largest crop trees (second to total vegetation control), and was the most cost effective.

To extend competition control, herbaceous weed control (HWC), a follow-up herbicide treatment typically applied in the first growing season, is often used. These treatments reduce competition by herbaceous plant species and help crop trees become established. Increases in pine growth responses typically last for several years following HWC treatments (Creighton *et al.*, 1987; Jokela *et al.*, 2000). Application of HWC can be either banded over the row or broadcast across the entire stand. Banded applications may reduce costs, but have mixed results in terms of pine growth responses. Jones *et al.* (2010) found that pine productivity in the Mississippi Lower Coastal Plain was improved by broadcast HWC over banded. In contrast, Creighton (1987) reported no difference across HWC application methods (banded, broadcast, spot) across 16 Southeastern locations. Responses to these HWC treatments appear to be site specific and may be a result of interactions with other silvicultural treatments.

Row spacing, which is related to planting density, is largely dependent upon desired forest products and planned harvest strategies, and can have a significant influence on the costs of other treatments, and ultimately, the profitability of the stand. Wide spacing can reduce costs by requiring fewer passes with equipment and using fewer seedlings. Pines planted on wider row spacing generally take longer to close the canopy thereby extending the length of time competing vegetation has to grow when compared to narrower pine spacings (Loehle *et al.*, 2009).

#### White-tailed Deer Habitat in Pine Plantations

White-tailed deer is the most popular big game animal in North America and is a valuable resource on public and private lands (Southwick, 2008). In 2006, deer hunting

generated over \$193 million in retail sales, and produced an overall economic impact of over \$322 million in North Carolina alone (Southwick, 2008). The millions of dollars spent annually in pursuit of deer can provide significant supplemental income to landowners through the sale of hunting leases, and provide additional incentive to manage for wildlife on privately-owned forests.

Managed pine plantations can provide quality deer habitat (Hurst and Warren, 1981b). The highest quality and abundance of deer food plants occurs in open, early successional habitat conditions. Forage availability declines once the canopy of a pine plantation closes and sunlight is excluded from the forest floor (Sossaman, 1973; Hazel *et al.*, 1976; Blake, 1987; Jones *et al.*, 2009a). In the Southeast, the most important components of deer diets are tender young vegetative growth of vines, woody trees and shrubs, forbs, and hard and soft mast. Tender young growth is more palatable and nutritious than hardened older growth, and is consumed at much higher rate (Blair, 1960). The highest quality deer habitats usually occur where there is wide variety and large quantity of nutritious palatable forage (Halls, 1984). In newly established pine plantations, practices that reduce or delay establishment of woody growth can promote these preferred shade-intolerant plants (Jones *et al.*, 2009a).

Early studies of site preparation effects on deer forage tended to be plant surveys and often lacked replication. Even so, these studies provided information that proved useful in planning future treatments. Hazel (1976) examined deer forage on North Carolina pine plantations recently converted from pocosins and reported that mechanical site preparation resulted in an increase in forage production and quality that peaked after four growing seasons. He also noted that the increased quality of forage on site prepared areas was a result of an increased diversity of plant species.

Early experimental research examining deer forage in response to silvicultural treatments mainly considered effect of a single type of treatment such as site preparation (either mechanical or chemical) (Lacascio *et al.*, 1990), harvest (Blair, 1960), and fertilization (Wood, 1986). More recent studies have focused on effects of combinations of mechanical and chemical site preparation (Miller *et al.*, 1989; Witt, 1991; Sparling, 1996; Branch, 1998; Chamberlain and Miller, 2006; Jones *et al.*, 2009a; Lane, 2010), herbicide tank mixes (Keyser and Ford, 2006), release treatments (Blake, 1987), thinning followed by prescribed fire (Masters *et al.*, 1993; Iglay *et al.*, 2010) and examination of site specific treatment effects (Edwards *et al.*, 2004; Keyser and Ford, 2006). Still, few studies have examined combinations of treatments on a long term operational scale resembling current intensive pine management regimes.

Mechanical site preparation can influence composition and structure of plant communities and deer food plants by altering soil conditions, and altering existing seed banks and rootstocks. Lacascio (1990) sampled deer forages for two years following various intensities of MSP (chainsaw residuals, shear-chop, shear-root rake-burn-disk) in the lower Piedmont of Georgia. The more intensive MSP (shear-root rake-burn-disk) reduced woody and vine forages in favor of grasses and forbs. Less intensive MSP (shear-chop) reduced woody forages, but resulted in significantly more Japanese honeysuckle (*Lonicera japonica*) and greenbriar (*Smilax* spp.) than other mechanical treatments.

Herbicides can alter abundance and type of deer forage by altering plant communities within intensively managed forests. The most commonly applied herbicides labeled for forestry site preparation include imazapyr, glyphosate, triclopyr, hexazinone, and sulfometuron methyl (Shepard *et al.*, 2004). Each herbicide varies in its efficacy and target species. For example, many species of vines including blackberries (*Rubus* spp.) and greenbriars, as well as many

legumes, have shown resistance to imazapyr following chemical site preparation (Hurst and Blake, 1987; Moore, 1996). Furthermore, species susceptibility can also vary within plant groups. In comparing woody plants, Zutter and Zedaker (1988) demonstrated that pines and blueberries (*Vaccinium* spp.) are resistant to hexazinone applications, while oaks (*Quercus* spp.) and sumacs (*Rhus* spp.) are not.

In general, herbicide applications do not completely remove deer forage, but rather alter the type of forage available. For example, Witt (1991) compared responses of deer food plants in the Georgia Piedmont among 4 CSP treatments (hexazinone, triclopyr, triclopyr + picloram, and imazapyr), an intensive MSP treatment (chop-shear-root rake-chop-burn), and a control (single chop-burn). Triclopyr and picloram + triclopyr treatments reduced woody and vine forages, but favored grasses and most herbaceous forages. Hexazinone treatments produced the most deer forage of all treatments. However, intensive mechanical and imazapyr treatments promoted forbs and legumes preferred by deer, possibly indicating higher quality forage in those treatments. Overall, the abundance of preferred early successional species was similar on MSP and CSP treatments after 2 growing seasons.

Keyser and Ford (2006) were also concerned over potential changes in deer forage between HWC treatments using various rates of imazapyr and a widely applied tank mix of imazapyr and sulfometuron methyl in the Virginia Piedmont. Although they observed that tank mixes reduced total forage and forage species richness compared to low rates of the imazapyr only treatment, like Witt (1991), these effects were no longer evident within 2 growing seasons post-treatment.

Herbaceous weed control treatments vary in regard to deer forage impacts depending on application method. Blake (1987) examined deer forages in banded and broadcast HWC

(hexazinone) in The Mississippi Coastal Plain. He observed more legume and vine forages on treated areas than on untreated control plots at 1-year post-treatment. The controls had greater total forage, but were dominated by less favorable panic grasses (*Panicum* spp.). Blake (1987) also showed that banded HWC provided more cover and more overall deer forage than broadcast HWC in the first year, but differences were no longer evident by the end of the second growing season. Banded HWC reduces vegetation on the rows while leaving the inter-row vegetation unaffected. This treatment creates two age classes and types of vegetation. As a result, banded HWC typically provide higher quality deer habitat compared to broadcast treatments (Chamberlain and Miller, 2006; Jones *et al.*, 2009a).

Current, intensive stand establishment treatments may use MSP, CSP tank mixes of two or three herbicides, and HWC treatment to provide extended competition control. In a 5 year study, Jones *et al.* (2009a) examined responses of deer food plants to a gradient of 5 intensities of stand establishment on infertile Mississippi Lower Coastal Plain sites. The least intensive treatment received subsoil-disk-bed MSP, no CSP, and single banded HWC of hexazinone and sulfometuron methyl. The most intensive treatment received subsoil-disk-bed MSP, CSP of imazapyr, glyphosate, and triclopyr, and broadcast release treatments (hexazinone + sulfometuron methyl) in the first two growing seasons. Jones (2009a) found that the relationships between deer forage cover, species richness, biomass, and carrying capacity were complex and varied based on regional characteristics. Forage value increased with MSP + CSP by controlling low quality plant species and allowing higher quality but less abundant plants to make up a larger proportion of the total forage. Total forage biomass was negatively correlated with treatment intensity and peaked two to three years post-treatment, but carrying capacity estimates varied depending on metabolic requirements of deer at different life stages (e.g.,

lactating does). Protein-based estimates peaked in moderate intensity treatments in years 1-3 while energy based estimates were generally greatest in years 4-5 and tended to be negatively correlated with treatment intensity (Jones *et al.*, 2009a).

Although forage is often highly abundant in areas of infertile soils, it is typically low in quality (Wood *et al.*, 1986; Shea *et al.*, 1992). Fertilization has potential to affect the vegetative community and forage quality. Application method (broadcast or banded) and timing may also affect the community response. Hazel (1976) reported a nearly 300% increase in deer forage in the first growing season of fertilized North Carolina loblolly pine stands compared to unfertilized stands. However, fertilized stands will most likely close canopy before unfertilized stands, effectively shortening the window of time forage is available.

#### Northern Bobwhite in Pine Plantations

In the southeastern US, northern bobwhites were historically associated with open, fire-maintained pine stands (Stoddard, 1931). However, current management of pines in commercial forests typically provides a short window of available habitat. Bobwhite use of pine plantations is greatest from the time a stand is harvested until approximately 3-5 years after replanting (Brennan, 1991). The quality and duration of suitable habitat is directly related to the stand establishment techniques applied. While some have proposed that forestry and quail are incompatible (Veech, 2006), populations continue to persist within intensively managed forest landscapes (Hanberry, 2007; Keyser *et al.*, 2011). Bobwhites require a diverse, patchy habitat composed of early successional areas of herbaceous vegetation, grassy areas for nesting purposes, patchy heavy brush or woody cover areas, and bare ground with little to no litter cover for foraging (Stoddard, 1931; Roseberry and Sudkamp, 1998). Typical diets are composed of fruits and seeds of many early successional forbs, grasses, and woody plants, as well as

invertebrates. Seeds of legumes are especially important in many Southeastern habitats because they are typically high in protein and energy (Peoples *et al.*, 1994), both of which are needed for egg production (Giuliano *et al.*, 1996) and maintenance. Northern bobwhites consume seed from a wide variety of plant species (Landers and Johnson, 1976) and may preferentially choose foods based on nutrient quality (Preacher, 1978).

Effects of various stand establishment regimes on bobwhite food plants have been well documented (Brunswig and Johnson, 1972; Robinson and Barkalow, 1979; Moore, 1996; Sparling, 1996; Branch, 1998; Jones, 2008). The earliest studies examined intensive mechanical site preparation effects on bobwhite food plants. Brunswig and Johnson (1972) found that 2-3 year-old stands receiving intensive MSP treatments (shear-pile-burn-disk) in Georgia contained the greatest diversity and abundance of bobwhite food plants although both measures declined drastically in older stands. Ragweed (*Ambrosia artemisiifolia*), partridge peas (*Chamaecrista* spp.), beggarweeds (*Desmodium* spp.), and lespedezas (*Lepedeza* spp.) were among the most commonly occurring food plants in young plantations. Woody shrubs became the dominant plants in older plantations.

Witt (1991) examined responses of quail food plants to 4 CSP treatments (hexazinone, triclopyr, triclopyr + picloram, and imazapyr), an intensive MSP treatment (chop-shear-root rake-chop-burn), and a control (single chop-burn) in the Georgia Piedmont from 2 to 4 years post-treatment. Imazapyr CSP resulted in a greater abundance of bobwhite food plants than all other CSP treatments, and the MSP treatment produced more quail food plants than the other chemical treatments. However, the MSP did not control woody species which began to outcompete higher value forbs by the fourth year.

In a similar study, Sparling (1996) and Branch (1998) surveyed quail food plants for 4 years following a MSP of root rake-windrow and various chemical site preparation treatments in the South Carolina Coastal Plain. Bobwhite food plant abundance increased in the first two years and then declined steadily until year 4. Imazapyr-treated plots produced the highest abundance of total and high-use quail food plants during the first two years. Hexazinone-treated areas produced slightly more in year three, and treatment differences were minimal in year four.

Most recently, Jones (2009b) quantified bobwhite food plants and habitat structure characteristics in response to five increasingly intensive stand establishment regimes. Moderate intensity stand establishment regimes that included chemical site preparation and banded herbaceous release treatments provided the most suitable habitat for bobwhites during the five year study. The least intensive treatment, which received a banded release but no chemical site preparation contained a high proportion of woody stems which outcompeted important herbaceous coverage.

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## CHAPTER 2

# RESPONSES OF NORTHERN BOBWHITE AND WHITE-TAILED DEER FOOD PLANTS TO A GRADIENT OF SITE PREPARATION INTENSITIES IN PINE PLANTATIONS IN THE LOWER COASTAL PLAIN OF NORTH CAROLINA<sup>1</sup>

### ABSTRACT

Intensively managed loblolly pine (*Pinus taeda*) forests are commonly established using combinations of mechanical and chemical site preparation and herbaceous weed control (HWC) treatments to manage competing vegetation and increase pine production. However, few long-term studies have described relationships between intensity of site preparation and effects on plant communities important for white-tailed deer (*Odocoileus virginianus*) and northern bobwhite quail (*Colinus virginianus*). Understanding potential tradeoffs between increasing pine productivity and wildlife habitat is important because pine plantations encompass considerable hectrage in the southeastern U.S. and offer conservation opportunities. Therefore, I examined the 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)

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<sup>1</sup> Marsh, G. M., V. R. Lane, R. L. Mihalco, D. A. Miller, T. B. Wigley, S. B. Castleberry, and K. V. Miller. To be submitted to *Forest Ecology and Management*.

site preparation treatments with HWC (broadcast or banded) on food plants from 1 to 8 years after site preparation in loblolly pine plantations (n = 6) in the Lower Coastal Plain of North Carolina. Changes in cover of woody shrubs and vines through use of chemical site preparation were the major driver of differences in food plants for white-tailed deer and northern bobwhites. The edaphic conditions of the region produce a low abundance of quality herbaceous food plants beneficial to deer and quail following disturbance. Instead, deer browse was limited to woody shrubs and vines, even from an early age. Grasses dominated total herbaceous cover and quail food plant cover for the first 3-4 years on all treatments. Legumes and other forbs important for deer and quail were sparse regardless of site preparation intensity. Mechanical and chemical site preparation techniques had short lived ( $\leq 4$  yrs) effects on grass, forb percent cover and species richness, but long-term effects on woody and vine forages. Increasing management intensity by including broadcast HWC or roller chop/narrow spacing mechanical site preparation did not result in additive reductions in cover or richness of woody food plants. However, broadcast HWC reduced grass and forb cover in the first year post-treatment. Wide row spacing and banded HWC benefited forages 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

Managed pine (*Pinus* spp.) plantations of the southeastern United States produce a significant percentage of the world's wood fiber (Wear and Greis, 2002), are among the most intensively managed forests in the world (Schultz, 1997), and comprise some of the largest remaining privately owned contiguous woodlands in the region. Timber productivity is the primary driver for decision-making in managed forests although other considerations also

influence management. Wildlife associated with commercial forests are an important secondary value for commercial forest landowners (Marsinko *et al.*, 1998). Hunt-lease programs on industry lands generate millions of dollars annually and create beneficial public relations opportunities. Such programs also provide benefits to industry through increased security from lessee policing that protects against trespass and property damage (Stroh *et al.*, 2001).

Stewardship programs, such as the Sustainable Forestry Initiative (SFI) help the forest industry maintain environmental and social standards by promoting responsible forest management. SFI<sup>®</sup> standards focus on sustainable timber harvest while protecting water quality, biodiversity, wildlife habitat, at-risk species, and forests with exceptional conservation value (Sustainable Forestry Initiative, 2010). Managed forests contribute to terrestrial biodiversity through varied silvicultural practices that result in diverse plant communities, stands in multiple successional states, and reduced pressure on natural forests for wood products (Miller *et al.*, 2009). However, because timber management can affect wildlife through changes in vegetation composition and structure, forest management intensification through multiple site preparation treatments has generated concerns on the effects of these practices to wildlife in intensively managed stands (Miller and Miller, 2004).

Alleviating resource limitations by reducing competing vegetation during pine plantation establishment can increase initial pine growth and survival and promote stand uniformity (Miller, 1991; Knowe, 1992). Site preparation achieves this through silvicultural treatments that alter the vegetative composition and structure of new plant communities, which can affect wildlife using these pine plantations. Typical stand establishment techniques include chemical site preparation, mechanical site preparation, herbaceous weed control, and/or woody release treatments. Interactions among treatments can produce growth gains that are additive or even synergistic in

many cases (Jokela *et al.*, 2000; Allen *et al.*, 2005). Habitat alterations due to site preparation treatments are primarily related to the abundance and diversity of available wildlife food plants and structure, or cover, provided by vegetation (Miller and Miller, 2004). The degree and types of changes vary with the intensity and timing of the selected treatments, as well as site-specific factors, such as soil type, soil moisture, past management, and existing vegetation (Lauer and Glover, 1999; Miller and Miller, 2004). Similar treatments may produce differential results across sites. For example, roller chopping before planting slash pine (*Pinus elliottii*) was detrimental to game food plants in northwestern Florida (Hebb, 1971), while it improved food plants in loblolly pine (*Pinus taeda*) stands in South Carolina (Cushwa and Jones, 1969). Knowledge of local conditions and interactions with these factors allow forest managers to choose appropriate treatments to achieve specific management goals.

Early successional habitats typically associated with regenerating pine plantations provide habitat for game species, such as white-tailed deer (*Odocoileus virginianus*) (Hazel *et al.*, 1976; Warren and Hurst, 1981) and northern bobwhite (*Colinus virginianus*) (Brunswig and Johnson, 1972; Warren and Hurst, 1981). Deer and quail are important game animals in the southeastern United States, and much of their diet is composed of plants associated with early successional habitats resulting from disturbances such as the clearcuts created as part of forest management (Stoddard, 1931; Halls, 1984). Therefore, understanding effects of site preparation techniques is important to managing white-tailed deer and northern bobwhite populations within intensively managed forests.

Young plantations generally provide the highest quality and greatest abundance of wildlife foods in the form of tender browse (Wolters, 1975), annual and perennial herbaceous plants, and soft mast (Felix *et al.*, 1986). However, early successional shade-intolerant species

gradually are replaced by shade-tolerant shrubs and woody vegetation until the canopy closes, after which the abundance of many important wildlife food plants declines drastically (Miller and Miller, 2004). Intensive management of pine plantations accelerates growth of crop trees and decreases the amount of time to canopy closure, although timing of this process varies due to a number of factors including site index, row spacing width, and stocking density.

The effects of various stand establishment regimes on deer forages and bobwhite food plants have been well-documented (Brunswig and Johnson, 1972; Robinson and Barkalow, 1979; Moore, 1996; Sparling, 1996; Branch, 1998; Jones, 2008). Although numerous studies have examined various aspects of intensive forest management, few have examined the long-term effects of combinations of mechanical site preparation (MSP) and chemical site preparation (CSP) treatments followed by herbaceous weed control (HWC) (Guynn *et al.*, 2004). Additionally, rapidly changing management regimes, such as new combinations of herbicides and improved mechanical treatments such as one pass combination plows, result in novel regeneration methods that have unknown impacts on habitat conditions.

Because of the importance of southeastern pine plantations to wildlife, we examined effects of 6 combinations of stand regeneration treatments tailored to the North Carolina Lower Coastal Plain on important food plants for white-tailed deer and northern bobwhite for 8 years post-establishment.

## METHODS

### Study area

We conducted our study on 6 sites managed for loblolly pine in the Lower Coastal Plain (LCP) of North Carolina, USA. Two sites in Craven County were owned and managed by Weyerhaeuser Company and 4 sites in Brunswick County were owned and managed by

International Paper, The Nature Conservancy, Resource Management Service, LLC, or North Carolina Wildlife Resources Commission during our study. The Craven county sites were dominated by Leaf and Bayboro soils, and the Brunswick county sites were dominated by Croatan, Hobcaw, and Ogeechee soils. All types are loamy, poorly drained soils classified as CRIFF A or B (Jokela and Long, 2000). All sites were previously planted in loblolly pine, and were clear-cut harvested between late 2000 and early 2001. Two Brunswick County study sites were eliminated in 2005 because high pine mortality lowered tree densities below standard forestry practices, likely due to excessively wet conditions. In addition, one treatment was eliminated at one Brunswick County site in 2008 due to high pine mortality resulting from poor water drainage. Mortality due to poor water drainage is uncommon in this region because many sites are lined with drainage ditches, and most sites are bedded. Study sites averaged 60.7 ha and each location was divided into 6 treatment plots of 4.5-12.2 ha each (Mihalco, 2004).

We chemically (imazapyr in the form of Chopper™, BASF Corp., Research Triangle Park, North Carolina, USA, at 3.51 L ha<sup>-1</sup> mixed with 11.58 L/ha of methylated seed oil) and/or mechanically (roller-chop or strip shear) prepared plots for planting in late summer 2001–winter 2002, with loblolly pine hand planted on beds within either narrow (3.0 x 2.4 m) or wide (6.1 x 1.5 m) spacing during February 2002. Chemical site preparation was applied with a skidder in August 2001. The strip-shear mechanical site preparation, used in combination with wide spacing, was accomplished with a v-blade followed by a bedding plow, leaving a 3.4 m cleared swath with a strip of piled debris between planting beds in February 2002. All plots were fertilized with diammonium phosphate incorporated into beds at 0.08 kg /m prior to planting. In March 2002, we applied herbaceous weed control (HWC) with 0.30 L/ha of Arsenal™ (imazapyr, BASF Corp., Research Triangle Park, North Carolina, USA) and 0.15 L ha<sup>-1</sup> of

Oust™ (sulfometuron methyl, E.I. du Pont de Nemours and Company, Inc., Wilmington, Delaware) as either backpack-sprayed 1.5 m bands centered on the beds or broadcast ground skidder applications. We used a randomized complete block design and treatment plots received 1 of 6 treatment combinations that varied in intensity of vegetation control (Table 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 and food plant classification

We sampled vegetation during June-August in 2002-2005 and 2007-2009. Within each treatment plot, we randomly located 10, 30 m line transects. Transects were located  $\geq 10$  m from plot boundaries, followed randomly generated compass bearings, crossed at least 1 bed, and were randomly oriented across plots to avoid clumping. We identified all plants to species or genus depending upon identifiable characteristic and confirmed identification using Radford *et al.* (1964). 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 ranked each plant species or appropriate taxa as low, medium, or high use for white-tailed deer based on Blair (1980), Warren and Hurst (1981), Miller and Miller (2005), and Hazel (1976) and considered medium and high use plants as preferred. We categorized taxa as forage producers for northern bobwhite according to Landers and Johnson (1976), Miller and Miller (2005), and Rosene (1988).

We quantified vertical structure using Nudds boards (Nudds, 1977) readings taken parallel to the rows in the inter-bed areas. We took 2 readings per transect at 10 m from the observer. We used the vertical structure measures to estimate amount of woody and vine forage within the browse range of white-tailed deer. We considered vegetation below 1.5 m to be available forage and used proportion of cover below that height to scale total cover measures obtained from drip-line transects.

### Statistics

We hypothesized that cover and richness of food plants for deer and quail were inversely related to management intensity. Our main effects were type of mechanical site preparation/spacing, use of chemical site preparation, type of HWC, and we blocked by site. Our response variables included food plant cover and richness by taxonomic group. Because we were interested in the time after stand establishment that differences occurred, we examined within-year treatment effects with analysis of variance (ANOVA) for all parameters. If treatments 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), but we present non-transformed values in results for ease of interpretation (Dowdy *et al.*, 2004).

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. Therefore, we examined pairwise comparisons using t-tests when overall main effects were significant (Dowdy

*et al.*, 2004). 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  $\alpha = 0.05$ .

We detected 6 interactions of 720 pairwise comparisons between chemical site preparation and spacing or HWC, but deemed these interactions biologically insignificant due to minor differences between means and high standard errors. Therefore, we present results of individual treatment component contrasts (e.g. mechanical site preparation) for within-year analyses.

## RESULTS

Pine canopy cover differed among treatments by year 4 and maintained those differences until the end of the study in year 8 (Figure 2.1). Canopy cover reflected the treatment intensity gradient and ranged from 66% on the least intensive treatment (WNBa), to 90% on the two most intensive treatments (NHBa, NHBr).

We recorded 240 plant taxa across all treatments and all years. We classified 93 of those as bobwhite food plants and 129 as preferred deer food plants. Deer food plants were dominated by woody species (64.5% coverage, 40 spp.) followed by vines (26.0% coverage, 17 spp.), and herbaceous (9.5% coverage, 72 spp.). Five species comprised approximately 54% of the total food plants across all treatments: white titi (*Cyrilla racemiflora*), pepperbush (*Clethra alnifolia*), poison ivy (*Toxicodendron radicans*), winged sumac (*Rhus copallinum*), and gallberry (*Ilex glabra*). Blackberries and dewberries (*Rubus* spp.) and yellow jessamine (*Gelsemium sempervirens*) were also important contributors in treatments receiving CSP.

Bobwhite food plants were dominated by herbaceous species (57.9%, 67 spp.), followed by vines (26.2%, 14 spp.), and woody (15.9%, 12 spp.). Six taxa composed approximately 55% of the total coverage of bobwhite food plants: panic grasses (*Panicum* spp.), pokeweed (*Phytolacca americana*), winged sumac, poison ivy, and blackberries.

#### White-tailed deer food plants

Total cover and cover of woody and vine deer forages peaked in year 4 in all treatments (Table 2.2, Figure 2.2). Forages were abundant on all treatments, but were more abundant on NO-CSP treatments (WNBa, NNBa, NNBr). Differences among treatments were primarily the result of CSP application (Table 2.2).

CSP had the greatest and longest lasting effects on woody and vine forages when compared with pine spacing/mechanical site preparation and HWC. Plots that did not receive CSP contained 2-5 times the cover of woody plants and vines present in CSP plots (Table 2.2). At peak abundance in year 4, woody and vine cover on NO-CSP plots was 77.7% compared to 41.3% on CSP plots. Woody and vine cover differed for MSP/spacing in years 1 and 8, for HWC in years 1 and 3, and CSP comparisons in all years (Table 2.2). Wide spacings (SSW) had nearly twice the year 1 cover of woody and vine food plants compared to narrow spacings (9.6% vs. 5.1%). Woody and vine food plant cover was similar between wide and narrow spacings until year 8 when SSW again exceeded RCN treatments (37.6% vs. 26.3%). Woody and vine forage cover was reduced by broadcast HWC treatments compared to banded HWC (Table 2.2). Woody and vine cover in banded treatments was twice that of broadcast in year 1 (5.1% vs. 2.6%) and 1.5 times greater in year 3 (37.7% vs. 23.3%).

Woody and vine forage species richness gradually increased through year 8, and was similar on both banded and broadcast HWC treatments in all years (Table 2.3). Vine richness

was greater on SSW treatments in year 6, but similar to RCN in all other years (Table 2.3). CSP reduced richness of forage vines in years 1 and 3 when compared to plots not receiving CSP, but resulted in dramatic reductions in woody forage richness in all years which led to changes in species composition.

Herbaceous forage cover also peaked in year 4, but was generally low (<11%) in all treatments and years (Figure 2.5). For all treatment comparisons, differences were only significant in year 4 when herbaceous cover was greatest in the most intensive treatments. Across all years, less intensive banded HWC treatments tended to have greater cover of herbaceous forages than broadcast treatments.

Species richness of herbaceous deer forages was greatest in years 3 or 4 in all treatments and subsequently declined (Table 2.3). There were no trends evident in MSP/spacing treatments although herbaceous richness was greater on the RCN treatments during year 3. Banded treatments had greater herbaceous richness than broadcast in the first 2 years post-treatment (Table 2.3). Herbaceous species richness did not differ between treatments receiving CSP and NO-CSP treatments in all years.

#### Northern bobwhite food plants

Cover of quail foods exhibited similar trends as deer food plants. Quail food cover peaked in year 4 for woody and vine (Figure 2.6) and herbaceous (Figure 2.7). Woody and vine, and total quail food plant cover was generally greater on NO-CSP treatments compared to those that did receive CSP, and CSP and NO-CSP treatments differed for woody and vine cover in every year except year 3 (Table 2.4). Total cover differed in response to CSP in all but years 3 and 4 (Table 2.4). MSP/spacing had no impact on woody and vine or total cover in any year. HWC reduced woody and vine, and total cover in years 1 and 3. Woody and vine cover on

banded treatments was more than twice than on broadcast in those years (2.7% banded vs. 1.0% broadcast in year 1 and 21.9% vs. 12.8% in year 3). Woody and vine food plants were dominant in later years (years 5-8) and herbaceous seed producers were more abundant in years 1-4.

The number of woody and vine food plant species generally increased over time on all treatments. Richness of vine or woody species showed little response to MSP/spacing or HWC application method (Table 2.5). CSP significantly reduced number of vine species in years 1 (3.2 vs. 1.9 species) and 3 (4.7 vs. 3.6 species) over NO-CSP. CSP and NO-CSP had a similar number of vine species in all other years; CSP had the greatest effect on woody species richness.

In years 1 and 2, herbaceous quail foods were generally most abundant on low intensity treatments, but more abundant on high intensity treatments in years 3 and 4 (Figure 2.7). The MSP/spacing treatments we examined had no effect on cover of herbaceous food plants in any year. Broadcast HWC reduced total cover of herbaceous quail food plants in year 1 (23.5% broadcast, 3.3% banded, Table 2.6) over banded HWC, but did not affect legume or other forb cover in other years (Table 2.7). Broadcast HWC reduced grass cover in year 1 over banded HWC, but both treatments were similar by year 2 (Table 2.7). CSP reduced total herbaceous cover in years 1 and 2, but did not reduce legume or forb cover in any year. Legumes were generally more abundant on CSP plots and other forbs were more abundant on plots that did not receive CSP. Cover of seed producing grasses was greater on NO-CSP treatments in years 1-2 and 6-8, but greater on CSP treatments in years 3 and 4.

As with deer food plants, CSP resulted in a shift in composition of the most abundant food plants in CSP vs. NO-CSP treatments. Grasses, pokeweed, winged sumac, and blackberries were 4 out of the 5 top quail food plants in all years (Figure 2.8). Poison ivy was the fifth most

abundant quail food in NO-CSP treatments; whereas laurel greenbrier was fifth in treatments receiving CSP (Figure 2.9).

Species richness of herbaceous quail food plants peaked in year 4 (8.8-10.8 species) and subsequently declined for all treatment comparisons (5.6-7.6 species in yr 8). Vines and woody quail food plant richness generally increased until year 8 (Table 2.5). Choice of MSP/spacing had no impact on quail food richness for herbaceous, vines, or woody species in any year. Broadcast HWC reduced herbaceous richness in year 1 over banded HWC, but had no effect on richness of vines or woody plants in any year. CSP did not alter herbaceous species richness in any year, but reduced vines in years 1 and 3, and woody species in years 1-2 and 4-6 (Table 2.5).

## DISCUSSION

### White-tailed deer food plants

Woody shrubs dominated our sites as is typical in the Lower Coastal Plain. Woody browse constitutes an important part of the diet for white-tailed deer in shrub dominated Lower Coastal Plain habitats where herbaceous species seldom persist more than 2-3 years following disturbance (Hazel *et al.*, 1976). We found that CSP reduced woody and vine, and total cover for deer food plants in all years over NO-CSP.

Total cover of preferred deer forages differed in response to CSP in all years. Titi and sweet pepperbush comprised a substantial portion of total plant cover within all stands. In Mississippi, a series of studies revealed that CSP treatments (hexazinone, imazapyr) decreased total deer forage 1 year after treatment, but no differences occurred between treatments and controls by the second year (Copeland 1986, Hurst and Warren 1986, Blake *et al.* 1987, Hurst 1987, Hurst and Watkins 1988, McNease and Hurst 1991). As these shrub species mature, much of the preferred browse material grows beyond the reach of deer. Titi and pepperbush tend to

proliferate in these poorly drained Lower Coastal Plain sites where they outcompete and eventually dominate understory plant communities, significantly reducing understory species richness and diversity (Christensen *et al.*, 1981). Control of woody species through CSP reduced total cover, but not availability of blackberries and yellow jessamine (both valuable forage species), which had greater cover on sites prepared with CSP. Woody vines are important contributors to deer diets in winter when many other forages are unavailable (Halls, 1984). Other vines, such as poison ivy, laurel greenbrier, were abundant in all of the treatments we examined.

Site preparation studies in South Carolina (Gassett *et al.*, 2000) and in Georgia (Witt, 1991; Moore, 1996) revealed that CSP may benefit deer forage quality by suppressing low preference woody browse in favor of more nutritious herbaceous species. More recently, Jones (2009a) reported a similar response in Mississippi Lower Coastal Plain plantations where lactation-level carrying capacity was greatest on moderate intensity treatments that had reduced woody biomass, but still had abundant herbaceous and woody forage species. We saw an increase in cover of herbaceous forage concurrent with a reduction in woody cover, but the magnitude was small, and herbaceous cover never exceeded 10%. Total herbaceous cover (non-preferred) was abundant (Lane, 2010) on our sites. However, cover of herbaceous deer forages was low on all of the treatments we examined. On our sites, much of the herbaceous community was composed of panic grasses, switch cane, broomsedge (*Andropogon virginicus*), dog fennel (*Eupatorium capillifolium*), and bracken fern (*Pteridium aquilinum*), which are all considered poor deer forage (Miller and Miller 2005).

Broadcast herbaceous weed control treatments typically impact forages in the year of application only (Keyser and Ford, 2006). We did not see significant reductions during the year

of application, but the banded HWC treatment generally produced more total deer forage than broadcast treatments because the banded treatment only applied herbicide on the beds over the crop trees and vegetation between the rows was not treated.

Woody forages are important in the Lower Coastal Plain due to low abundance of preferred native herbaceous forages. In our study, CSP resulted in long lasting reductions in total forage due to declines in woody and vine species. This contrasts with other studies examining CSP in other regions have shown that reductions in woody cover can increase cover of herbaceous species important to deer (Loehle *et al.*, 2009). Because the results we observed differ from other studies conducted in other physiographic conditions, managers should consider local plant communities and edaphic factors before assuming similar responses (Wilkins *et al.*, 1993).

#### Northern bobwhite food plants

Herbaceous species dominated total cover on all of our treatment sites (Lane, 2010) and were the dominant food plants for bobwhites for the first 4 years. Brunswig and Johnson (1972) noted a significant reduction in bobwhite feeding conditions the fourth year following site preparation after peaking in years 2-3 (Robinson and Barkalow, 1979; Witt, 1991; Branch, 1998).

Across all treatments and all years, 8 of the 10 top quail foods plants were seed-producing grasses or sedges comprising approximately 50% of the total cover across all plant groups. Legumes are important seed producers for quail across their range and in many cases are used disproportionately to their abundance (Landers and Johnson, 1976b). In our study, cover of legumes was extremely low (< 2%), but was greatest in CSP treatments. Although other studies (Welch *et al.*, 2004; Iglay, 2007; Burke *et al.*, 2008; Miller and Chamberlain, 2008) have

reported an increased abundance of legumes following imazapyr treatments, legumes are a relatively uncommon component of the vegetative community in early successional pocosins. Pokeweed, *Hypericum* spp., and *Polygonum* spp. were among the most abundant forbs on NO-CSP. These species are not high quality seed producers, but they can be important contributors to bobwhite diets when they are abundant (Landers and Johnson, 1976).

## CONCLUSION

The successional time scales we observed in our treatments from stand initiation to canopy closure were similar to those in previous studies (Jones *et al.* 2008b; Miller *et al.*, 1995). However, the unique plant communities of the poorly-drained shrub-dominated Lower Coastal Plain resulted in responses not seen in other regions. The edaphic conditions on these sites result in species rich early successional herbaceous communities, but often lack abundant legumes and forbs that are important food plants for deer and quail. Chemical site preparation resulted in long term reductions in total deer forage with no concurrent increase in forage quality. Even in newly regenerating plantations, woody and vine forages are the primary foods of white-tailed deer in these habitat types. The deer forage in these Lower Coastal Plain sites is relatively poor quality because of low soil nutrients and seasonally high water tables that created the pocosins that originally dominated the region. Bobwhite food plants benefited from reductions in woody cover, with responses similar to previous studies.

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Table 2.1. Treatments used to evaluate white-tailed deer (*Odocoileus virginianus*) and northern bobwhite (*Colinus virginianus*) food plant responses to combinations of chemical and mechanical site preparation techniques in the Lower Coastal Plain of North Carolina, summers of 2002-05, 2007-09.

Intensity	Treatment	Abbrev. <sup>a</sup>	MSP <sup>b</sup>	CSP <sup>bc</sup>	Year 1 HWC <sup>d</sup>	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)

<sup>a</sup>Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC

<sup>b</sup>MSP = mechanical site preparation; CSP = chemical site preparation

<sup>c</sup>Chopper<sup>TM</sup> (0.58 L ha<sup>-1</sup> mixed with 11.68 L ha<sup>-1</sup> of oil)

<sup>d</sup>HWC = herbaceous weed control, Arsenal<sup>TM</sup> (0.30 L ha<sup>-1</sup>) and Oust<sup>TM</sup> (0.15 L ha<sup>-1</sup>)

Table 2.2. Mean percent cover, standard error, and contrast results for individual treatment components comparing white-tailed deer (*Odocoileus virginianus*) food plants. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) commercial loblolly pine plantations in the Lower Coastal Plain of North Carolina.

Type	Yr	Mechanical Site Prep. and Spacing <sup>ab</sup>						Herbaceous Weed Control						Chemical Site Preparation					
		RCN <sup>c</sup>		SSW		F	P <sup>d</sup>	Banded		Broadcast		F	P	NO-CSP		CSP		F	P
		Mean	SE	Mean	SE			Mean	SE	Mean	SE			Mean	SE	Mean	SE		
Herbaceous	1	5.8	4.3	5.4	2.4	0.08	0.78	5.8	4.3	2.6	2.0	0.77	0.39	6.8	3.3	2.4	0.9	3.07	0.09
	2	5.5	2.4	3.8	1.3	1.06	0.32	5.5	2.4	5.2	2.6	0.03	0.87	6.0	2.2	3.6	1.0	2.79	0.11
	3	5.2	1.4	2.3	0.8	4.63	0.06	5.2	1.4	3.6	1.0	0.78	0.40	3.5	0.7	3.7	0.9	0.00	0.96
	4	8.4	2.7	5.5	2.3	20.60	< 0.01	8.4	2.7	5.6	1.7	5.14	0.05	5.3	1.6	7.7	2.0	6.62	0.02
	6	1.7	0.5	1.9	0.8	0.01	0.94	1.7	0.5	1.2	0.5	0.77	0.40	1.3	0.3	1.9	0.6	0.62	0.44
	7	3.2	1.2	2.8	1.3	0.01	0.91	3.2	1.2	1.0	0.4	2.55	0.15	1.7	0.6	2.9	1.0	2.22	0.16
	8	2.3	0.6	1.5	0.7	1.06	0.33	2.3	0.6	1.2	0.5	1.62	0.24	1.5	0.5	1.8	0.5	0.89	0.36
Woody & Vine																			
Cover	1	5.1	1.4	9.6	2.2	15.53	< 0.01	5.1	1.4	2.6	0.9	10.46	0.01	9.7	1.5	1.8	0.6	93.15	< 0.01
	2	24.9	6.0	24.8	4.0	0.24	0.63	24.9	6.0	21.0	5.6	0.50	0.49	35.9	4.1	11.3	1.4	11.02	< 0.01
	3	37.7	9.5	37.4	5.8	0.06	0.82	37.7	9.5	23.3	5.5	6.24	0.03	43.8	5.7	21.2	2.7	24.89	< 0.01
	4	63.2	11.1	62.6	9.4	0.00	0.99	63.2	11.1	52.7	7.8	2.11	0.18	77.7	6.8	41.3	3.6	27.58	< 0.01
	6	35.3	6.9	37.2	4.9	0.41	0.54	35.3	6.9	31.4	6.4	0.88	0.37	46.8	3.9	22.5	2.7	40.71	< 0.01
	7	28.9	6.0	37.4	6.0	1.93	0.20	28.9	6.0	30.4	6.9	0.55	0.48	45.8	4.2	20.1	2.8	55.24	< 0.01
	8	26.3	5.4	37.6	4.9	8.61	0.02	26.3	5.4	31.7	6.9	0.02	0.89	45.1	3.4	22.0	2.8	64.40	< 0.01
Total Cover																			
	1	10.9	4.8	15.0	3.3	4.29	0.06	10.9	4.8	5.2	2.0	2.42	0.14	16.5	3.4	4.2	1.4	45.13	< 0.01
	2	30.4	6.6	28.6	4.3	0.01	0.92	30.4	6.6	26.2	5.6	0.60	0.45	41.9	3.8	14.9	2.1	57.15	< 0.01
	3	42.9	9.5	39.7	5.8	0.40	0.54	42.9	9.5	27.0	5.5	6.74	0.03	47.2	5.4	24.9	2.9	21.28	< 0.01
	4	71.6	11.1	68.1	9.4	0.12	0.73	71.6	11.1	58.4	7.8	3.41	0.10	83.0	5.9	49.0	3.6	22.18	< 0.01
	6	37.0	0.5	39.1	0.8	0.38	0.56	37.0	0.5	32.7	0.5	0.97	0.35	48.2	3.7	24.4	2.8	33.65	< 0.01
	7	32.1	1.2	40.2	1.3	1.62	0.24	32.1	1.2	31.3	0.4	1.15	0.32	47.4	4.0	22.9	2.7	41.75	< 0.01
	8	28.6	0.6	39.1	0.7	6.35	0.04	28.6	0.6	32.9	0.5	0.00	0.97	46.5	3.3	22.0	2.8	52.58	< 0.01

<sup>a</sup> Mechanical site preparation and spacing treatments were paired.

<sup>b</sup> Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

<sup>c</sup> RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

<sup>d</sup> 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. Mean species richness, standard error, and contrast results for individual treatment components comparing white-tailed deer (*Odocoileus virginianus*) food plants. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) commercial loblolly pine plantations in the Lower Coastal Plain of North Carolina.

Type	Yr	Mechanical Site Prep. and Spacing <sup>ab</sup>						Herbaceous Weed Control						Chemical Site Preparation					
		RCN <sup>c</sup>		SSW		F	P <sup>d</sup>	Banded		Broadcast		F	P	NO-CSP		CSP		F	P
		Mean	SE	Mean	SE			Mean	SE	Mean	SE			Mean	SE	Mean	SE		
Herbaceous Richness	1	3.3	1.4	4.8	2.1	2.96	0.11	3.3	1.4	2.0	0.8	4.10	0.06	3.6	1.2	3.1	1.3	0.48	0.50
	2	5.3	1.3	4.4	1.6	1.64	0.22	5.3	1.3	3.9	1.2	5.19	0.04	4.5	1.1	4.6	1.1	0.01	0.91
	3	7.5	1.3	4.3	1.1	18.73	< 0.01	7.5	1.3	6.3	1.6	0.15	0.71	5.9	1.2	6.0	1.1	0.00	0.99
	4	7.5	2.1	6.5	2.3	1.14	0.31	7.5	2.1	6.8	2.1	1.72	0.22	6.8	1.9	7.0	1.6	0.06	0.80
	6	4.3	1.5	5.8	2.2	1.84	0.21	4.3	1.5	4.4	1.1	0.01	0.91	4.2	1.2	5.4	1.4	1.49	0.24
	7	5.4	2.1	5.6	2.1	0.81	0.40	5.4	2.1	4.9	1.5	0.03	0.86	4.9	1.5	5.7	1.6	1.98	0.18
	8	5.9	1.2	5.5	2.0	0.33	0.58	5.9	1.2	4.3	1.3	1.54	0.25	5.1	1.3	5.3	1.3	0.65	0.43
	Vine Richness	1	2.7	0.6	3.6	0.7	2.39	0.14	2.7	0.6	2.1	0.4	2.43	0.14	3.6	0.5	1.9	0.3	15.98
2		3.6	0.5	4.0	0.4	0.56	0.47	3.6	0.5	2.9	0.4	1.74	0.21	3.7	0.4	3.3	0.4	0.69	0.41
3		5.0	0.7	4.8	0.8	0.01	0.92	5.0	0.7	4.2	0.8	0.61	0.45	5.2	0.7	4.1	0.5	5.84	0.03
4		6.5	0.7	7.0	0.8	0.56	0.47	6.5	0.7	5.9	0.8	1.04	0.34	6.8	0.7	6.2	0.6	1.42	0.25
6		6.1	0.9	7.9	0.5	6.12	0.04	6.1	0.9	6.8	1.2	0.67	0.44	6.4	0.8	7.4	0.6	1.99	0.18
7		6.9	0.6	6.9	0.6	0.74	0.41	6.9	0.6	6.3	0.9	0.02	0.89	6.8	0.6	6.5	0.6	0.01	0.94
8		6.9	0.9	6.6	0.3	0.14	0.72	6.9	0.9	5.9	0.9	0.61	0.46	7.0	0.6	5.9	0.5	2.35	0.15
Woody Richness		1	5.2	1.2	6.6	0.9	3.40	0.09	5.2	1.2	5.2	1.1	0.00	1.00	8.2	0.7	3.1	0.5	58.66
	2	6.3	1.0	7.8	0.9	6.30	0.02	6.3	1.0	6.9	1.0	1.24	0.28	8.8	0.7	5.1	0.7	48.69	< 0.01
	3	7.5	1.2	7.8	0.9	0.52	0.49	7.5	1.2	7.1	1.2	0.01	0.92	9.2	0.6	5.7	0.8	24.57	< 0.01
	4	8.6	1.1	9.5	1.5	1.15	0.31	8.6	1.1	8.8	1.2	0.03	0.87	10.2	0.9	7.8	1.0	14.75	< 0.01
	6	9.5	1.2	10.8	1.5	2.71	0.13	9.5	1.2	10.4	0.8	2.11	0.18	12.0	0.7	8.4	0.9	31.84	< 0.01
	7	10.1	1.1	10.4	1.8	0.05	0.83	10.1	1.1	10.0	1.1	0.27	0.62	11.4	1.2	9.1	0.9	14.72	< 0.01
	8	10.0	1.0	11.1	1.4	1.61	0.24	10.0	1.0	11.3	1.2	3.56	0.10	11.9	1.0	9.8	0.9	11.60	< 0.01

<sup>a</sup> Mechanical site preparation and spacing treatments were paired.

<sup>b</sup> Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

<sup>c</sup> RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

<sup>d</sup> 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 2.4. Mean percent cover, standard error, and contrast results for individual treatment components comparing northern bobwhite (*Colinus virginianus*) food plants. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) commercial loblolly pine plantations in the Lower Coastal Plain of North Carolina.

Type	Yr	Mechanical Site Prep. and Spacing <sup>ab</sup>						Herbaceous Weed Control						Chemical Site Preparation					
		RCN <sup>c</sup>		SSW		F	P <sup>d</sup>	Banded		Broadcast		F	P	NO-CSP		CSP		F	P
		Mean	SE	Mean	SE			Mean	SE	Mean	SE			Mean	SE	Mean	SE		
Herbaceous	1	23.2	7.3	25.6	7.3	0.22	0.64	23.2	7.3	4.8	2.2	11.56	< 0.01	25.2	10.5	10.5	6.7	12.91	< 0.01
Cover	2	35.3	10.3	38.7	9.2	0.16	0.70	35.3	10.3	31.0	9.5	0.41	0.53	42.1	14.7	28.0	11.5	3.80	0.06
	3	21.2	4.4	18.4	5.3	0.13	0.72	21.2	4.4	13.9	3.0	1.92	0.20	15.7	4.1	19.5	5.8	0.16	0.69
	4	31.1	8.6	32.5	8.4	0.03	0.86	31.1	8.6	24.8	5.7	0.66	0.44	25.7	10.0	33.3	11.1	1.89	0.19
	6	4.5	1.5	4.6	1.9	0.00	0.97	4.5	1.5	5.2	2.0	0.17	0.69	5.8	3.2	3.7	1.3	1.38	0.26
	7	5.3	1.8	3.5	1.7	1.04	0.34	5.3	1.8	3.3	1.5	1.77	0.22	4.3	2.7	3.7	1.7	0.07	0.80
	8	2.6	0.9	2.2	1.3	0.04	0.84	2.6	0.9	2.3	1.2	0.02	0.90	2.8	2.0	1.9	1.0	0.55	0.47
Woody & Vine Cover	1	2.7	0.8	3.6	0.8	2.15	0.16	2.7	0.8	1.0	0.3	12.89	< 0.01	3.8	1.0	1.0	0.7	59.59	< 0.01
	2	13.4	2.8	12.1	2.5	0.84	0.37	13.4	2.8	10.0	2.9	3.21	0.09	16.1	3.8	7.6	3.0	42.26	< 0.01
	3	21.9	3.4	21.2	4.5	0.14	0.72	21.9	3.4	12.8	2.0	5.90	0.04	21.3	4.8	15.6	3.4	4.35	0.05
	4	38.4	7.9	39.4	9.7	0.04	0.84	38.4	7.9	33.1	9.3	0.54	0.48	47.1	14.4	26.8	7.1	13.57	< 0.01
	6	19.5	5.0	18.4	5.6	0.08	0.78	19.5	5.0	14.6	3.8	2.51	0.15	22.8	7.8	12.3	4.1	13.89	< 0.01
	7	14.8	3.3	15.4	4.9	0.11	0.75	14.8	3.3	11.9	3.1	1.31	0.29	19.0	6.2	9.4	2.9	9.83	0.01
Total Cover	8	16.1	4.8	13.8	4.3	0.25	0.63	16.1	4.8	12.4	3.2	1.34	0.28	19.9	6.6	8.6	2.7	15.76	< 0.01
	1	25.9	8.0	29.1	7.9	0.37	0.55	25.9	8.0	5.8	2.3	12.45	< 0.01	29.0	11.4	11.5	7.2	22.84	< 0.01
	2	48.7	12.4	50.7	10.2	0.06	0.81	48.7	12.4	41.1	11.3	1.36	0.26	58.1	17.0	35.6	13.2	16.15	< 0.01
	3	43.1	3.4	39.6	4.5	1.00	0.34	43.1	3.4	26.7	2.0	10.40	0.01	37.0	5.7	35.1	7.5	2.05	0.17
	4	69.5	7.9	71.9	9.7	0.16	0.70	69.5	7.9	57.9	9.3	1.63	0.23	72.8	19.5	60.1	17.2	2.67	0.12
	6	24.1	1.5	23.0	1.9	0.11	0.75	24.1	1.5	19.8	2.0	1.74	0.22	28.6	7.9	16.0	4.9	18.70	< 0.01
Total Cover	7	20.2	1.8	18.9	1.7	0.00	0.99	10.2	1.8	15.2	1.5	3.45	0.10	23.3	6.3	13.1	3.7	11.74	< 0.01
	8	18.7	0.9	16.0	1.3	0.34	0.58	13.9	0.9	14.7	1.2	1.46	0.26	22.7	6.7	10.5	3.2	18.77	< 0.01

<sup>a</sup> Mechanical site preparation and spacing treatments were paired.

<sup>b</sup> Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

<sup>c</sup> RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

<sup>d</sup> 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. Mean species richness, standard error, and contrast results for individual treatment components comparing northern bobwhite (*Colinus virginianus*) food plants. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) commercial loblolly pine plantations in the Lower Coastal Plain of North Carolina.

Type	Yr	Mechanical Site Prep. and Spacing <sup>ab</sup>						Herbaceous Weed Control						Chemical Site Preparation					
		RCN <sup>c</sup>			SSW			Banded		Broadcast		F	P	NO-CSP		CSP		F	P
		Mean	SE	F	Mean	SE	F	P	Mean	SE	Mean			SE	Mean	SE			
Herbaceous Richness	1	6.3	1.8	7.7	1.8	4.09	0.06	6.3	1.8	4.4	1.6	11.97	<0.01	6.6	1.3	5.7	1.4	3.36	0.08
	2	6.3	1.4	6.3	1.3	0.00	1.00	6.3	1.4	6.2	1.2	0.03	0.87	6.4	1.0	6.0	1.1	1.51	0.23
	3	9.3	1.8	6.4	1.7	1.88	0.20	9.3	1.8	7.8	1.9	0.04	0.84	7.8	1.3	7.6	1.5	0.11	0.74
	4	9.1	2.5	8.6	2.1	0.23	0.64	9.1	2.5	9.5	2.4	0.42	0.53	8.8	1.7	9.4	1.6	0.88	0.36
	6	7.0	2.3	8.5	2.7	0.84	0.38	7.0	2.3	7.1	1.5	0.01	0.92	6.8	1.8	8.3	1.6	1.60	0.22
	7	7.7	2.7	7.3	2.5	0.38	0.55	7.7	2.7	6.1	2.0	0.42	0.54	6.5	1.8	7.5	1.8	3.52	0.08
	8	6.7	1.8	6.1	2.1	0.03	0.87	6.7	1.8	4.9	1.4	3.04	0.12	5.6	1.5	6.1	1.1	1.06	0.32
	Vine Richness	1	2.4	0.4	3.1	0.5	1.86	0.19	2.4	0.5	2.3	0.4	0.38	0.54	3.2	0.4	1.9	0.3	13.32
2		3.3	0.5	3.8	0.4	1.12	0.31	3.3	0.5	2.9	0.5	0.56	0.47	3.4	0.4	3.2	0.4	0.59	0.45
3		4.5	0.7	4.1	0.8	0.05	0.83	4.5	0.7	3.9	0.8	0.28	0.61	4.7	0.7	3.6	0.5	4.95	0.04
4		5.5	0.8	6.3	0.8	1.88	0.20	5.5	0.8	5.4	0.8	0.04	0.84	6.0	0.7	5.4	0.6	1.94	0.18
6		6.0	0.9	7.5	0.5	6.00	0.04	6.0	0.9	6.4	1.3	0.24	0.64	6.2	0.8	7.1	0.7	1.92	0.19
7		6.4	0.8	6.5	0.7	1.00	0.35	6.4	0.8	5.6	1.0	0.05	0.84	6.3	0.7	6.1	0.7	0.06	0.81
8		6.4	0.9	6.1	0.4	0.14	0.72	6.4	0.9	5.3	1.0	0.76	0.41	6.5	0.7	5.4	0.6	1.82	0.20
Woody Richness		1	2.1	0.5	2.8	0.6	2.22	0.16	2.1	0.5	1.9	0.5	0.14	0.71	3.3	0.4	1.2	0.4	26.78
	2	2.3	0.4	2.8	0.5	1.23	0.29	2.3	0.4	2.6	0.5	0.95	0.34	3.2	0.4	1.8	0.4	20.32	<0.01
	3	2.6	0.7	2.8	0.6	0.60	0.46	2.6	0.7	2.3	0.5	0.00	0.95	3.1	0.5	2.1	0.5	4.49	0.05
	4	3.1	0.7	3.8	0.8	0.88	0.37	3.1	0.7	3.3	0.8	0.03	0.87	4.0	0.7	2.8	0.5	5.79	0.03
	6	3.1	0.7	3.6	0.8	1.44	0.26	3.1	0.7	3.0	0.6	0.09	0.77	3.9	0.5	2.6	0.6	15.74	0.00
	7	4.0	0.7	3.4	0.9	0.68	0.43	4.0	0.7	3.3	0.8	1.06	0.33	4.0	0.7	3.1	0.5	4.00	0.07
	8	4.0	0.5	3.8	0.6	0.14	0.72	4.0	0.5	4.4	0.8	1.19	0.31	4.4	0.5	3.8	0.6	1.97	0.18

<sup>a</sup> Mechanical site preparation and spacing treatments were paired.

<sup>b</sup> Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

<sup>c</sup> RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

<sup>d</sup> 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 2.6 . Mean percent cover, standard error, and contrast results for individual treatment components comparing northern bobwhite (*Colinus virginianus*) herbaceous food plants. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) commercial loblolly pine plantations in the Lower Coastal Plain of North Carolina.

Type	Yr	Mechanical Site Prep. and Spacing <sup>ab</sup>						Herbaceous Weed Control						Chemical Site Preparation					
		RCN <sup>c</sup>		SSW		F	P <sup>d</sup>	Banded		Broadcast		F	P	NO-CSP		CSP		F	P
		Mean	SE	Mean	SE			Mean	SE	Mean	SE			Mean	SE	Mean	SE		
Grass	1	16.3	6.1	17.9	5.9	0.49	0.50	16.3	6.1	1.5	0.9	9.34	0.01	7.2	6.1	16.6	4.0	6.23	0.02
Cover	2	30.0	8.8	35.3	8.8	0.17	0.68	30.0	8.8	25.2	7.2	4.00	0.06	24.5	8.5	35.8	7.7	3.68	0.07
	3	18.7	3.6	16.2	4.7	0.15	0.71	18.7	3.6	11.8	2.6	0.01	0.92	17.7	3.0	12.9	4.2	0.72	0.41
	4	23.3	6.6	25.4	6.6	0.30	0.60	23.3	6.6	20.2	4.7	1.16	0.31	26.8	5.3	19.1	6.2	2.23	0.16
	6	2.8	1.3	2.9	1.5	0.04	0.85	2.8	1.3	3.2	1.3	0.00	0.96	2.1	1.7	3.8	0.6	2.79	0.12
	7	2.3	1.2	1.4	1.0	1.31	0.28	2.3	1.2	2.1	1.2	0.17	0.69	1.4	1.3	2.4	0.8	2.76	0.12
	8	1.2	0.7	1.2	0.8	0.04	0.84	1.2	0.7	1.4	0.9	2.81	0.13	0.8	1.0	1.7	0.5	2.39	0.14
Legume	1	0.4	0.3	0.8	0.7	0.45	0.51	0.4	0.3	0.2	0.1	1.25	0.28	0.2	0.1	0.7	0.6	1.51	0.23
	2	0.4	0.2	0.5	0.2	0.35	0.57	0.4	0.2	0.5	0.3	1.35	0.26	0.4	0.2	0.5	0.3	0.44	0.51
	3	0.3	0.2	0.3	0.2	0.15	0.71	0.3	0.2	0.3	0.1	0.00	1.00	0.2	0.1	0.4	0.2	1.35	0.26
	4	0.9	0.5	1.0	0.5	0.07	0.80	0.9	0.5	0.7	0.3	0.24	0.64	0.6	0.4	1.1	0.5	1.47	0.24
	6	0.2	0.1	0.2	0.2	0.38	0.55	0.2	0.1	0.0	0.0	1.15	0.31	0.1	0.1	0.2	0.1	0.08	0.79
	7	1.6	0.7	0.8	0.5	0.35	0.57	1.6	0.7	0.2	0.1	2.58	0.15	0.7	0.4	1.0	0.6	0.56	0.47
Other Forb	1	6.0	4.4	4.6	2.4	0.15	0.71	6.0	4.4	3.0	2.0	0.64	0.43	7.0	4.1	2.0	0.8	3.70	0.07
	2	5.0	2.5	2.8	1.1	1.75	0.21	5.0	2.5	5.3	2.6	0.03	0.86	5.7	2.8	3.0	1.0	3.36	0.08
	3	1.2	0.5	0.6	0.2	1.34	0.27	1.2	0.5	1.0	0.4	0.00	0.97	1.2	0.4	0.7	0.3	3.26	0.09
	4	3.1	1.7	1.6	0.6	1.44	0.26	3.1	1.7	1.2	0.3	1.54	0.25	2.5	1.4	1.5	0.5	1.13	0.30
	6	0.7	0.3	0.5	0.2	0.48	0.50	0.7	0.3	0.6	0.3	0.44	0.52	0.8	0.3	0.4	0.1	2.11	0.17
	7	0.4	0.1	0.4	0.1	0.12	0.74	0.4	0.1	0.2	0.1	1.28	0.29	0.2	0.1	0.4	0.1	1.63	0.22
8	0.8	0.2	0.4	0.2	2.34	0.16	0.8	0.2	0.4	0.1	6.75	0.03	0.5	0.2	0.5	0.2	0.06	0.81	

<sup>a</sup> Mechanical site preparation and spacing treatments were paired.

<sup>b</sup> Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

<sup>c</sup> RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

<sup>d</sup> 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).

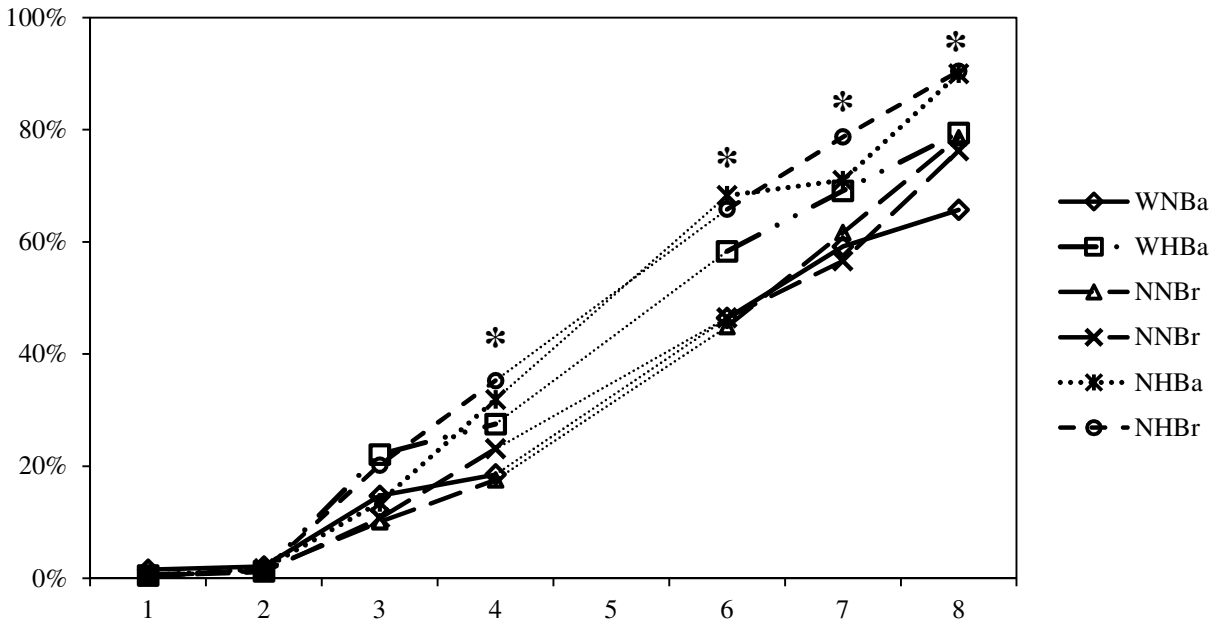


Figure 2.1. Mean percent cover of loblolly pine crop trees by treatment. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) commercial plantations in the Lower Coastal Plain of North Carolina. Asterisks denote differences among treatments within a year ( $P \leq 0.05$ ). Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC

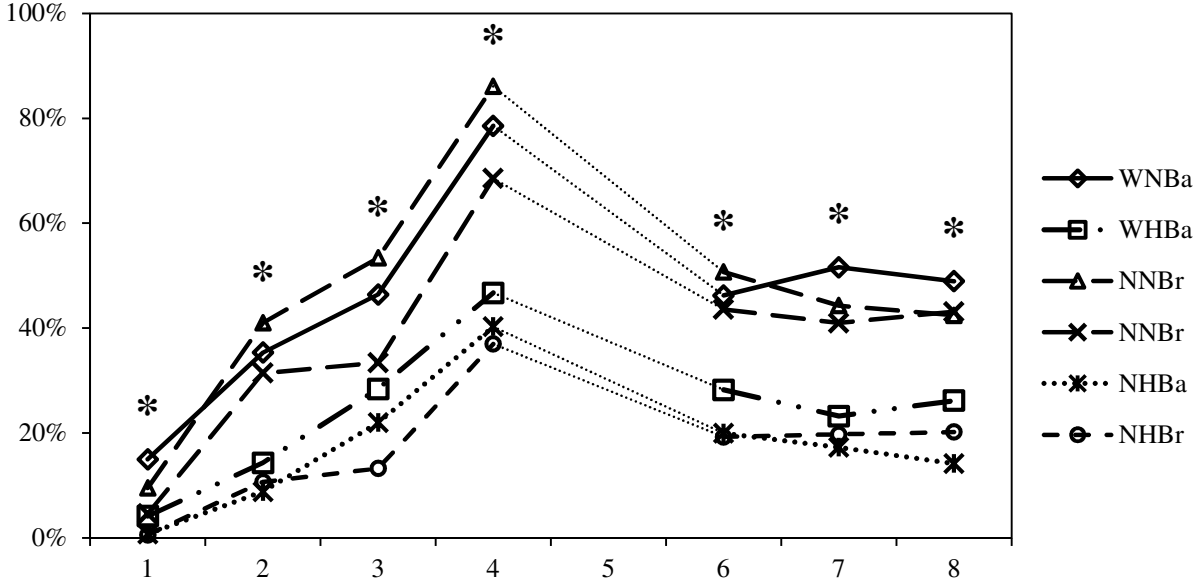


Figure 2.2. Mean percent cover of woody and vine white-tailed deer (*Odocoileus virginianus*) food plants by treatment. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina. Asterisks denote differences among treatments within a year ( $P \leq 0.05$ ). Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC

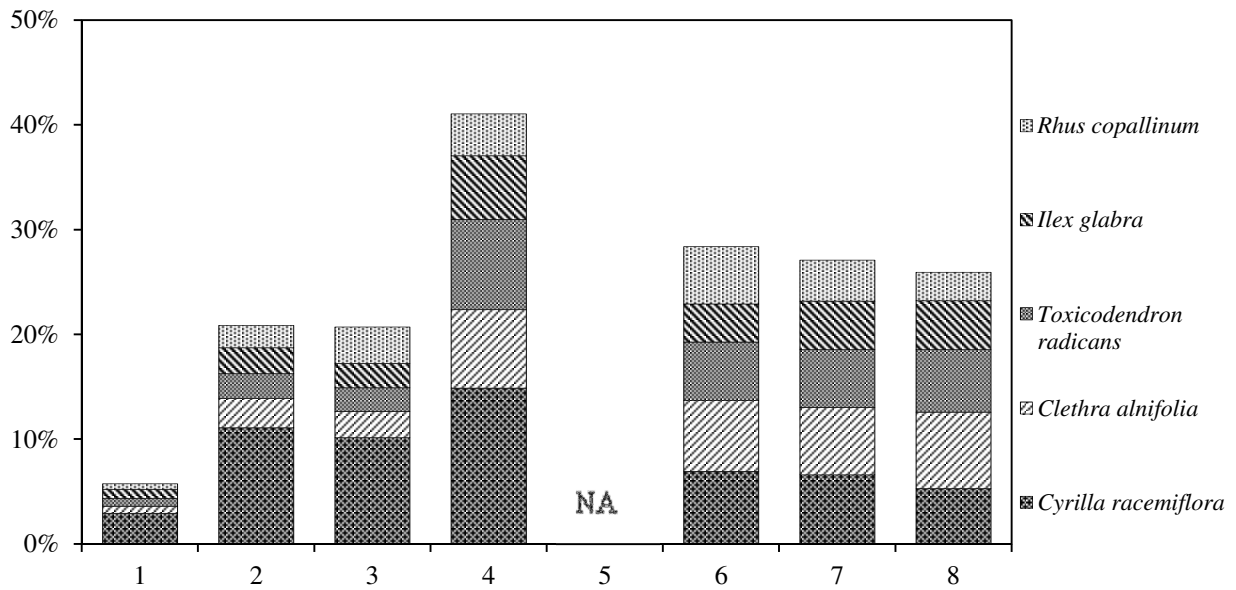


Figure 2.3. Mean percent cover by year of the most abundant white-tailed deer (*Odocoileus virginianus*) food plants\ taxa for NO-CSP treatments. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina.

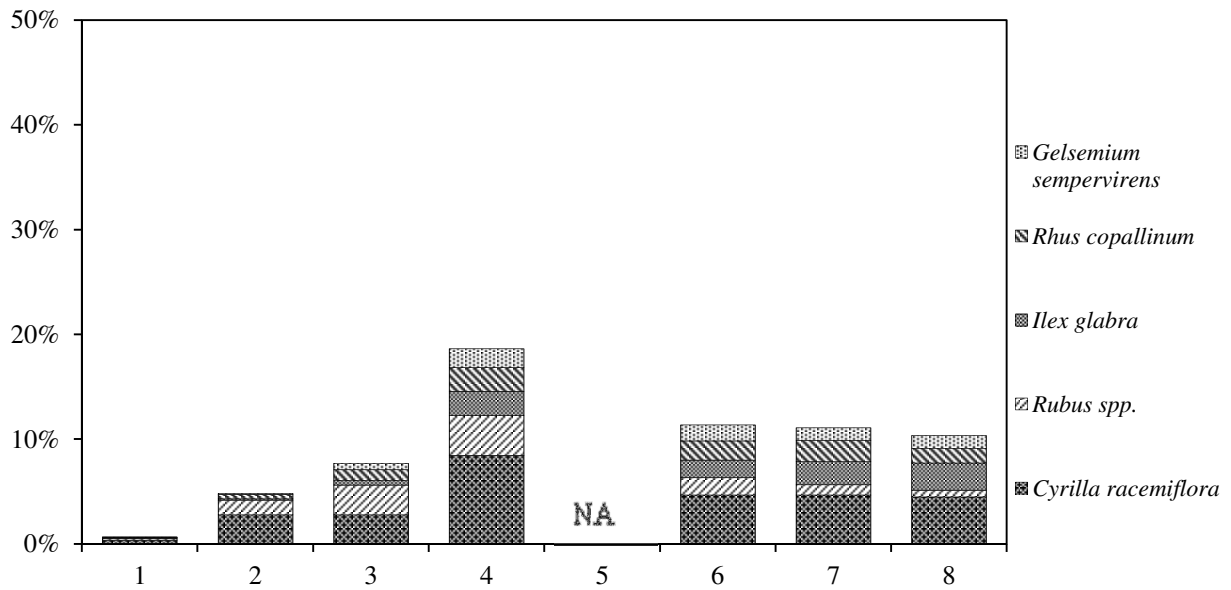


Figure 2.4. Mean percent cover by year of the most abundant white-tailed deer (*Odocoileus virginianus*) food plants for treatments receiving CSP. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina.

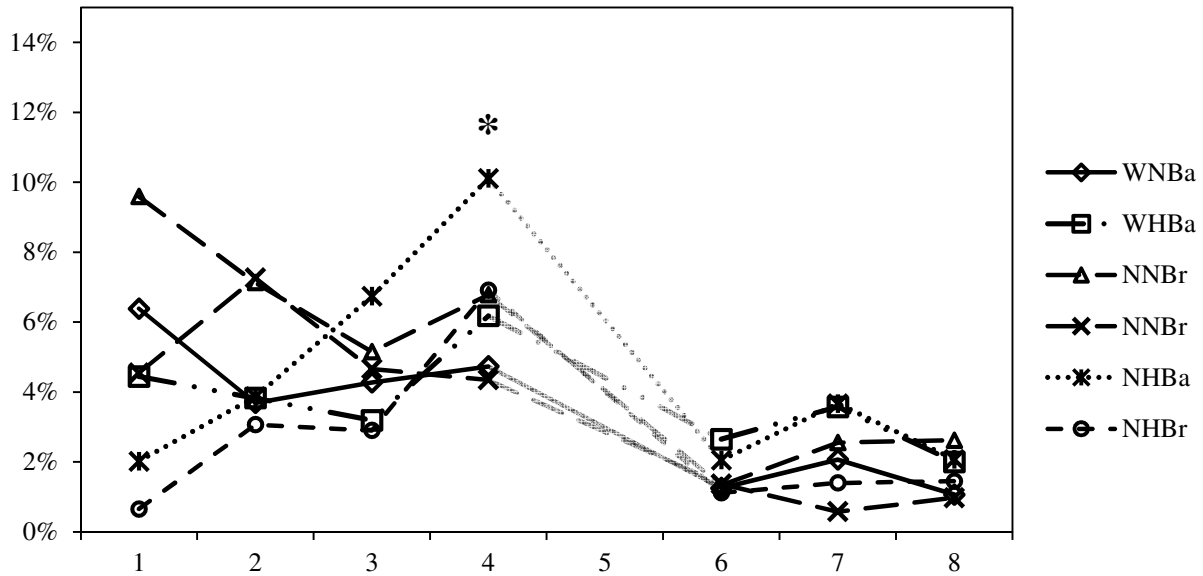


Figure 2.5. Mean percent cover of herbaceous white-tailed deer (*Odocoileus virginianus*) food plants by treatment. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina. Asterisks denote differences among treatments within a year ( $P \leq 0.05$ ). Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC

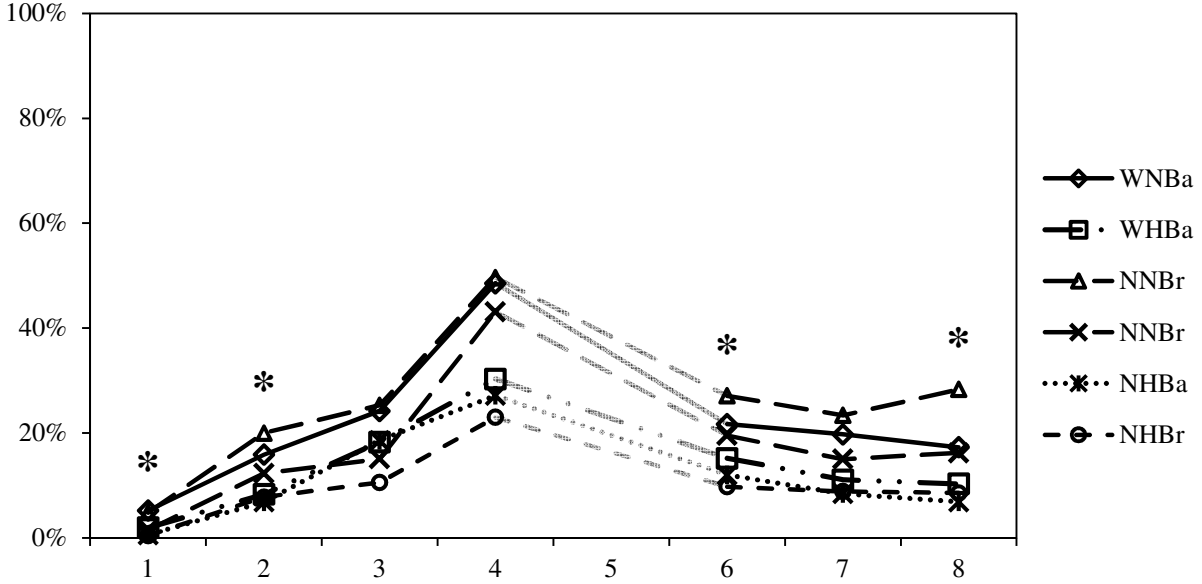


Figure 2.6. Mean percent cover of woody and vine northern bobwhite (*Colinus virginianus*) food plants by treatment. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina. Asterisks denote differences among treatments within a year ( $P \leq 0.05$ ). Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC

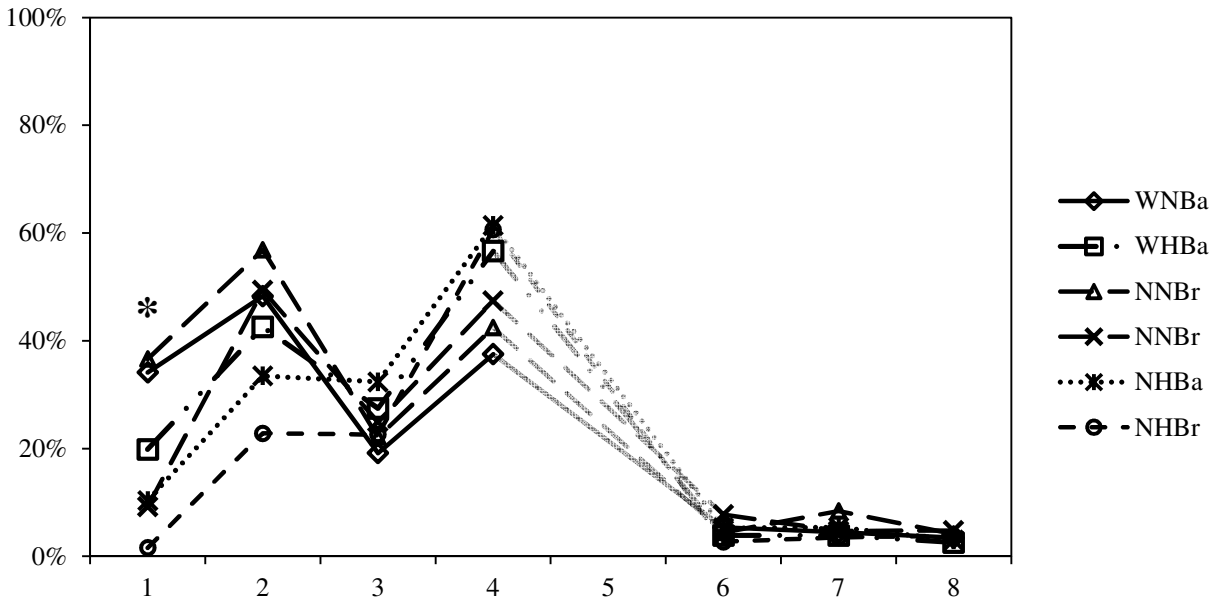


Figure 2.7. Mean percent cover of herbaceous northern bobwhite (*Colinus virginianus*) food plants by treatment. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina. Asterisks denote differences among treatments within a year ( $P \leq 0.05$ ). Treatment abbreviations: W=wide spacing, N=narrow spacing; N=no chemical site prep, H=chemical site prep; Ba=banded HWC, Br=broadcast HWC

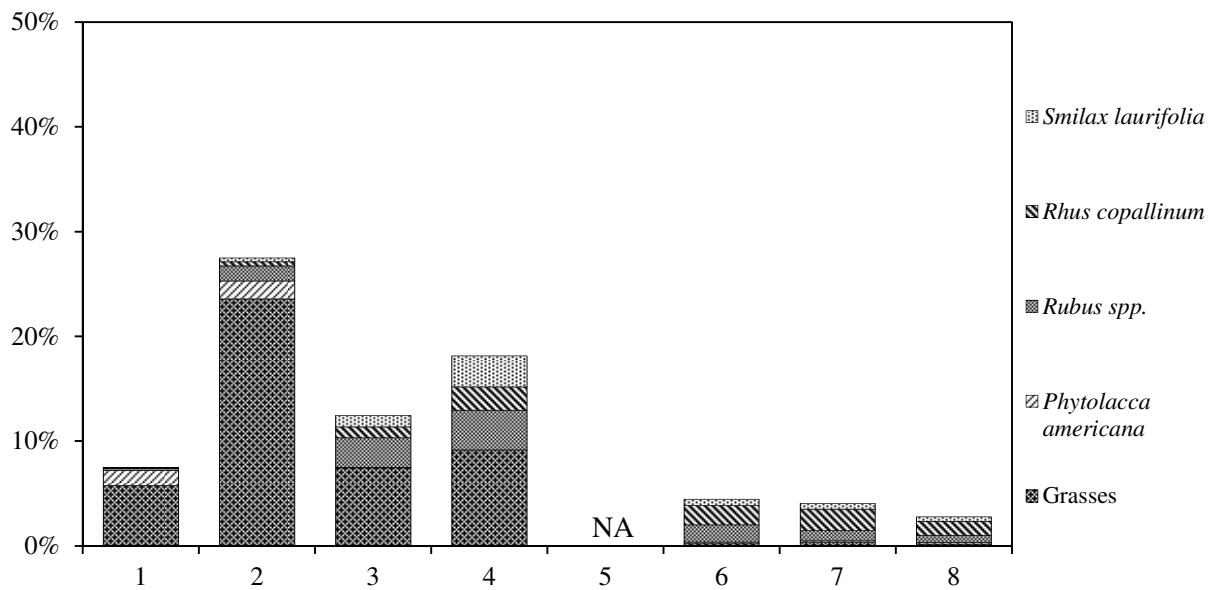


Figure 2.8. Mean percent cover by year of the most abundant northern bobwhite (*Colinus virginianus*) food plant taxa across treatments receiving CSP. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina.

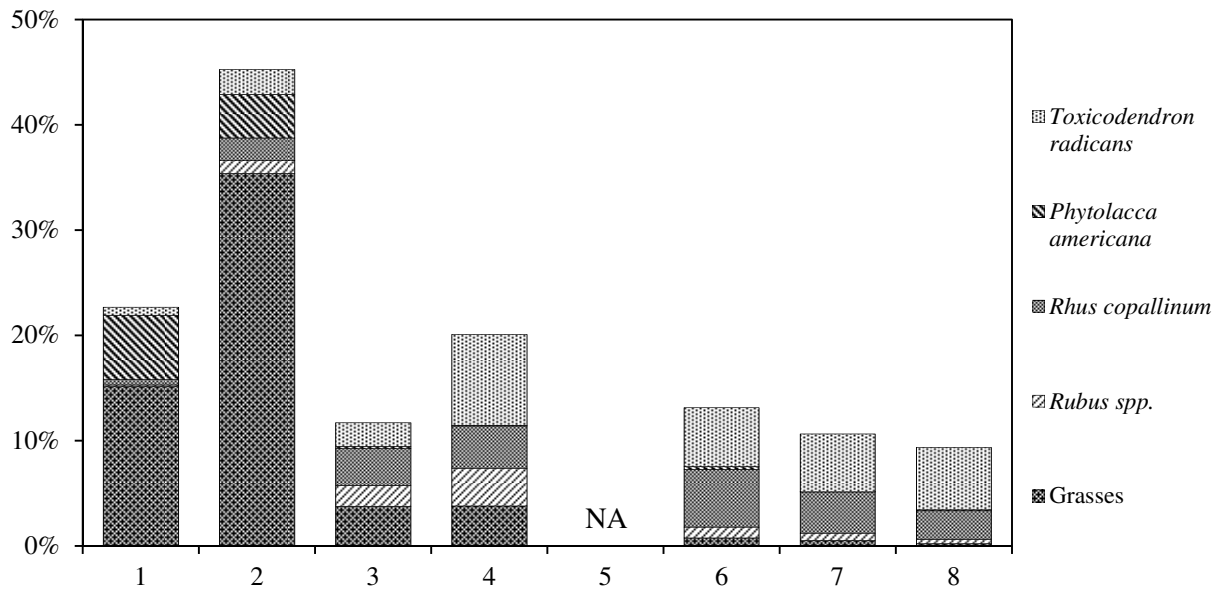


Figure 2.9. Mean percent cover by year of the most abundant northern bobwhite (*Colinus virginianus*) food plant taxa across NO-CSP treatments. We collected data 1-4 and 6-8 years following site preparation in 6 (yr. 1-3) or 4 (yr. 4, 5-8) loblolly pine plantations in the Lower Coastal Plain of North Carolina.

## CHAPTER 3

### CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Pine plantations of the southeastern United States provide a significant portion of the world's wood fiber and have the potential to be managed for significant financial gains. Forest land managers have a wide variety of silvicultural treatments at their disposal to address resource limitations to increase pine growth and profitability. Silvicultural treatments applied at stand initiation and designed to reduce competing vegetation set the stage for crop trees and other native vegetation for the upcoming rotation. Resulting alterations of vegetative structure and composition directly affect wildlife habitat for game species such as white-tailed deer and northern bobwhites. I examined how chemical site preparation (CSP), pine spacing, and herbaceous weed control (HWC) treatments affect food plants for white-tailed deer and northern bobwhite quail in the Lower Coastal Plain of North Carolina.

Loblolly pine thrives on a wide variety of sites across the Southeast. My study examined silvicultural treatments on converted pocosin type habitats characterized by poorly drained soils and dense grass and shrub communities. The responses I observed were primarily driven by chemical site preparation treatment effects on the woody shrubs.

Herbaceous weed control results in consistent gains in loblolly pine growth across most Southeastern U.S. Therefore, HWC was applied on all of my treatments but I examined two application methods: banded and broadcast. Similar to previous studies, HWC resulted in short

term effects on herbaceous food plants for quail, and had no effect on herbaceous deer food plants. The herbaceous communities on my sites were dominated by grasses and had low abundance of forbs. These infertile and poorly drained sites produce few herbaceous species that are preferred deer forages.

The successional time scales I observed in my treatments from stand initiation to canopy closure were similar to those in previous studies. However, the unique plant communities of the poorly-drained shrub-dominated Lower Coastal Plain resulted in responses not seen in other regions. The specific edaphic conditions on these site result in species rich early successional herbaceous communities, but often lack abundant legumes and forbs that are important food plants for deer and quail. Chemical site preparation resulted in long term reductions in total deer forage with no concurrent increase in forage quality. Even in newly regenerating plantations, woody and vine forages are the primary foods of white-tailed deer in these habitats. The deer forage in these Lower Coastal Plain habitats is relatively poor quality because of low soil nutrients and seasonally high water tables that created the pocosin communities that originally dominated the region. Bobwhite food plants benefited from reductions in woody cover, with responses similar to previous studies.

## APPENDIX

Table A.1. Stand attributes, standard errors, and contrast results for individual treatment component comparisons in 8 year old commercial loblolly pine plantations in the Lower Coastal Plain of North Carolina.

Variable	Mechanical Site Prep. and Spacing <sup>ab</sup>						Herbaceous Weed Control						Chemical Site Preparation					
	RCN <sup>c</sup>		SSW		<i>F</i>	<i>P</i> <sup>d</sup>	Banded		Broadcast		<i>F</i>	<i>P</i>	NO-CSP		CSP		<i>F</i>	<i>P</i>
	Mean	SE	Mean	SE			Mean	SE	Mean	SE			Mean	SE	Mean	SE		
Survival	72.6	3.8	84.3	3.5	0.03	0.99	72.6	3.8	81.5	3.7	10.09	0.01	75.8	3.1	83.3	3.0	3.30	0.09
QMD (cm)	16.5	0.9	15.3	0.4	4.08	0.08	16.5	0.9	16.7	0.8	0.18	0.68	16.4	0.6	16.0	0.6	0.52	0.48
Height (m)	11.0	0.3	11.3	0.2	0.33	0.58	11.0	0.3	11.3	0.3	0.72	0.42	11.2	0.1	11.2	0.3	0.03	0.86
Basal Area (m <sup>2</sup> /ha)	18.4	1.6	16.8	1.3	1.75	0.22	18.4	1.6	21.2	1.4	7.14	0.03	18.7	1.3	18.9	1.2	0.00	0.96
Total Yield (Mg/ha)	63.7	9.9	58.5	7.7	0.89	0.37	63.7	9.9	78.9	9.6	3.44	0.10	66.7	7.1	67.7	8.2	0.03	0.88
MAI (Mg/ha/yr)	8.0	1.6	7.3	1.4	0.89	0.37	8.0	1.2	9.9	1.2	3.44	0.10	8.5	0.9	8.3	1.0	0.03	0.88

<sup>a</sup> Mechanical site preparation and spacing treatments were paired.

<sup>b</sup> Mechanical site preparation and herbaceous weed control treatments compared with t-tests. Chemical site preparation compared with orthogonal contrasts.

<sup>c</sup> RCN = roller-shop/narrow spacing; SSW = strip shear/wide spacing.

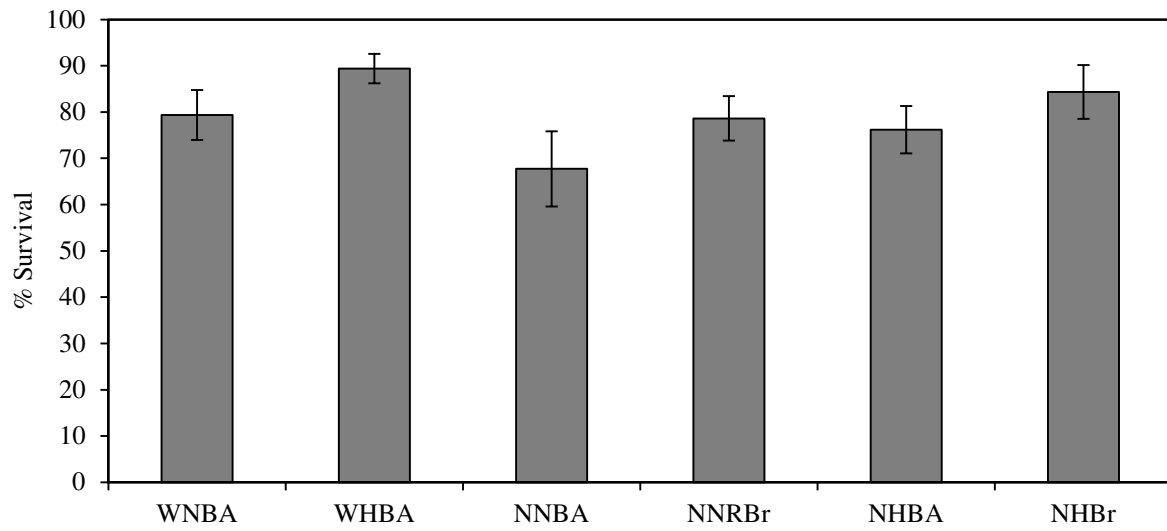


Figure A.1. Mean percent survival and standard errors for treatment comparisons of loblolly pine (*Pinus taeda*) plantations in the Lower Coastal Plain of North Carolina after 8 growing seasons.

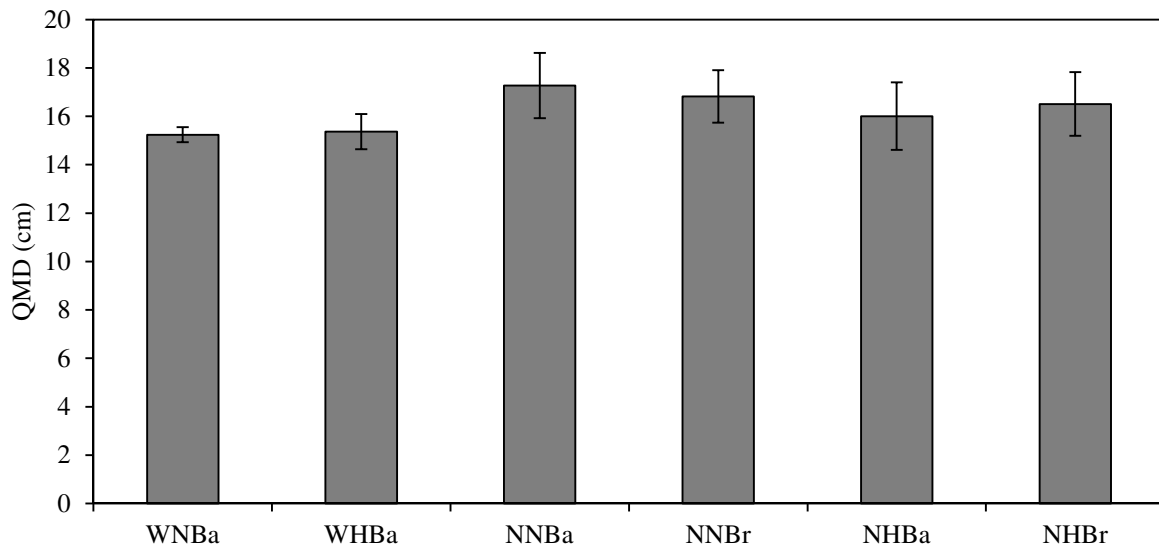


Figure A.2. Quadratic mean diameter and standard errors for treatment comparisons of loblolly pine (*Pinus taeda*) plantations in the Lower Coastal Plain of North Carolina after 8 growing seasons.

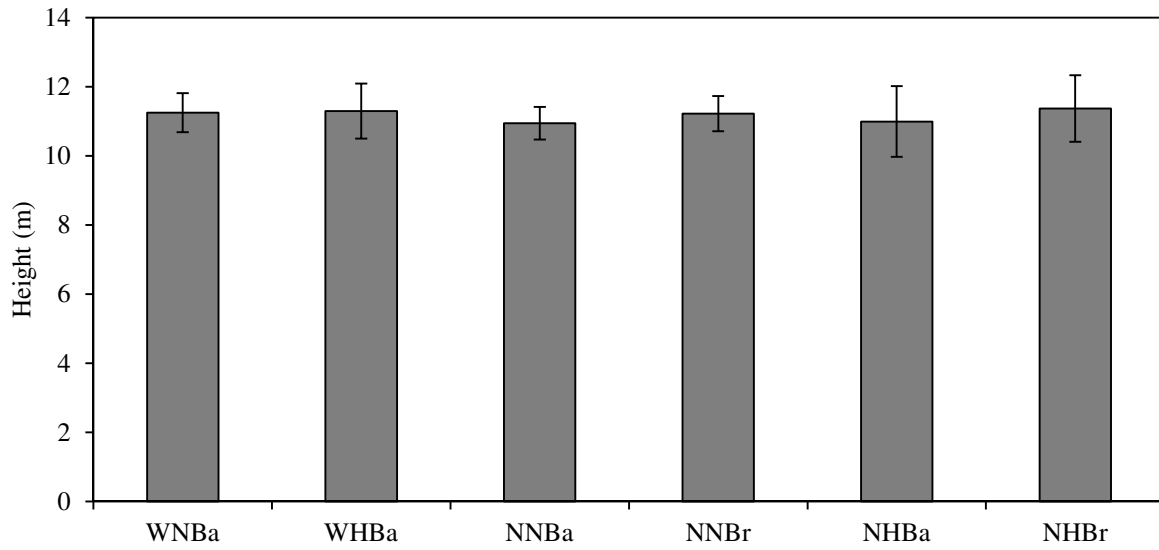


Figure A.3. Mean height and standard errors for treatment comparisons of loblolly pine (*Pinus taeda*) plantations in the Lower Coastal Plain of North Carolina after 8 growing seasons.

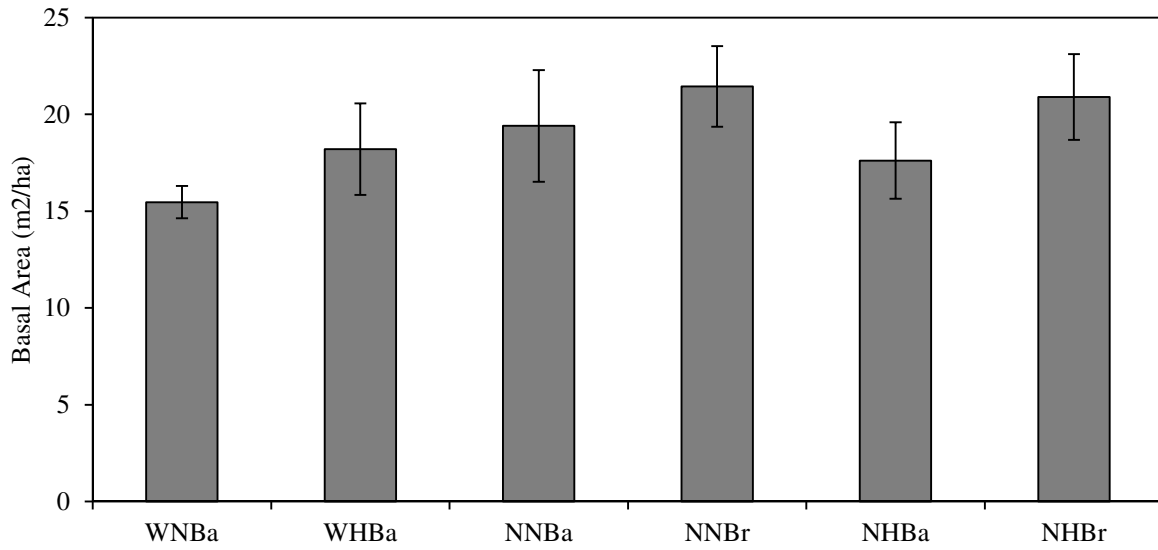


Figure A.4. Mean basal area and standard errors for treatment comparisons of loblolly pine (*Pinus taeda*) plantations in the Lower Coastal Plain of North Carolina after 8 growing seasons.

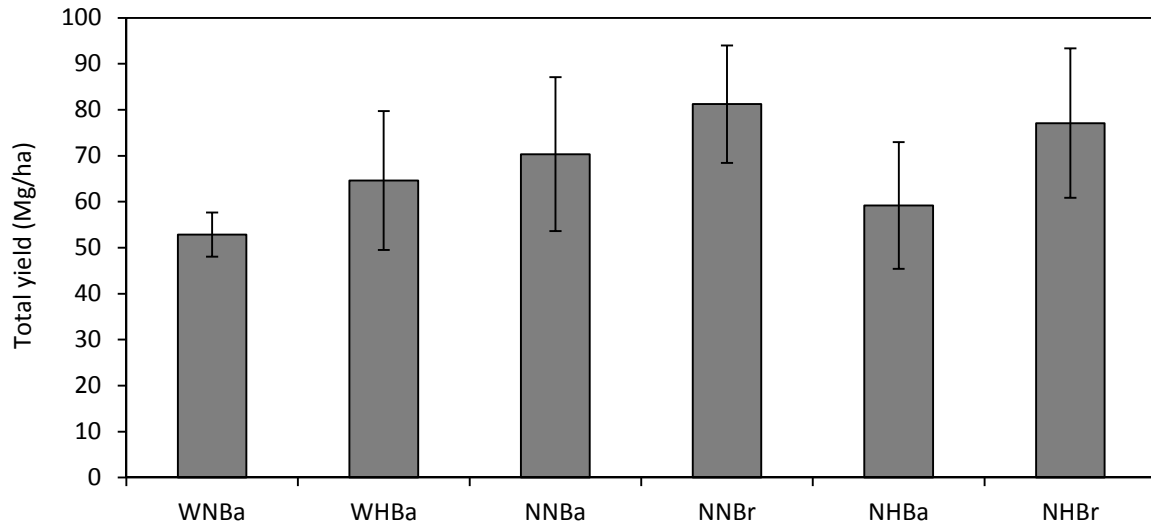


Figure A.5. Mean total yield and standard errors for treatment comparisons of loblolly pine (*Pinus taeda*) plantations in the Lower Coastal Plain of North Carolina after 8 growing seasons.