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Effects of Five Different Intensities of Stand Establishment on Wildlife Habitat Quality and Tree Growth in Loblolly Pine (Pinus Taeda) Plantations in Southern Mississippi

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EFFECTS OF FIVE DIFFERENT INTENSITIES OF STAND ESTABLISHMENT ON WILDLIFE HABITAT QUALITY AND TREE GROWTH IN LOBLOLLY PINE (*Pinus taeda*) PLANTATIONS IN SOUTHERN MISSISSIPPI

By

Phillip Daniel Jones

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in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Forest Resources
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Pages in Study: 166

Candidate for Degree of Doctorate of Philosophy

I evaluated effects of 5 intensive pine plantation establishment regimes during years 1 – 5 post-establishment on vegetation communities, loblolly pine (*Pinus taeda*) growth, nutritional carrying capacity for white-tailed deer (*Odocoileus virginianus*), habitat values for northern bobwhite (*Colinus virginianus*), and projected financial viability in the Lower Coastal Plain of Mississippi. Treatments were combinations of mechanical site preparation (MSP), chemical site preparation (CSP), and herbaceous weed control (HWC) designed to reflect the range of operational intensities on industrial forest lands in the southeastern U.S. Results should inform plantation management decisions throughout the region.

Pine growth increased with greater treatment intensity. At age 5, trees in the most intensively managed treatment were 1.5 m taller than those in the least intensive treatment. Mechanical site preparation improved growth by alleviating soil physical problems. Growth and yield projections indicated that increased fiber yield may not justify investment in more intensive regimes; financial analysis favored the least expensive treatment, though all regimes produced potential internal rates of return > 9% when managed to financial maturity.

Use of MSP with banded HWC yielded abundant low-quality deer forage sufficient for body maintenance; nutritional needs for lactating does were better served by CSP with banded HWC. Broadcast HWC reduced biomass of high-quality forbs. In this region of limited soil nutrients and abundant low-quality forages, the optimal combination of maintenance-level and lactation-level nutrition was provided by CSP or CSP and MSP combined with banded HWC.

I evaluated vegetation communities for nesting, loafing, brood-rearing, and fall and winter food suitability for northern bobwhite. No treatment provided brood-rearing habitat due to combined lack of bare ground and forb coverage. Fall and winter feeding, nesting, and loafing cover were best produced by MSP and CSP combined with banded HWC. However, lack of brood-rearing cover may reduce or eliminate usable space in all treatments.

Differences between vegetation communities were caused by use of CSP, which eliminated many residual woody and vine species, and by differences in broadcast versus banded HWC. Herbicide use decreased plant diversity and species richness, and impacted successional trajectory. Community differences persisted through year 5.

DEDICATION

During the decision process of whether and when to return to graduate school, my wife Amy put it simply: "We can either be poor for the rest of our lives, or you can go back to school now and we'll be poor for a few years while the kids are too young to know the difference." So, I dedicate this document, which she will never read, to my lovely and wise wife, who encouraged me to take a step I might otherwise have foregone. She was willing to leave her beloved home state of Colorado to sojourn with me in the land of my birth. She created a network of friends here for us and our children. She gave birth to two additional children, home-schooled, worked part-time, pursued her own dream of becoming a published author, and helped me to enjoy this season of life. This work has my name on it, but it belongs to her, also.

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INTRODUCTION

Herbicide use for vegetation control is a prominent feature of forest management, having fully or partially replaced numerous traditional silvicultural methods (Newton 1975). A pulse of new herbicides has found use especially in even-aged plantation management, where relative ease of access and a common desired outcome make application more cost effective. Although industrial forest management strategies change in response to silvicultural, economic, and social issues, future strategies likely will include increased use of herbicides (Wigley 2000). In 2002, approximately 286,000 ha of southern pine plantations received applications of herbaceous weed control, and 433,000 ha received chemical site preparation (Dubois et al. 2003), mostly relying on tank mixes of 2 or 3 herbicides (Shepard et al. 2004). This high level of herbicide use has raised questions regarding possible loss of quality wildlife habitat (Miller and Witt 1990, Miller and Miller 2004). Maximizing potential pine timber growth is typically associated with maximum reduction in competing vegetation, which translates into loss of non-pine vegetation biomass and diversity, and simplification of vegetative structure.

Forest-based industry in the southeastern U.S. is responsible for 60% of the nation's forest products (Prestemon and Abt 2002), and forest industry is a major contributor to the economies of every southern state (Tilley and Munn 2007). Private forest land currently produces a much greater share of wood relative to public land than would be expected based on acreage, and expectations are that intensively managed pine plantations in the South will continue to play an important role in providing wood products for the foreseeable future (Sedjo 2001, Prestemon and Abt 2002). Control of competing vegetation with herbicides typically produces increases of up to 150% in volume for pine species in the southeastern United States (Wagner et al. 2004). Quantifying impacts of intensive management on tree growth will allow foresters to assess the potential utility of treatment elements and inform future management decisions.

Vegetation control methods generally are applied in pine plantations as part of site preparation and post-plant release during the first 1 – 2 years of stand establishment. This period is one of great potential value for many wildlife species, particularly in areas with large blocks of even-aged pine stands (Johnson 1987). The herbaceous plant community and diversity of cover present in recent clearcuts creates forage and habitat structure important for socially and economically important species such as northern bobwhite (*Colinus virginianus*) and white-tailed deer (*Odocoileus virginianus*). This situation prevails to some degree until the pine canopy closes and shades out understory vegetation. Because the goal of intensive pine management is to shorten the period between planting and canopy closure by boosting the growth rate of the pines, this increases the necessity of ensuring that treatment impacts on habitat are beneficial.

Financial concerns also must be addressed. Fee hunting is a common way for Mississippi’s nonindustrial forest and agricultural landowners to supplement their incomes, and is especially prominent on landholdings that are primarily forested (Jones et al. 2001). Landowners who depend on lease fees for revenues should be aware of the effects site preparation and release have on habitat and tree growth. Because commercial landowners commonly lease hunting rights (Morrison et al. 2001), they also should be aware of trade-offs or synergies between timber production and habitat management.

This study was undertaken to evaluate effects of 5 intensities of site preparation and release treatment in commercial loblolly pine (*Pinus taeda*) plantations on vegetation communities present in the Mississippi Lower Coastal Plain. It addresses issues of vegetation diversity, pine growth, habitat creation and maintenance for white-tailed deer and northern bobwhite, and financial viability for private industrial and nonindustrial forest landowners. Results should be of interest to companies and landowners operating at a commercial scale, as it samples over large areas, encompassing the variety found at operational levels. Treatments were intended to reflect the full intensity range of stand establishment practices common to forest industry in the Mississippi Lower Coastal Plain, and were designed with input from several timber companies. By examining this broad spectrum of treatments from a variety of perspectives, I hope to provide a comprehensive assessment of the advantages and concerns associated with intensive pine plantation establishment.

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CHAPTER 2

GROWTH RESPONSE OF LOBLOLLY PINE (*Pinus taeda*) TO 5 LEVELS OF STAND ESTABLISHMENT INTENSITY

ABSTRACT

The upward trend of intensive management in southern pine forests is expected to continue, both in area and intensity level. Much of the Mississippi Lower Coastal Plain (LCP) is managed intensively using some combination of mechanical site preparation, chemical site preparation, and herbaceous weed control (HWC). I studied pine growth response and competition control on loblolly pine (*Pinus taeda*) plantations 3 – 5 years following establishment using five combinations of chemical site preparation, mechanical site preparation, and HWC. Treatments were designated *a priori* as 1 (least intensive) through 5 (most intensive) largely based on anticipated impact on the vegetation community. I measured pine height and diameter at breast height (dbh); woody stem density; hardwood basal area (BA); coverage of herbaceous plants, understory woody plants, and pine trees; and estimated differences in pine response using age-shift calculations at age 5. Pine height and dbh correlated with treatment intensity; treatment 5 maintained an average advantage of 1.4 m height and 2.5 cm dbh over treatment 2, the least responsive treatment. Woody stem density varied widely and was not affected by treatment, and non-pine woody coverage also did not differ among treatments. Coverage

of herbaceous plants was reduced in treatments receiving broadcast HWC, and in treatment 2, where slower establishment of pines may have acted as a release for woody plants. Age-shift gains relative to treatment 2 ranged from 0.4 – 1.0 years. Based on year 5 measurements of hardwood BA, it is likely that treatments 1 and 2 will fall farther behind treatments 3 – 5 as the stands mature. Greatest control of competing vegetation and maximum growth of pines was achieved with the most intensive treatment.

INTRODUCTION

Pine production on both industrial and nonindustrial private forest land in the U.S. South is expected to respond to increasing demand over the next few decades. Harvest is projected to increase under some scenarios from 175 million m^3 in 1997 to 255 million m^3 by 2050 (Haynes 2002), requiring a 60% increase in pine plantations on private lands managed in an increasingly intensive manner (Prestemon and Abt 2002). Intensive management strategies have drastically increased pine growth (Miller et al. 1995, Borders and Bailey 2001). Furthermore, gains from separate management actions, such as fertilization and competition control, are often additive in effect (Zutter and Miller 1998, Jokela et al. 2000, Miller et al. 2003), making greater intensity management more economically feasible.

The LCP exhibits silvicultural challenges common throughout the coastal U.S. South. Drainage on LCP sites is often poor, and the rooting environment is improved commonly through mechanical site preparation using a combination plow to subsoil, disk, and bed (Morris and Lowery 1988, Smidt et al. 2005). The warm, moist climate promotes vigorous vegetative competition with planted pines, and some level of chemical competition control during the early stages of stand establishment is standard procedure. In 2002, approximately 286,000 ha of southern pine plantations received applications of herbaceous weed control (HWC), and 433,000 ha received chemical site preparation (Dubois et al. 2003), mostly relying on tank mixes of 2 or 3 herbicides (Shepard et al. 2004).

The objective of my research was to quantify response of pine growth and competing vegetative competition along a management gradient. My study took an incremental approach, increasing management intensity in single steps to create a gradient of operational pine plantation management regimes. My definition of intensity rested primarily on amount of herbicide used during stand establishment, as intensive management is generally associated with chemical competition control (Yin and Sedjo 2001, McCullough et al. 2005). I expected pine growth to respond positively to increasing intensity, while expecting competing vegetation to respond negatively. This research is a subset of a larger project investigating effects of intensive loblolly pine plantation management on wildlife habitat quality in the LCP (Edwards 2004, Edwards et al. 2006).

STUDY AREA

The LCP of Mississippi is part of the Outer Coastal Plains Mixed Forest Ecological Province (McNab and Avery 1992), which contains 37% of the softwood volume in the South (Conner and Hartsell 2002). In 1999, 30% of the forest land in this region was owned or leased to forest industry (Conner and Hartsell 2002). I monitored growth of loblolly pine (*Pinus taeda*) in stands established at 4 commercial forest sites in

George, Lamar, and Perry Counties in southern Mississippi from planting through year 5. Stands were harvested during summer 2000 – winter 2001 and averaged 66 ha in size. Two soil associations common to the Mississippi LCP (Pettry 1977) occurred on the stands (United States Department of Agriculture 1995). The McLaurin-Heidel-Prentiss soil association was common to 2 stands and comprised of gently sloping, moderately well-drained, sandy and loamy soils. The Prentiss-Rossella-Benndale soil association occurred on 2 stands and was characterized by loamy and fine sandy loam soils.

METHODS

My treatments consisted of combinations of site preparation and HWC. Management techniques and choices of herbicides and application rates were determined by a consensus of participating companies and investigators, and were designed to reflect the range of operational intensities used commonly by participating companies. I treated stands (*n* = 4) as blocks and assigned randomly each treatment (*n* = 5) to a plot ≥8 ha, each treatment occurring once per stand. Treatment borders were designed such that all plots within a stand were influenced uniformly by topography and drainages. Chemical site preparation was performed during July – August 2001, mechanical site preparation during September-December 2001, and HWC during March – April 2002 (year 1) and March – May 2003 (year 2).

Treatment 1 consisted of mechanical site preparation using a combination plow to subsoil, disk, and bed, pulled behind a bulldozer with a V-blade attached to the front to clear debris. During March-April 2002, HWC consisting of 0.9 kg/ha of Oustar® (E. I.

du Pont de Nemours and Company, Inc., Wilmington, Delaware) was applied in a band of 1.5 m width centered on rows of planted pines.

Treatment 2 consisted of chemical site preparation using a mixture of 2.4 L/ha Chopper® Emulsifiable Concentrate (BASF Corp., Research Triangle Park, North Carolina), 3.5 L/ha Accord® (Dow AgroSciences LLC, Indianapolis, Indiana), 3.5 L/ha Garlon 4® (Dow AgroSciences LLC, Indianapolis, Indiana), and 1% volume to volume ratio of Timberland 90® surfactant (UAP Timberland LLC, Monticello, Arkansas) in a broadcast spray solution of 93.6 L/ha. Banded HWC was applied as per treatment 1.

Site preparation for treatment 3 consisted of mechanical site preparation as described for treatment 1 combined with chemical site preparation as per treatment 2. Additionally, banded HWC was applied identically to treatments 1 and 2. Treatment 4 consisted of mechanical and chemical site preparation followed by a year 1 broadcast HWC using 0.9 kg/ha of Oustar. Treatment 5 was identical to treatment 4 except for an additional broadcast HWC treatment in year 2.

Apart from these treatments, management was standardized across all plots. Loblolly pines were planted on each site during winter of 2001 – 2002 on a 3.0 × 2.1-m spacing (1,551 trees/ha), with each participating companies using its own 1-0 bare root seedlings. Two sites were machine planted, and 2 sites hand planted due to high coarse woody debris. Although seedling sources and planting methods differed among sites, they were consistent within sites (i.e., blocks). All stands were fertilized with a broadcast application of 280 kg/ha diammonium phosphate in April 2002.

I measured pine height and diameter at breast height (dbh) and hardwood dbh on 5 0.01-ha plots within each experimental unit. I measured pine dbh to the nearest 0.25

cm and height to the nearest 0.03 m during January – March of 2005 – 2007. I calculated hardwood basal area (BA) from dbh measurements (nearest 0.25 cm) performed in January 2007.

I determined age-shift gains (Huang and Teeter 1990, South et al. 2006) due to treatment at age 5 by graphing height (*y*) against age (*x*) for all treatments within each block, then comparing the differences in *x*-coordinates with the least responsive treatment. I estimated gains to the nearest 0.1 year.

In June 2004 – 2006, I surveyed vegetation communities in each experimental unit using 10 randomly-placed 30-m transects to determine understory coverage of woody and herbaceous vegetation, and coverage of planted pines. I determined woody stem density (not including planted pines) using 40 randomly placed 1-m^2 circular plots to survey woody stems ≥46 cm tall in June 2004 – 2006. Stems were identified to species. A 30-m buffer strip inside the plot boundary was excluded from sampling.

I used a repeated measures, mixed model ANOVA to test for main effects of year and treatment and year × treatment interaction for woody stem density; woody, herbaceous, and pine canopy coverage; and pine height and diameter. I compared means among treatments ($n = 5$) and years ($n = 3$) in SAS PROC MIXED (SAS Institute 2000). I treated stands (i.e., blocks, $n = 4$) as the random effect, years as the repeated effect, treatment × stand as the subject. For each analysis, I selected the best combination of data transformation, use of the random statement, and covariance structure, choosing the combination that minimized AIC_C (Akaike's Information Criterion corrected for small sample size; Littell et al. 2006, Gutzwiller and Riffell 2007). This is not a case of mixing analytical paradigms as warned against in Anderson et al. (2001); only one *a priori* model is analyzed, and the AIC_C is not used to rank models, but rather to determine which analysis procedure makes the best use of the data. I determined if log or square root transformation improved AIC_C and used it accordingly. I then selected the best covariance structure from among: autoregressive covariance with treatment as a group, autoregressive covariance without treatment as a group, and unstructured covariance. I then assessed the utility of the random statement, and chose whether to retain it based on lesser AIC_C value. I used the Kenwardroger adjustment in denominator degrees of freedom for repeated measures and small sample sizes (Littell et al. 2006, Gutzwiller and Riffell 2007). I considered differences significant if $P < 0.05$. I compared means using Fisher's least significant difference with the LSMEANS PDIFF option (Littell et al. 1996). I compared age-shift response using PROC GLM (SAS Institute 2000). For ease of data interpretation, I present actual means although I conducted most analyses on transformed data.

RESULTS

Pine growth responded positively to treatment intensity (Table 2.1). Increasing treatment intensity increased height ($F_{4,\,16.2} = 7.82$, $P = 0.001$) consistently across all years ($F_{8,\,30.7} = 0.52$, $P = 0.831$); height growth averaged 1.36 m/yr across all treatments. Diameter also was increased by greater treatment intensity ($F_{4,\,15} = 7.93$, $P = 0.001$) consistently across all years ($F_{8,\,17.3} = 1.03$, $P = 0.453$) and averaged 2.26 cm/yr across all treatments. Treatment 2, the second-least intensive treatment, showed the least numerical response for height and dbh, whereas treatment 5 showed the greatest. Treatment 5 averaged 1.4 m taller and 2.4 cm greater dbh than treatment 2 over the 3-year study period, with treatments 1, 3, and 4 intermediate.

Woody stem densities exhibited strong year effects ($F_{2, 14} = 23.65$, $P \leq 0.001$), increasing markedly from year 3 to year 4, followed by a sharp decline in year 5 (Table 2.2). There was no treatment effect for woody stem density ($F_{4, 15} = 1.31$, $P = 0.309$), although treatment 1 exhibited 2.5 times the average densities of treatments 2 – 5 for years 3 – 4. In year 3 American beautyberry (*Callicarpa americana*) and eastern baccharis (*Baccharis halimifolia*) represented 22% and 17% of woody stems, respectively. The increase in year 4 was fueled by yaupon (*Ilex vomitoria*) and wax myrtle (*Myrica cerifera*) which each comprised 12% of woody stems; American beautyberry declined to 16% and eastern baccharis remained stable. In year 5, eastern baccharis, common persimmon (*Diospyros virginiana*), and tungoil tree (*Aleurites fordii*) composed 22%, 16%, and 13% of the samples, respectively.

Woody plant coverage was not affected by treatment ($F_{4 ,42} = 2.56$, $P = 0.053$) consistently across all years ($F_{8, 42} = 1.06$, $P = 0.411$) (Table 2.3). Coverage increased from year 3 to year 5 in all treatments ($F_{2, 42} = 25.49$, $P \leq 0.001$); increases ranged from 14.6% in treatment 4 to 18.4% in treatment 2. Coverage of planted pines was associated with increased treatment intensity ($F_{4, 11.7} = 8.57$, $P = 0.002$) consistently across all years ($F_{8, 27.9} = 0.57$, $P = 0.795$) (Table 2.3). Pine coverage was greatest in treatments 4 and 5, least in treatments 1 and 2. Pine coverage increased in all treatments from year 3 to year 5 ($F_{2, 27.6} = 81.0$, $P \leq 0.001$) by 18.2 to 23.7%.

Age-shift response differed among treatments ($F_{4, 15} = 4.14$, $P = 0.020$) (Table 2.4). Treatment 2 had the lowest growth curve in all stands, and thus provided the baseline for comparison. Treatment 5 had the greatest response, gaining 1.0 years more than treatment 2 and 0.6 years more than treatment 1. Treatments 3 and 4 were intermediate in response, gaining an average 0.65 years over treatment 2. Hardwood BA did not differ among treatments ($F_{4, 15} = 2.26$, $P = 0.111$), despite ranging from 0.93 – 8.86 m^2/ha (Table 2.4).

Increasing treatment intensity was associated with reduced coverage of understory herbaceous plants ($F_{4, 15} = 7.36$, $P = 0.002$) consistently across years ($F_{8, 17.3} = 0.96$, $P = 0.495$) (Table 2.3). Coverage in treatment 5 averaged 65% that of treatment 1 over all 3 years, with treatments 2 – 4 intermediate. Coverage declined from year 3 to year 5 in all treatments ($F_{2, 14} = 112.01$, $P \leq 0.001$); reductions in percent coverage ranged from 40.9 in treatment 5 to 56.9 in treatment 4.

DISCUSSION

I did not include a traditional, untreated control because my purpose was to compare response to operational treatments. The lack of an untreated control precludes the analysis of improvements in growth from some treatment elements. However, industrial forest landowners in the South are unlikely to establish plantations without some form of site preparation and HWC. Therefore, I used the lowest level of intensity as the baseline for comparison.

Increasing intensity of management during stand establishment resulted in greater pine growth and increased pine dominance. Although the experimental design was not factorial, data indicated that increases in height and diameter were attributable to the combined use of mechanical and chemical site preparation, and to the application of broadcast HWC. The relative growth responses have remained stable among treatments since differences developed in the second growing season (Edwards et al. 2006) following application of the last treatment element.

Mechanical site preparation has typically increased early pine growth response in the Gulf Coastal Plain (Miwa et al. 2004), and this was evidenced in my study by the response of treatment 2. I expected that pine growth would correspond directly with intensity level as I defined it, that is, on the basis of herbicide use. While this was generally true, treatment 2, the second least intensive treatment, consistently yielded the least response across all sites. Treatment 2 did a better job of controlling herbaceous weeds than treatments 1 and 3, and controlled woody competition as well as either. Bedding and subsoiling were prescribed in the other treatments to improve rooting environment and water regime, and it appeared the lack of these amendments limited the capacity of pines in treatment 2 to respond to reduced competition (Rahman et al. 2006). Eisenbies et al. (2005) compared loblolly pine grown on chemically prepared sites in the South Carolina Coastal Plain and reported the addition of bedding or mole-plowing and bedding increased height, dbh, and tree biomass at age 5. This was comparable to treatments 2 and 3 of my study, where addition of mechanical site preparation increased height and dbh over chemical site preparation alone.

Herbaceous weed control has the potential to act as a release not only to the crop pines but also to their woody competitors (Miller et al. 2003). This effect was not obvious in my study, perhaps due to the relatively fine gradations between treatments. Miller et al. (2003) applied extreme treatments designed to attain absolute control of certain vegetation classes for a period of 3 – 5 years to more clearly define relationships among competition types and pine growth; in contrast, my treatments were based on management regimes practiced by industry, and were not as intensive. Treatment 5, which received 2 years of broadcast HWC, was my most extreme treatment, and therefore most likely to experience release of woody competitors. However, treatment 5 exhibited a degree of woody competition control similar to treatments receiving only a single year of banded HWC. This result may be an effect of the near elimination of woody stems due to chemical site preparation (Edwards et al. 2006) combined with herbaceous competition control promoting quick dominance of the site by pines. None of the sites in Miller et al. (2003) received chemical site preparation, and therefore likely had a greater woody component available for release by HWC than did my chemically site-prepared treatments.

Productivity gains in young stands measured as percentages are unreliable for predicting differences in long-term volume production (South et al. 2006). Presenting treatment responses as age-shift differences may be more useful to managers for estimating future growth and subsequent revenues, provided they remain stable, or at least predictable. Lauer et al. (1993) reported that height-growth differences between treatments with or without weed control did not change from ages 7 - 9, and herbaceous competition becomes a much less significant factor once pines begin dominating sites (Tiarks and Haywood 1986, Zutter and Miller 1998, Balandier et al. 2006). Xu et al. (1998) found that increasing site preparation intensity in the Georgia Piedmont yielded differences in height, diameter, and stand volume from age 5 through at least age 12. Because I had only 3 years of measurement data ending at age 5, age-shift calculations may be considered preliminary, yet potentially useful for predicting future response when coupled with hardwood BA. Continuing measurements through crown closure should provide adequate information to predict if size differences can be maintained through mid-rotation.

South et al. (2006) reported that loblolly pine on sites with no or low hardwood BA (i.e., ≤3 m^2/ha at age 15) typically responded to herbaceous control by maintaining growth gains into mid-rotation, whereas those with hardwood BA ≥4 m^2/ha may either lose those gains or even suffer further losses in stand volume due to release of woody competition. Because my sites were measured at age 5, it was not possible to compare hardwood BA directly with South et al. (2006). However, Glover and Zutter (1993) indicated that, when herbicides were part of the initial control method, hardwood BAs of ≤ 2.3 m^2/ha in pine stands at age 4 may only grow to ≤ 4.8 m^2/ha by age 22. Given the range of woody competition in my stands at age 5, it seems reasonable to expect that treatments 3 – 5, with hardwood BAs of 0.93 – 2.37 m^2/ha, have a much greater chance of retaining growth gains than treatments 1 and 2.

Because treatment 2 provided the baseline for my age-shift calculations, I do not know how much growth it may have gained from HWC, only what the other treatments gained relative to it. Creighton et al. (1987) estimated a height gain of 1.0 m at age 5 for loblolly pine given 1 year of HWC, regardless of whether application was banded or broadcast; a second application added 0.8 m height. The addition of a second HWC in my study for treatment 5 added an average of 0.64 m height over the single application in treatments 3 and 4. Given Creighton et al.'s (1987) 1.0-m height gain from 1 year of HWC, the age-shift gain for treatment 2 attributable to HWC would be 0.7 years, and gains should be increased likewise across all other treatments.

Lack of differences in woody stem density may be best explained by within-site variation. Numerical differences among treatments in years 3 and 4 were more or less as expected and indicated that chemical site preparation was more responsible for suppression of woody competition than mechanical disturbance. Although the average response was predictable, sites did not display a consistent pattern of response to treatments. I examined soil types within each stand in association with stem counts and could discern no effect attributable to soils. The fact that I applied generalized rather than site-specific prescriptions meant that specific treatments may or may not have been ideal for any given stand.

The drastic decline of woody stem density across all treatments in year 5 may have been due to a combination of natural succession and drought during the growing season of year 5. From January-June of year 5, weather stations nearest each stand averaged 33.8 cm below normal cumulative rainfall of 85.8 cm; during years 3 and 4, rainfall in this same period averaged 18.1 cm above and 9.2 cm below normal, respectively (National Climate Data Center 2007). This drought may have accelerated the stem exclusion process.

MANAGEMENT IMPLICATIONS

Greater management intensity in loblolly pine plantations during the establishment phase in the Mississippi LCP increased growth and dominance of crop trees, potentially reducing rotation length by at least 1 year. Mechanical site preparation appeared to allow loblolly pines in this region to respond rapidly to the competitive advantages rendered by herbicide application. Broadcast HWC may provide an additional increment of growth over banded application, but a second year of broadcast HWC did not promote additional height or diameter growth. Chemical site preparation was adequate to prevent release of woody competition following any level of HWC. Managers who wish to maintain growth gains from HWC, and thereby shorten rotation length or increase volume production, should consider a combination of chemical and mechanical site preparation to reduce initial hardwood competition to low levels. The application of a second broadcast HWC application will likely increase growth rate, but is of questionable financial value (Jones 2008).

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Table 2.1. Dormant season height (m) and diameter at breast height (dbh; cm) of 3- to 5-year-old loblolly pine (*Pinus taeda*) plantations under 5 regimens of establishment intensity varying from low (1) to high (5) in the Lower Coastal Plain of Mississippi, 2005 – 2007.

		Treatment					P-values		
Age		1	2	3	4	5	Yr	Trt	Yr*Trt
3	Height	3.36	3.08	3.51	3.89	4.32	<0.001	0.001	0.831
	SE	0.09	0.09	0.07	0.17	0.17			
4	Height	4.69	4.39	4.95	5.30	5.87			
	SE	0.09	0.10	0.08	0.12	0.19			
5	Height	6.11	5.64	6.30	6.62	7.10			
	SE	0.11	0.12	0.10	0.09	0.14			
All		AB[a]	A	BC	CD	D			
3	dbh	4.5	3.9	5.2	5.6	6.5	<0.001	0.001	0.453
	SE	0.2	0.2	0.1	0.2	0.2			
4	dbh	6.7	6.3	7.5	7.9	8.8			
	SE	0.2	0.3	0.2	0.2	0.2			
5	dbh	9.2	8.3	9.8	10.2	10.7			
	SE	0.2	0.2	0.2	0.2	0.2			
All		AB	A	BC	CD	D			

[a] Treatments denoted by the same upper case letter do not significantly differ (α=0.05). *P*-values and treatment differences correspond to least square means.

Table 2.2. Density (stems/ha) of woody stems ≥50 cm tall in 3- to 5-year-old loblolly pine (*Pinus taeda*) plantations under 5 regimens of establishment intensity varying from low (1) to high (5) in the Lower Coastal Plain of Mississippi, June 2004 – 2006.[a]

		Treatment					*P*-values[b]		
Age		1	2	3	4	5	Yr	Trt	Yr*Trt
3	Stems	5,812.5	3,187.5	2,250.0	2,625.0	2,812.5	≤0.001	0.309	0.876
	SE	793.0	1572.5	952.0	915.7	1,174.3			
4	Stems	13,250.0	4,500.0	4,652.5	5,687.5	3,437.5			
	SE	2,225.4	1,229.0	1,251.6	1,451.9	543.7			
5	Stems	562.5	562.5	375.0	875.0	437.5			
	SE	213.5	62.5	297.6	388.6	157.3			

[a] Actual means presented; analysis conducted on log-transformed data; degrees of freedom = 2,42 for tests of year effect, 4,42 for tests of treatment effect, and 8,42 for tests of yr × trt interaction.

[b] *P*-values correspond to least square means.

Table 2.3. Percent coverage of herbaceous plants, woody plants, and planted pines in 3- to 5-year-old loblolly pine (*Pinus taeda*) plantations under 5 regimens of establishment intensity varying from low (1) to high (5) in the Lower Coastal Plain of Mississippi, June 2004 – 2006.

			Treatment					*P*-values[a]		
Cover type	Age		1	2	3	4	5	Yr	Trt	Yr*Trt
Herbaceous	3	Coverage	125.2[b]	107.7	119.4	118.7	84.8	≤0.001	0.002	0.495
		SE	11.9	8.6	11.4	6.4	8.3			
	4	Coverage	95.1	81.4	91.4	79.1	65.2			
		SE	6.3	3.0	1.8	2.0	1.1			
	5	Coverage	76.2	51.7	67.6	61.8	43.9			
		SE	9.5	2.9	3.8	3.2	2.9			
	All	Coverage	98.8	80.3	92.8	86.5	64.6			
		SE	7.8	7.5	7.4	7.5	5.7			
			A[c]	B	AB	AB	C			
Woody[d] (non-pine)	3	Coverage	34.2	22.5	12.8	19.9	13.3	≤0.001	0.240	0.570
		SE	7.5	6.8	2.8	8.0	3.8			
	4	Coverage	38.6	28.1	17.9	21.1	27.4			
		SE	2.7	6.7	3.0	7.0	9.9			
	5	Coverage	50.1	40.9	30.5	34.5	30.8			
		SE	2.3	10.0	6.6	11.8	9.3			

Table 2.3. Continued.

			Treatment					*P*-values		
Cover type	Year		1	2	3	4	5	Year	Trt	Year*Trt
Pine[d]	3	Coverage	14.0	11.5	16.8	20.2	23.8	≤0.001	0.002	0.795
		SE	2.8	2.2	4.2	5.3	6.9			
	4	Coverage	20.1	18.7	27.2	31.7	37.4			
		SE	2.2	2.1	2.1	4.5	5.6			
	5	Coverage	32.2	30.5	36.9	43.9	44.7			
		SE	2.4	2.6	2.8	6.1	6.7			
			AB	A	BC	CD	D			

[a] Degrees of freedom = 2,42 for tests of year effect, 4,42 for tests of treatment effect, and 8,42 for tests of yr × trt interaction.

[b] Coverage sometimes exceeded 100% due to overlayering.

[c] Within each cover type, treatments denoted by the same upper case letter do not differ significantly (α=0.05). *P*-values and treatment differences correspond to least square means.

[d] Actual means presented; analysis conducted on square root transformed data.

Table 2.4. Age-shift gains (yrs) and hardwood basal areas (BA; m^2/ha) of loblolly pine (*Pinus taeda*) plantations at age 5 subjected to 5 regimens of establishment intensity varying from low (1) to high (5) in the Lower Coastal Plain of Mississippi, 2007.

	Treatment						
	1	2[a]	3	4	5	*F*-values[b]	*P*-values
Age shift[c]	0.4	0.0	0.5	0.8	1.0	4.14	0.020
SE	0.1	0.0	0.1	0.2	0.4		
	AB[d]	A	BC	BC	C		
Hardwood BA[c]	8.86	6.73	1.90	2.37	0.93	2.26	0.111
SE	3.97	2.71	0.36	1.29	0.30		

[a] Treatment 2 provided the baseline for age-shift measurement.

[b] Degrees of freedom = 4,15.

[c] Actual means presented; analysis conducted on log-transformed data.

[d] Treatment means designated by the same upper case letter do not differ significantly (α=0.05). *P*-values and treatment differences correspond to least square means.

CHAPTER 3

VEGETATION COMMUNITY RESPONSE TO 5 LEVELS OF STAND ESTABLISHMENT INTENSITY FOR LOBLOLLY PINE (*Pinus taeda*) IN SOUTHERN MISSISSIPPI

ABSTRACT

Stand establishment techniques involving multiple herbicide applications are standard procedure on most industrial pine plantation sites, raising concerns about biodiversity. Management decisions impact not only plant communities but also the habitat potential they create for wildlife. I tested the effects of 5 levels of stand establishment intensity on vegetation communities in 1- to 5-yr-old loblolly pine plantations (*n* = 4) in the Lower Coastal Plain (LCP) of Mississippi using measures of species richness, diversity, coverage, and community composition. Treatments were combinations of mechanical site preparation (MSP), chemical site preparation (CSP), and herbaceous weed control (HWC). Tree richness and diversity were reduced by increasing treatment intensity; tree coverage, which included crop and non-crop trees, was less in moderate-intensity treatments. Vine richness and coverage were less in more intensive treatments, but 2 diversity indices differed on whether vine diversity was likewise affected. Richness and coverage of forbs and graminoids was lessened by broadcast HWC, with effects mostly limited to the year of application. Plant communities differed in all 5 years, with the impact of CSP apparent throughout the study. Early seral

communities were favored by CSP, but broadcast HWC suppressed resulting herbaceous plants. Though CSP may somewhat reduce stand-level plant diversity, it may increase overall biodiversity within plantation-dominated landscapes by supplying early succession wildlife habitat.

INTRODUCTION

Intensively managed pine plantations will play an important role in providing wood products for the foreseeable future (Prestemon and Abt 2002). Although industrial forest management strategies change in response to silvicultural, economic, and social issues, future strategies likely will include increased use of herbicides (Wigley 2000). Management regimes will consist of tank mixes of multiple herbicides prior to planting and one or more post-planting herbaceous weed control treatments. In 2002, approximately 286,000 ha of southern pine plantations received applications of herbaceous weed control, and 433,000 ha received chemical site preparation (Dubois et al. 2003), mostly relying on tank mixes of 2 or 3 herbicides (Shepard et al. 2004).

A trade-off exists between timber yield and competing vegetation. Control of competing vegetation with herbicides typically produces increases of up to 150% in volume for pine species in the southeastern United States (Wagner et al. 2004). However, increasing intensity of site preparation can reduce abundance and diversity of woody and herbaceous plant species depending on herbicide type (Miller et al. 1999), rate (Zutter and Zedaker 1988), proportion of the area receiving treatment (Schabenberger and Zedaker 1999), and the additive effects of mechanical site preparation (Harrington and Edwards 1996).

Preserving biodiversity in managed forests is a major concern for sustainable forest management (Hartley 2002, Guynn et al. 2004, Stephens and Wagner 2007), embodied in the requirements of certification systems that place emphasis on maintaining and enhancing biodiversity (Brown et al. 2001, Cauley et al. 2001). Plant communities play a double role in this effort because they contribute their own diversity and create habitat potential for wildlife. Early succession environments in the southeastern U.S. have declined in recent decades due to fire suppression and reforestation of abandoned farmland (Trani et al. 2001), and young pine plantations may provide most of early succession environments potentially suitable for disturbance-dependent wildlife species in landscapes dominated by commercial pine management. Because intensive pine management involves reducing competition from non-pine vegetation and shortening the period before crown closure, it is appropriate to consider the impact such management has on this community.

Previous studies of vegetation communities following pine stand establishment have focused on controlling different categories of competing vegetation (Swindel et al. 1989, Miller et al. 1995), response to varying methods of mechanical (Conde et al. 1983a,b, Swindel et al. 1983, Stransky et al. 1986, Locascio et al. 1991) or chemical site preparation (Neary et al. 1990), and banded versus broadcast herbaceous weed control (Blake et al. 1987). There is as yet little information on the impact of tank mixtures of herbicides, multiple herbicide applications, and the combination of mechanical and chemical site preparation (Miller and Miller 2004). This study was designed to investigate these treatment elements by incrementally increasing management intensity to reflect the range of commercial plantation establishment regimes as practiced in the southeastern U.S.

STUDY AREA

The Lower Coastal Plain (LCP) exhibits silvicultural challenges common throughout the southeastern U.S. Mechanical site preparation using a combination plow to subsoil, disk, and bed is an effective (Morris and Lowery 1988) and widely used (Smidt et al. 2005) method to address issues of poor drainage and soil compaction common in the region. The warm, moist climate promotes vigorous vegetative competition with planted pines, and some level of chemical competition control during stand establishment is standard procedure.

I studied vascular vegetation communities on loblolly pine plantations established at 4 commercial forest sites in the Mississippi LCP. Stands were harvested between September 2000 – February 2001 and averaged 66 ha in size. Vegetation at all sites was representative of the Outer Coastal Plain Mixed Forest Province (Bailey 1980). Two soil associations occurred on the stands (United States Department of Agriculture 1995). The McLaurin-Heidel-Prentiss soil association was common to 2 stands and comprised of gently sloping, moderately well-drained sandy and loamy soils. The Prentiss-Rossella-Benndale soil association occurred on 2 stands and was characterized by loamy and fine sandy loam soils.

METHODS

Study Design

Treatments were combinations of mechanical site preparation (MSP), chemical site preparation (CSP), and herbaceous weed control (HWC) designed to reflect the range of operational intensities used on industrial forest lands in the southeastern U.S. Intensive management is often associated with chemical competition control (McCullough et al. 2005), so I correlated treatment number with the amount of herbicide used during stand establishment to assign treatments ranging from least (treatment1) to most (treatment 5) intensive, the one exception being the addition of MSP between treatments 2 and 3. I assigned randomly each of the 5 treatments to an area ≥8 ha, each treatment occurring once per stand, for 4 replications per treatment in a randomized complete block design. Chemical site preparation was performed at all sites during July – August 2001; MSP was performed during September – December 2001. Herbaceous weed control was applied during March – April 2002 (year 1) and March – May 2003 (year 2).

Treatment 1 consisted of MSP using a combination plow to subsoil, disk and bed, pulled behind a bulldozer with a V-blade attached to the front to clear debris. Herbaceous weed control consisting of 0.9 kg/ha of Oustar® (E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware; sulfometuron methyl and hexazinone; 13 oz/ac) was applied in a band of 1.5 m width over the tops of pine seedlings.

Treatment 2 consisted of chemical site preparation (CSP) using a mixture of 2.4 L/ha Chopper Emulsifiable Concentrate® (BASF Corp., Research Triangle Park, North

Carolina; imazapyr; 32 oz/ac), 3.5 L/ha Accord® (Dow AgroSciences LLC, Indianapolis, Indiana; glyphosate; 48 oz/ac), 3.5 L/ha Garlon 4® (Dow AgroSciences LLC, Indianapolis, Indiana; triclopyr; 48 oz/ac), and 1% volume to volume ratio of Timberland 90® surfactant (UAP Timberland LLC, Monticello, Arkansas) in a broadcast spray solution of 93.6 L/ha. Banded HWC was applied as per treatment 1.

Site preparation for treatment 3 consisted of MSP as described for treatment 1 combined with CSP as per treatment 2. Banded HWC was applied identically to treatments 1 and 2. Treatment 4 consisted of MSP and CSP followed by a year 1 broadcast HWC using 0.9 kg/ha of Oustar. Treatment 5 was identical to treatment 4 except for an additional broadcast HWC treatment in year 2.

Apart from these treatments, management was standardized across all plots. Loblolly pines were planted on each site during winter of 2001 – 2002 on a 2.1 × 3.0-m spacing (1,551 trees/ha), with each participating company using its own seedlings. Two sites were machine planted, and 2 sites were hand planted due to prohibitive amounts of coarse woody debris. Although seedling sources and planting methods differed among sites, they were consistent within sites (i.e., blocks). All stands were fertilized with a broadcast application of diammonium phosphate at 280 kg/ha in April 2002.

Sampling

I quantified vegetation communities during June 2002 – 2006 using 10 randomly-placed 30-m transects and 40 randomly placed 1-m^2 circular plots in each experimental unit. I measured species coverage on transects, and determined species richness by counting total number of species found on transects and in circular plots combined. I identified all plants to the species level with the exceptions of wiregrass (*Aristida* spp.) and yellow-eyed grass (*Xyris* spp.). Each plant species was assigned to 1 of 5 growth-form categories (i.e., forb, graminoid, shrub, tree, vine) for further analysis. To minimize potentially confounding edge effects, I excluded from sampling a 30-m buffer strip inside plot boundaries.

Data Analysis

I calculated 2 diversity indices used widely in community ecology studies. The Shannon index (*H`*; Shannon and Weaver 1949) indicates the level of uncertainty associated with predicting the species of an individual selected at random from a given community. It ranges from 0 when there is no diversity to ~5 in the most diverse communities. The Simpson index (*D*; Simpson 1949) measures the probability that 2 individuals selected at random from a given community will be of different species; it ranges from 0 (no diversity) to a theoretical maximum of 1. I calculated both indices based on plant species coverage in each experimental unit using the program PAST (Hammer et al. 2005).

I used a repeated measures, mixed model ANOVA to test for main effects of year and treatment and year × treatment interaction for species diversity, species richness, and coverage of forbs, graminoids, shrubs, vines, trees, and total vegetation. I compared means among treatments ($n = 5$) and years ($n = 5$) in SAS PROC MIXED (SAS Institute 2000). I treated stands (i.e., blocks, $n = 4$) as the random effect, years as the repeated effect, and treatment × stand as the subject. For each analysis, I selected the best combination of data transformation, covariance structure, and use of the random statement, choosing the combination that minimized AIC_C (Akaike's Information Criterion corrected for small sample size; Littell et al. 2006, Gutzwiller and Riffell 2007). This is not a case of mixing analytical paradigms as warned against in Anderson et al. (2001); only one *a priori* model is analyzed, and the AIC_C is not used to rank models, but rather to determine which analysis procedure makes the best use of the data. I first determined if log transformation improved AIC_C and used it accordingly. I then selected the best covariance structure from among: autoregressive covariance with treatment as a group, autoregressive covariance without treatment as a group, and unstructured covariance. I then assessed the utility of the random statement, and chose whether to retain it based on lesser AIC_C value. I used the Kenwardroger adjustment in denominator degrees of freedom for repeated measures and small sample sizes (Littell et al. 2006, Gutzwiller and Riffell 2007). I considered differences significant if $P \leq 0.05$. I used LSMEANS SLICE to identify a treatment effect within years following a significant interaction (Littell et al. 2006). I compared means using Fisher's least significant difference with the LSMEANS PDIFF option (Littell et al. 2006). For ease of data interpretation, I present actual means although I conducted some analyses on transformed data.

I conducted blocked multi-response permutation procedures (MRBP; Biondini et al. 1988) in PCORD 4.0 to test the hypothesis that plant community composition did not differ among treatments. Though similar to parametric procedures such as discriminant analysis and multivariate ANOVA, MRBP does not require assumptions of multivariate normality or homogeneity of variance, which are often not met by community data (McCune and Grace 2002). The MRBP calculated a weighted mean within-group distance (δ), and then determined the probability of a smaller or equal δ. An *A* statistic measured the grouping effect size from 0 – 1; values of $A > 0.3$ are considered relatively high. To reduce noise I excluded from the dataset species that occurred in ≤5% of the experimental units (McCune and Grace 2002). I screened data for outliers by block and found no samples >2 standard deviations from block means; therefore, I retained all samples for analysis. For each year, the dataset consisted of square-root transformed species coverage; I selected Euclidean distance as the distance measure (Mielke 1991) and used median alignment within blocks to focus analysis on within-block differences (McCune and Grace 2002). If within-year tests indicated a treatment effect, I performed separate post hoc MRBP analyses to determine which pairs of treatments differed (McCune and Grace 2002). For all group tests, the sample dissimilarity space was determined using a matrix of 20 plots × 135 – 188 species, depending on year.

As a complement to the MRBP analysis, I determined indicator species (i.e., characteristic species found mostly in a given treatment and present in most samples from that treatment [Dufrêne and Legendre 1997]) within each year using PCORD 4.0. Dufrêne and Legendre's (1997) method relies on the proportional abundance and proportional frequency of a species to calculate an indicator value (*IV*) for each species within each treatment, which represents the percentage of perfect indication. The greatest *IV* for each species is then tested for statistical significance against the random expectation calculated by Monte Carlo permutation. Species with few occurrences never yield an *IV* stronger than expected by chance (McCune and Grace 2002), thus precluding the selection of rare species. I tested *IV*s for significance using 1000 randomizations and accepted significance if $P \leq 0.05$.

RESULTS

Growth-form Metrics

The 5 growth forms were variously affected by different treatment elements, with woody and vine species more affected by site preparation and herbaceous species by HWC. Vine richness (Table 3.1) was reduced by CSP from 12 to 9.5 species, and reduced again to 7 species by repeated broadcast HWC. Vine coverage (Table 3.2) was similarly affected, being reduced by CSP from 49 to 29%, and further reduced to 16% by repeated broadcast HWC. Shannon diversity of vines was reduced by CSP ($H`_1 = 1.51$, $\overline{H}`_{2-5} = 1.01$; $P \leq 0.001$), but Simpson diversity was similar across treatments ($\overline{D} = 0.53$; $P = 0.397$). Tree richness was reduced by combined CSP and MSP in treatments 3 – 5 ($\overline{X} = 7.6$ species) compared with either MSP or CSP alone ($\overline{X} = 10.2$ species). Both indices expressed differences in tree diversity; $H`$ was greater in treatments 1 and 2 ($\overline{H}` = 1.3$) than in treatments 3 – 5 ($\overline{H}` = 0.67$; $P = 0.003$), and D was greater in treatment 1 (0.68) than in treatments 3 – 5 ($\overline{D} = 0.33$; $P = 0.007$). Tree coverage was increased by either MSP only (treatment 1), which allowed residual trees to resprout, or by broadcast HWC (treatments 4 and 5), which released planted pines from herbaceous competition. Shrubs were less affected by treatment than any other life form, with only Shannon diversity differing among treatments ($H`_1 = 1.57$, $\overline{H}`_{2-5} = 1.34$; $P = 0.039$) in response to CSP. Both indices indicate overall species diversity decreased as treatment intensity increased (Table 3.3).

Year × treatment interactions limited treatment differences for forbs and graminoids to years 1 – 3. Broadcast HWC reduced richness and coverage of forbs and graminoids compared with banded HWC, but effects were mostly limited to the year of application. In year 1, species richness of forbs averaged 28 species among treatments that had received banded HWC and 11 species in treatments that had received broadcast HWC. Likewise, forb coverage was greater in treatments with banded HWC (14%) than in treatments with broadcast HWC (1.5%). The combination site preparation also may have influenced graminoid response in year 1, in which the response of treatment 3 was intermediate to that of the others. Graminoid richness averaged 8 species in treatments 1 and 2, and 5 species in treatments 4 and 5; coverage differed between the same groups (14% vs. 1.5%, respectively). Total richness averaged 60 species in treatments 1 and 2, compared with 29 species in treatments 4 and 5. Again, total vegetation coverage also differed between the same treatment groups, averaging 46% in treatments 1 and 2 versus 6% in treatments 4 and 5.

In year 2, the herbaceous community in treatment 4 recovered from the year 1 broadcast HWC and became more similar to treatments 1 – 3 and less similar to treatment 5, which had received a second broadcast HWC application. Mean species richness was greater in treatments 1 – 4 than in treatment 5 for forbs and graminoids ($\bar{x}$ = 32 vs. 14 and 11 vs. 6, respectively). Total richness was likewise greater in treatments 1 – 4 ($\bar{x}$ = 66 species) than in treatment 5 (35 species). Coverage of forbs followed the same pattern, with treatments 1 – 4 averaging 21% coverage compared with 7% in treatment 5. Mean graminoid coverage in treatments 1 – 3 was 3 times greater than in treatment 5, with treatment 4 intermediate. Total plant coverage in treatments 1 – 4 averaged 103%, compared with 29% in treatment 5.

In contrast to the single broadcast HWC in treatment 4, some effects of the second broadcast HWC in treatment 5 continued into the following year. Total species richness in year 3 remained greater in treatments 1 – 4 ($\overline{x}$ = 83 species) than in treatment 5 (66 species). Forb coverage was 2 times greater in treatments 3 and 4 (27%) than in treatment 5 (14%). Total plant coverage in treatment 5 increased by 92%, yet continued to be less than treatments 1, 3, and 4. In year 4, total plant coverage averaged 137% across all treatments; differences reappeared in year 5, when treatments 2 and 5 decreased to 121% coverage whereas treatment 1 remained stable at 158%.

Plant Communities

Plant community composition differed among treatments in all 5 years indicating that the treatments created a broad range of vegetation communities (Table 3.4). Pair-wise comparisons from year 1 indicated that treatments receiving banded HWC differed from those receiving broadcast HWC. Treatment 1, the only treatment without CSP, differed from all other treatments in years 2 – 5. In year 2, treatment 5 received its second HWC application and was different from all other treatments, remaining so through year 3. Associations in year 4 were more complex and, except for no CSP in treatment 1, did not appear to correlate with any particular treatment element or combination of elements. Effect sizes between significance groups in year 4 were generally less than in other years (Table 3.5). In year 5, community differences reflected clearly the establishment intensity gradient, indicating that some effects of both site preparation and HWC were still operative. Yearly effect sizes were moderate, ranging from 0.08 – 0.14. Within years, effect sizes of significant pair-wise comparisons were consistently greatest between treatments 1 and 5, averaging 0.22.

Twenty-one species were classified as indicator species over the 5 years of the study (Table 3.6). Indicator status for treatment 1 was conferred upon 7 vine, 4 tree, and 2 forb species. The remaining 8 indicator species, comprised of 3 graminoids, 2 forbs, 2 shrubs and 1 tree, were divided among treatments 2 – 5. Treatment 1 was marked by 5 – 7 indicator species each year, with 3 vine species acting as indicators for 4 years each. Among the remaining treatments, only treatment 2 was assigned indicator species in more than one year, and no species acted as an indicator for multiple years.

DISCUSSION

Vegetation Community

Plant species express differential susceptibility to herbicides, potentially resulting in distinctive communities (Harrington et al. 1998, Miller and Miller 2004). In my study, all chemical treatments were identical in composition and application rate. Community differences were therefore due to variations in herbicide coverage, number of HWC applications, or herbicide interaction with MSP.

Differences among plant communities can be understood as a combination of direct treatment impacts and interactions with seral stage. Similar to a report by Swindel et al. (1983), MSP failed to control a strong residual community characterized by an abundance of residual vine species, such as Virginia creeper (*Parthenocissus quinquefolia*), greenbriers (*Smilax* spp.), and poison ivy (*Toxicodendron radicans*), and by clusters of sweetgum (*Liquidambar styraciflua*) sprouts. In addition, physical disturbance, such as that in treatment 1, provides opportunity for pioneer species to establish, resulting in greater overall community diversity and species richness (Thompson and DeGraaf 2001). Retention of residual species also affected community similarity, separating treatment 1 from the chemically site-prepared treatments once the short-term grouping effect of HWC was past. Similar to results in other conifers (Lindgren and Sullivan 2001, Biring et al. 2003), CSP was more effective than MSP at removing or suppressing species from the post-harvest stand, opening the way for a more durable response from early seral species like that reported by Miller et al. (1995) and creating communities with a more distinctively early succession character. Recovery of the forb community from HWC applied in year 1 was similar regardless of whether the application was banded or broadcast. However, by year 3 perennials began to dominate, leaving less growing space for recolonizing forbs suppressed by the second broadcast HWC application. This resulted in the continued separation of the treatment 5 community, which was never fully overcome. The different rates at which treatments approached crown closure began to influence communities in year 4, by which time shading and litter from loblolly were pronounced in treatment 5, potentially speeding the decline of annual forbs (Moir 1966, Monk and Gabrielson 1985). These different successional dynamics may result in community differences even after crown closure, most particularly with treatment 1. This is supported by the relatively stable effect size (*A*) of treatment 1 versus treatments 2 – 5, compared with decreasing effect sizes and a gradual erosion of pair-wise differences among treatments 2 – 5, which indicates that communities in those treatments converged after year 1.

The relative lack of indicator species for treatments 2 – 5 reflects the impact of CSP, which created a fairly homogeneous, relatively depauperate community of vines and woody plants among these treatments, limiting potential indicator species to pioneering herbaceous species. Additionally, the diverse herbaceous communities present in treatments 1 – 3 reduced the likelihood for any given herbaceous species to be particularly limited to any one treatment. Several indicator species assignments after year 1 seemed less related to treatment and more related to a convergence of micro-habitat, seed source, and chance. For example, there seems to be no relevant reason for treatments 1 and 2 to be indicated by different oak species, as occurred in year 5. The overall inconsistency of indicator species in treatments receiving CSP would seem to indicate a level of randomness, whereas the multi-year assignments to treatment 1, particularly of vine species, lends more support to the value of those species as true treatment indicators.

Growth-form Metrics

The primary purpose of CSP was to remove woody species capable of being long-term competitors with the crop trees. The HWC applications were intended to improve pine survival and early growth by releasing pines from herbaceous competition immediately following planting. The degree and duration of response to treatment for each class of competitor indicates that the goal of each silvicultural operation was fulfilled.

If we consider the impact of each incremental increase in treatment intensity, there was a slow and steady accretion of effects, often attributable to a given treatment element. For instance, species richness of vines was reduced by CSP, and then further reduced by the second broadcast HWC application. In some cases, attribution of effects was less apparent. For instance, it might be debated whether the reduction of *H`* and *D* from treatment 1 to treatment 3 was due more to CSP or MSP. The averages indicate that although treatment 2 did not differ statistically from treatment 1, its diversity levels were closer to treatments 3 and 4; therefore, the reduction in total diversity was probably due mostly to CSP, and enhanced by mechanical disturbance.

Miller et al. (1995) maintained vegetation control regimes for 3 – 5 years after planting and compared resulting plant coverage. Complete herbaceous weed control reduced herbaceous cover to <15%, and accelerated the dominance of woody species (Miller et al. 1995). In my study, treatments 4 and 5 had similarly low levels of herbaceous cover in the years they received broadcast HWC. Woody plants other than pines had already been eliminated or suppressed by CSP; thus, the primary woody species released by the broadcast HWC was loblolly pine (Jones 2007). Conversely, complete control of woody competition by Miller et al. (1995) increased the presence of grasses and forbs and led to longer dominance by the herbaceous component; in my study this response was most evident with forb coverage in the CSP treatments. Graminoids, however, were less responsive to release from woody competition, and expressed patterns independent of site preparation technique.

Differences in response to treatment between *H`* and *D* were most likely attributable to index response to species richness. The Shannon index is influenced more strongly by changes in species richness than by changes in dominance, whereas the reverse is true of the Simpson index (Peet 1974). Treatment differences in species richness were correlated with *H`* for vines and shrubs, but were not likewise correlated with *D*. Similarly, year changes in graminoid richness were paralleled by changes in *H`*, but not with *D*. The increase in *H`* from year 1 to year 2 was expected, because HWC in spring of year 1 was likely to reduce species richness, particularly in the broadcast treatments (Blake et al. 1987, Keyser et al. 2003, Mihalco 2004). Diversity in stands of other conifer species likewise increased in the growing season following chemical release (Brockway et al. 1998, Bell and Newmaster 2002).

Biodiversity

Herbicides are used in stand establishment to control vegetative competition, and impacts on the plant community in turn affect wildlife habitat. The period between harvest and crown closure in the regenerated stand represents a significant opportunity for wildlife species dependent on early seral communities (Johnson 1987). Moderate use of herbicides during site preparation and release may temporarily decrease plant diversity within a given stand (Neary et al. 1990); however, by providing distinctive early successional habitat, herbicides may increase overall biodiversity in landscapes dominated by pine plantation silviculture.

Wildlife communities in pine forests change with advancing successional stage (Atkeson and Johnson 1979, Johnson and Landers 1982) in response to structural elements, vegetation composition, or both. Hanberry (2005) found that differences in bird response to snag density in regenerating loblolly plantations were not apparent until the second year following CSP, when ground-level vegetation had recovered. Retention of snags and remnant unmerchantable trees in stands with CSP only (e.g., treatment 2) may provide vital habitat structure for many bird species, increasing avian species richness and abundance compared with mechanically prepared sites (Darden 1980, O'Connell and Miller 1994, Hanberry 2007). Retention of such structural diversity in young plantations also may help stabilize populations of mature forest birds (Yahner 2003) by allowing them to continue using regenerating areas (Caine and Marion 1991). Similarly, management that retains ground cover in the form of coarse woody debris or leaf litter may allow mature forest amphibians to persist following harvest and site preparation (Russell et al. 2002). Foraging strategies may influence the presence or abundance of small mammal species at different successional stages, with grazing species more prominent in young stands than in closed-canopy stands (Mengak et al. 1989). In this study, banded HWC provided a better winter foraging environment for northern bobwhite (*Colinus virginianus*) than broadcast HWC, comparable to results from less intensively established stands (Jones 2008). White-tailed deer (*Odocoileus virginianus*) benefited from CSP, which allowed development of nutritious forbs in treatments limited to banded HWC (i.e., treatments 2 and 3); by contrast, MSP alone (i.e., treatment 1) promoted the quick reestablishment of lower quality browse, with consequently lower nutritional carrying capacity (Edwards 2004, Jones 2008). Use of appropriate vegetation control methods during stand establishment can therefore benefit tree growth and provide wildlife habitat features to maintain or improve overall biodiversity.

In comparison with secondary succession in old fields, secondary succession in regenerating plantations is truncated by the planting of crop trees and the reestablishment of residual forest species (Thompson and DeGraaf 2001), thus reducing the available space and time frame for ruderal species and pushing the stand toward dominance by woody plants (Bormann and Likens 1979, Felix et al. 1983). Opportunities for early successional communities were best created with CSP or CSP and MSP combined, which pushed the successional timeline farther back than MSP alone. However, following CSP with broadcast HWC suppressed the herbaceous component and released the planted pines to dominate the stand more quickly, similar to Miller et al. (2003). Treatments 4 and 5 experienced less growth of forbs in coverage and time than other treatments, reducing their value as wildlife habitat for species dependant on early seral communities. Such species would be better served by the use of CSP or CSP and MSP combined followed by, at most, banded HWC.

Because shading and ground litter limit herbaceous coverage and diversity, strategies to decrease these factors may increase the time and space available for early seral communities. Deferring woody competition control to 2 – 3 years after MSP could allow development of an herbaceous community similar to treatment 1 prior to release; following release, the entire stand, except for the crop trees, would return to an earlier sere again dominated by herbaceous species. Increasing the spacing of planted pines would reduce relative coverage of pine needles and increase the time to crown closure (Radtke and Burkhart 1999) without necessarily reducing financial viability (Huang and Kronrad 2004, VanderSchaaf and South 2004), providing more time and space for ground story plants.

Biodiversity also should be considered beyond the stand level to include the landscape mosaic (Brown et al. 2001, Hartley 2002). Using an assortment of stand establishment techniques should help conserve gamma diversity by creating a greater variety of plant communities and habitat characteristics. However, there may be legitimate limitations on these techniques. Broadcast HWC, especially when applied for >1 year, may reduce stand-level plant diversity below desirable levels without providing adequate habitat potential to compensate for that reduction. Haeussler et al. (1999) found a significant negative correlation between species diversity and volume of lodgepole pine (*Pinus contorta*) in 10-yr-old stands established using a range of MSP intensities. This result is similar to my study, where more intensively established plantations expressed lesser diversity and greater crop tree heights and diameters (Jones 2008). This indicated some level of trade-off between crop tree growth and species diversity during the period before crown closure. All treatment combinations in my study resulted in successfully established plantations, so the primary result of greater establishment intensity was increased growth rate through reduced competition. Forest managers should be aware of these trade-offs to determine what constitutes an acceptable loss of stand-level diversity for a given increase in production, and consider whether certain treatments should be precluded from use for the sake biodiversity.

MANAGEMENT IMPLICATIONS

Biodiversity in pine plantations may be benefited by the use of CSP. While mechanically prepared areas had greater plant diversity, the increase was due to retention of residual species which could be found in other stands or in the same stand at a later age. Early succession habitat in areas otherwise dominated by closed canopy forest may increase floral and faunal regional diversity, especially when there is some variation in establishment methodology. Herbaceous weed control should be limited to banded application to prevent destruction of early seral communities created by CSP.

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Table 3.1. Mean plant species richness in 5 loblolly pine (*Pinus taeda*) plantations 1 – 5 years following establishment treatments ranging from low (1) to high (5) intensity in the Lower Coastal Plain of Mississippi, 2002 – 2006.[a]

Life form	Year	Treatment[b]										*P*-values[c]		
		1		2		3		4		5				
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trtd	Yr×Trt
Forb	2002	29.00^{A}	6.7	28.25^{A}	10.1	28.00^{A}	5.8	12.25^{B}	2.5	10.00^{B}	2.9	≤0.001	≤0.001	0.002
	2003	32.25^{A}	5.6	29.25^{A}	6.0	34.75^{A}	5.1	30.75^{A}	6.5	13.75^{B}	5.3		≤0.001	
	2004	34.50	6.9	39.00	9.9	39.00	7.4	39.75	8.9	29.00	7.3		0.227	
	2005	37.25	7.5	37.25	9.7	44.50	7.7	43.50	9.0	37.25	7.1		0.103	
	2006	34.75	9.2	32.50	10.9	40.50	6.7	38.50	6.2	35.00	8.1		0.080	
Graminoid	2002	7.75^{A}	0.6	8.75^{A}	1.4	6.00^{AB}	0.4	4.25^{B}	0.9	5.00^{B}	1.5	≤0.001	0.003	0.014
	2003	9.00^{A}	2.0	11.25^{A}	1.1	11.50^{A}	1.7	11.25^{A}	1.7	6.00^{B}	0.9		≤0.001	
	2004	16.75	1.8	18.00	2.1	16.25	2.5	14.75	2.8	14.75	2.2		0.368	
	2005	16.00	3.3	18.00	2.7	18.00	1.8	14.75	2.2	14.25	2.9		0.149	
	2006	13.25	1.5	12.00	1.1	14.00	2.5	13.50	1.5	12.00	1.7		0.758	
Shrub	2002	9.00	1.2	6.50	0.9	6.75	0.3	5.00	0.0	3.75	0.6	≤0.001	0.051	0.374
	2003	8.00	0.4	7.75	1.0	7.25	0.8	6.75	1.0	6.25	0.9			
	2004	8.75	1.1	7.25	1.7	7.75	1.1	8.25	1.1	6.75	0.9			
	2005	10.75	1.3	8.75	2.3	9.00	1.1	8.75	1.5	9.00	1.4			
	2006	12.00	1.5	10.00	1.9	9.50	1.0	10.25	0.9	8.50	1.2			
Tree	2002	8.75	0.9	6.75	1.5	4.25	0.5	4.25	0.3	5.25	0.6	≤0.001	0.002	0.087
	2003	7.25	0.3	7.75	0.6	6.00	0.7	5.50	0.6	6.00	0.4			
	2004	11.75	1.7	10.50	1.0	6.75	0.9	9.00	0.7	7.25	0.5			
	2005	12.75	1.1	12.25	0.9	9.00	1.1	9.50	1.2	10.00	0.7			
	2006	13.00	1.5	11.25	0.9	11.00	1.9	10.50	1.7	9.25	0.6			
	All	10.70^{A}	0.7	9.70^{A}	0.6	7.40^{B}	0.7	7.75^{B}	0.7	7.55^{B}	0.5			

Table 3.1. Continued.

		Treatment[b]												
Life		1		2		3		4		5		P-values[c]		
form	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[d]	Yr×Trt
Vine	2002	9.75	0.9	5.25	1.0	5.75	1.0	4.50	0.3	3.75	1.0	≤0.001	≤0.001	0.058
	2003	11.50	1.2	7.75	1.3	8.50	1.6	8.25	1.5	3.25	0.8			
	2004	12.50	1.6	10.50	1.6	9.25	1.9	10.75	1.6	7.75	1.9			
	2005	12.25	0.5	10.75	1.8	11.50	1.0	12.00	1.1	9.50	1.3			
	2006	14.25	0.6	11.75	2.1	12.50	1.0	13.50	0.6	10.50	0.6			
	All	12.05^{A}	0.5	9.20^{B}	0.8	9.50^{B}	0.8	9.80^{B}	0.9	6.95^{C}	0.8			
Total	2002	64.25^{A}	7.6	55.50^{AB}	12.0	50.75^{B}	4.8	30.25^{C}	1.8	27.75^{C}	4.2	≤0.001	≤0.001	≤0.001
	2003	68.00^{A}	4.6	63.75^{A}	6.8	68.00^{A}	3.9	62.50^{A}	4.5	35.25^{B}	4.5		≤0.001	
	2004	84.25^{A}	8.4	85.25^{A}	10.3	79.00^{A}	6.7	82.50^{A}	8.3	65.50^{B}	9.2		0.036	
	2005	89.00	8.0	87.00	10.5	92.00	7.3	88.50	8.1	80.00	7.3		0.575	
	2006	87.25	10.8	77.50	14.0	87.50	6.2	86.25	5.7	75.25	8.0		0.218	

[a] Actual means presented. Analyses were performed on square-root transformed data. *P*-values refer to least square means.

[b] Differences among treatment means are designated by different letters within rows.

[c] Degrees of freedom were as follows: $\mathrm{Yr}_{\mathrm{Forb}}$` = 4,24.7; $\mathrm{Trt}_{\mathrm{Forb}}$ = 4,5.77; Yr × $\mathrm{Trt}_{\mathrm{Forb}}$ = 16,25.1; $\mathrm{Yr}_{\mathrm{Graminoid}}$` = 4,55.5; $\mathrm{Trt}_{\mathrm{Graminoid}}$ = 4,17.6; Yr × $\mathrm{Trt}_{\mathrm{Graminoid}}$ = 16,56.3; $\mathrm{Yr}_{\mathrm{Shrub}}$` = 4,57.6; $\mathrm{Trt}_{\mathrm{Shrub}}$ = 4,16.2; Yr × $\mathrm{Trt}_{\mathrm{Shrub}}$ = 16,57.6; $\mathrm{Yr}_{\mathrm{Tree}}$` = 4,54.2; $\mathrm{Trt}_{\mathrm{Tree}}$ = 4,14.2; Yr × $\mathrm{Trt}_{\mathrm{Tree}}$ = 16,54.3; $\mathrm{Yr}_{\mathrm{Vine}}$` = 4,53.4; $\mathrm{Trt}_{\mathrm{Vine}}$ = 4,14.9; Yr × $\mathrm{Trt}_{\mathrm{Vine}}$ = 16,54.6; $\mathrm{Yr}_{\mathrm{Total}}$` = 4,50.6; $\mathrm{Trt}_{\mathrm{Total}}$ = 4,14.1; Yr × $\mathrm{Trt}_{\mathrm{Total}}$ = 16,52.1.

[d] When Yr*Trt is significant, Trt *P*-values are for within-year comparisons.

Table 3.2. Mean plant growth-form coverage in 5 loblolly pine (*Pinus taeda*) plantations 1 – 5 years following establishment treatments ranging from low (1) to high (5) intensity in the Lower Coastal Plain of Mississippi, 2002 – 2006.[a]

		Treatment[b]												
Life		1		2		3		4		5		*P*-values[c]		
form	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[d]	Yr×Trt
Forb	2002	12.0^{A}	2.1	19.1^{A}	9.6	11.6^{A}	3.0	1.6^{B}	0.4	1.4^{B}	0.5	≤0.001	≤0.001	≤0.001
	2003	22.5^{A}	7.1	28.0^{A}	9.7	27.1^{A}	7.0	27.4^{A}	5.2	6.9^{B}	5.3		≤0.001	
	2004	14.5^{BC}	3.7	20.8^{ABC}	7.6	24.7^{AB}	6.3	29.5^{A}	9.3	13.6^{C}	6.9		0.040	
	2005	9.5	2.4	14.5	5.7	18.0	2.4	13.8	3.6	11.9	3.4		0.464	
	2006	6.4	1.4	7.2	3.8	11.2	2.8	10.7	3.6	5.7	1.9		0.509	
Graminoid	2002	15.0^{A}	3.4	18.0^{A}	5.8	8.8^{A}	1.8	1.9^{B}	0.7	1.1^{B}	0.4	≤0.001	≤0.001	0.010
	2003	28.7^{AB}	6.7	32.9^{A}	4.9	22.1^{AB}	6.4	21.4^{BC}	7.0	10.4^{C}	2.9		0.003	
	2004	38.4	5.6	47.2	9.3	45.1	8.2	43.3	6.6	49.4	10.9		0.8063	
	2005	29.1	2.2	37.0	8.1	33.6	4.8	36.4	5.8	25.1	1.2		0.4974	
	2006	16.7	2.2	15.1	1.4	18.2	2.4	15.3	2.4	12.7	2.8		0.8302	
Shrub	2002	4.4	1.2	1.5	0.7	0.8	0.4	0.7	0.4	0.6	0.4	≤0.001	0.283	0.729
	2003	11.2	1.3	7.8	2.2	6.3	2.1	6.4	2.3	2.5	0.7			
	2004	21.5	4.4	16.6	4.9	10.2	2.5	14.5	5.5	7.7	2.4			
	2005	20.7	1.9	19.6	6.4	13.2	2.1	15.3	4.4	15.6	4.9			
	2006	26.1	2.7	25.5	6.9	21.3	4.3	23.4	6.9	19.9	5.4			
Tree	2002	2.7	0.3	1.9	0.8	1.6	0.3	1.7	0.2	1.6	0.4	≤0.001	0.017	0.165
	2003	10.4	2.4	6.7	0.9	8.3	1.7	9.6	2.9	5.8	1.5			
	2004	26.6	5.9	17.4	3.8	19.4	3.9	25.5	4.6	29.5	4.9			
	2005	40.2	5.2	27.2	3.9	31.8	2.4	37.6	4.7	49.2	4.9			
	2006	56.1	5.2	46.0	5.9	46.1	3.2	55.3	6.0	55.6	2.4			
	All	27.2^{A}	4.8	19.8^{C}	3.9	21.4^{BC}	3.8	25.9^{AB}	4.7	28.3^{A}	5.2			

Table 3.2, Continued.

		Treatment[b]												
		1		2		3		4		5		*P*-values[c]		
Life form	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[d]	Yr×Trt
Vine	2002	12.1	1.7	4.4	2.6	6.2	3.1	1.0	0.6	0.7	0.3	≤0.001	≤0.001	0.087
	2003	48.6	6.5	20.7	8.1	39.0	15.7	25.6	9.3	3.4	2.4			
	2004	72.2	8.9	39.7	9.4	49.6	13.4	45.8	3.9	21.1	7.0			
	2005	58.9	4.3	29.9	4.7	39.8	6.4	28.7	2.9	28.2	4.7			
	2006	53.0	9.9	29.3	4.6	38.1	2.0	35.8	3.3	25.5	2.3			
	All	49.0^{A}	5.4	24.8^{BC}	3.7	34.5^{B}	5.2	27.4^{B}	3.9	15.8^{C}	3.1			
Total	2002	46.2^{A}	5.8	45.0^{AB}	18.5	28.9^{B}	4.2	6.9^{C}	1.1	5.3^{C}	1.2	≤0.001	≤0.001	≤0.001
	2003	121.3^{A}	8.9	96.0^{B}	8.9	102.7^{AB}	11.3	90.4^{B}	3.7	29.0^{C}	7.5		≤0.001	
	2004	173.4^{A}	16.8	141.6^{BC}	15.7	149.1^{AB}	14.1	158.6^{AB}	13.6	121.2^{C}	12.2		0.008	
	2005	158.4	9.8	128.2	11.0	136.4	5.6	131.8	8.0	130.0	7.4		0.194	
	2006	158.4^{A}	11.8	123.1^{B}	10.8	134.9^{AB}	8.7	140.6^{AB}	12.0	119.4^{B}	5.3		0.050	

[a] Actual means presented. Analyses were performed on square-root transformed data. *P*-values refer to least square means.

[b] Differences among treatment means are designated by different letters within rows.

[c] Degree of freedom were as follows: Yr_{Forb}` = 4,57.4; $\text{Trt}_{\text{Forb}}$ = 4,15.2; Yr × $\text{Trt}_{\text{Forb}}$ = 16,57.4; $\text{Yr}_{\text{Graminoid}}$` = 4,56.1; $\text{Trt}_{\text{Graminoid}}$ = 4,16.6; Yr × $\text{Trt}_{\text{Graminoid}}$ = 16,57; Yr_{Shrub}` = 4,12; $\text{Trt}_{\text{Shrub}}$ = 4,15; Yr × $\text{Trt}_{\text{Shrub}}$ = 16,17.9; $\text{Yr}_{\text{Tree}}$` = 4,56.5; Trt_{Tree} = 4,18.2; Yr × Trt_{Tree} = 16,57.3; Yr_{Vine}` = 4,12; $\text{Trt}_{\text{Vine}}$ = 4,15; Yr × $\text{Trt}_{\text{Vine}}$ = 16,17.9; $\text{Yr}_{\text{Total}}$` = 4,51.7; $\text{Trt}_{\text{Total}}$ = 4,15.9; Yr × $\text{Trt}_{\text{Total}}$ = 16,53.4.

[d] When Yr*Trt is significant, Trt *P*-values are for within-year comparisons.

Table 3.3. Mean Shannon (*H*`) and Simpson (*D*) plant species diversity in 5 loblolly pine (*Pinus taeda*) plantations 1 – 5 years following establishment treatments ranging from low (1) to high (5) intensity in the Lower Coastal Plain of Mississippi, 2002 – 2006.[a]

		Treatment[b]												
Diversity		1		2		3		4		5		*P*-values[c]		
index	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[c]	Yr×Trt
H`	2002	2.98	0.10	2.42	0.27	2.51	0.04	2.48	0.13	2.25	0.22	0.024	0.005	0.635
	2003	2.93	0.16	2.73	0.17	2.55	0.27	2.73	0.20	2.12	0.22			
	2004	3.01	0.16	2.88	0.17	2.80	0.19	2.77	0.19	2.31	0.08			
	2005	3.11	0.21	3.01	0.15	2.86	0.09	2.63	0.09	2.53	0.16			
	2006	2.96	0.09	2.77	0.19	2.76	0.14	2.56	0.21	2.27	0.20			
	All	3.00^{A}	0.06	2.76^{AB}	0.09	2.69^{B}	0.07	2.64^{B}	0.07	2.30^{C}	0.02			
D	2002	0.91	0.01	0.82	0.06	0.87	0.00	0.88	0.02	0.84	0.04	0.030	0.003	0.475
	2003	0.90	0.02	0.88	0.04	0.81	0.07	0.86	0.05	0.78	0.06			
	2004	0.91	0.02	0.89	0.02	0.88	0.04	0.88	0.04	0.81	0.01			
	2005	0.92	0.02	0.91	0.02	0.89	0.01	0.86	0.02	0.85	0.03			
	2006	0.91	0.01	0.88	0.02	0.88	0.02	0.84	0.04	0.79	0.05			
	All	0.91^{A}	0.01	0.88^{AB}	0.01	0.87^{B}	0.02	0.86^{B}	0.01	0.81^{C}	0.02			

[a] Actual means presented. Analyses were performed on square-root transformed data. *P*-values refer to least square means.

[b] Differences among treatment means are designated by different letters within rows.

[c] Degree of freedom were as follows: Year$_{H`}$ = 4,34.4; Treatment$_{H`}$ = 4,5.99; Year × Treatment$_{H`}$ = 16,27.1; Year$_{D}$ = 4,12; Treatment$_{D}$ = 4,14.8; Year × Treatment$_{D}$ = 16,17.9.

Table 3.4. Significance groupings[a] and effect sizes (*A*) of plant communities in 5 loblolly pine (*Pinus taeda*) plantations 1 – 5 years following establishment treatments ranging from low (1) to high (5) intensity in the Lower Coastal Plain of Mississippi, 2002 – 2006.

	Treatment						
Year	1	2	3	4	5	*P*-value[b]	*A*
2002	A	A	A	B	B	≤0.001	0.11
2003	A	B	B	B	C	≤0.001	0.14
2004	A	B	B	B	C	≤0.001	0.11
2005	A	BD	BC	CE	DE	≤0.001	0.08
2006	A	B	BC	CD	D	≤0.001	0.11

[a] Treatments within years designated by the same upper case letter did not differ significantly (α=0.05).

[b] *P*-values are equal to the probability of a smaller or equal δ resulting from MRBP analysis.

Table 3.5. Mean effect sizes ($\overline{A}$) of within-year comparisons by significance grouping of plant communities in 5 loblolly pine (*Pinus taeda*) plantations 1 – 5 years following establishment treatments ranging from low (1) to high (5) intensity in the Lower Coastal Plain of Mississippi, 2002 – 2006.

Year	Treatments	$\overline{A}$
2002	1,2,3 vs 4,5	0.16
2003	1 vs 2,3,4,5	0.19
2003	2,3,4 vs 5	0.21
2004	1 vs 2,3,4,5	0.16
2004	2,3,4 vs 5	0.12
2005	1 vs 2,3,4,5	0.14
2005	2 vs 4	0.05
2005	3 vs 5	0.08
2006	1 vs 2,3,4,5	0.17
2006	2 vs 4,5	0.07
2006	3 vs 5	0.08

Table 3.6. Indicator values[a] (*IV*) of designated indicator species for 5 loblolly pine (*Pinus taeda*) plantation establishment treatments ranging from low (1) to high (5) intensity in the Lower Coastal Plain of Mississippi, 2002 – 2006.

Species	Treatment	Year	*IV*	*P* – value[b]
Chamaechrista fasciculata	4	3	50	0.042
Dicanthelium scoparium	3	3	33	0.043
Digitaria ciliaris	2	3	54	0.028
Diospyros virginianus	1	3	50	0.001
" "	1	4	41	0.002
" "	1	5	46	0.004
Eupatorium leucolepis	1	5	73	0.008
Eupatorium serotinum	1	4	38	0.026
Hypericum drummodii	5	4	59	0.030
Ilex vomitoria	2	2	38	0.025
Liquidambar styraciflua	1	2	57	0.019
" "	1	4	48	0.018
Lonicera japonica	1	1	67	0.011
Magnolia virginiana	1	4	47	0.050
Mecardonia acuminata	5	4	61	0.019
Panicum anceps	2	4	58	0.044
Parthenocissus quinquefolia	1	1	52	0.025
" "	1	2	60	0.023
" "	1	3	56	0.003
" "	1	4	52	0.004
Quercus marilandica	2	5	38	0.026
Quercus phellos	1	5	49	0.043
Rhus copallina	1	5	39	0.050
Rubus argutus	1	1	37	0.028
" "	1	2	36	0.012
Smilax glauca	1	1	61	0.007
Smilax rotundifolia	1	3	52	0.019
Toxicodendron radicans	1	2	87	0.001
" "	1	3	73	0.001
" "	1	4	67	0.004
" "	1	5	59	0.005
Vitis rotundifolia	1	1	83	0.003
" "	1	2	59	0.001
" "	1	3	46	0.001
" "	1	4	39	0.004

[a] Indicator values represent the percentage of perfect indication by a given species.
[b] Based on 1,000 Monte Carlo randomizations of species coverage data.

CHAPTER 4

WHITE-TAILED DEER (*Odocoileus virginianus*) FORAGE AND CARRYING CAPACITY ESTIMATORS AT 5 LEVELS OF LOBLOLLY PINE STAND ESTABLISHMENT INTENSITY

ABSTRACT

Stand establishment techniques involving multiple herbicide applications are becoming standard procedure on industrial pine plantations, raising concern over potential impacts to white-tailed deer forage production. We tested effects of 5 levels of stand establishment intensity on deer forage in 1- to 5-yr-old loblolly pine (*Pinus taeda*) plantations ($n = 4$) in the Lower Coastal Plain (LCP) of Mississippi using forage biomass and 4 measures of carrying capacity (CC) reflecting crude protein or digestible energy requirements for body maintenance (CPM and DEM) and lactation (CPL and DEL). I also tested the utility of forage biomass combined with deer use rating for indexing CC. Treatments were combinations of mechanical site preparation (MSP), chemical site preparation (CSP), and herbaceous weed control (HWC). Forage biomass and composition were affected primarily by herbicide use. Total forage biomass and forage biomass of grasses and forbs was reduced by broadcast HWC. Forage biomass of vines was reduced by CSP and multiple broadcast HWC applications. Maintenance-level CC estimates were reduced by broadcast HWC, and CPM estimates were correlated closely with total forage biomass and with a biomass-based forage index. Lactation-level CC estimators were greater in moderate-intensity treatments and depended on 4 – 12 high-quality forage species. In this region of limited soil nutrients and an abundance of low quality forages, nutritional needs for lactating does were better served by CSP with banded HWC. Biomass-based indices of CC may be suitable for indexing CPM in the LCP, but were not useful for indexing CPL or energy-based models. Forage management for deer in areas dominated by pine plantations should focus on providing a diverse landscape and improving forage quality in pine stands. Management to produce bulk rather than quality forage may reduce the value of young plantations for deer in the LCP.

INTRODUCTION

Intensively managed pine plantations will play an important role in providing wood products for the foreseeable future (Prestemon and Abt 2002). Although industrial forest management strategies change in response to silvicultural, economic, and social issues, future strategies likely will include increased use of herbicides (Wigley 2000). Management regimes will consist of tank mixes of multiple herbicides prior to planting and one or more post-planting herbaceous weed control treatments. In 2002, approximately 286,000 ha of southern pine plantations received applications of herbaceous weed control, and 433,000 ha received chemical site preparation (Dubois et al. 2003), mostly relying on tank mixes of 2 or 3 herbicides (Shepard et al. 2004).

A trade-off exists between timber yield maximization and management of associated vegetation for wildlife. Increases of up to 150% in volume produced are typical for pine species in the southeastern United States managed with herbicides (Wagner et al. 2004). However, increasing intensity of site preparation can reduce abundance and diversity of woody and herbaceous plant species depending on herbicide type (Miller et al. 1999), rate (Zutter and Zedaker 1988), proportion of the area receiving treatment (Schabenberger and Zedaker 1999), and additive effects of mechanical site preparation (Harrington and Edwards 1996).

The interval between planting and canopy closure has historically provided a window of relatively abundant white-tailed deer (*Odocoileus virginianus*) forage (Blair and Enghardt 1976, Johnson 1987). At previously researched application rates, single herbicide treatments generally had minor and temporary impacts on plant communities (Zutter and Zedaker 1988, Miller et al. 1999). Studies comparing white-tailed deer habitat responses on chemically- and mechanically-prepared sites generally agreed that deer forage production was reduced for one growing season following site preparation, peaked 2 – 3 growing seasons post-treatment, and declined until canopy closure (Hurst and Warren 1980, Felix et al. 1986, Scanlon and Sharik 1986).

However, the silvicultural goal of intensive pine plantation establishment is to reduce vegetative competition with pine seedlings and shorten the time between planting and canopy closure, which may negatively affect nutritional habitat quality for white-tailed deer. The goal of my research was to compare effects of 5 operational loblolly pine plantation establishment intensities on deer forage production and nutritional carrying capacity during years 1 – 5 post-establishment. I hypothesized that forage production and deer carrying capacity (CC) would decrease as treatment intensity increased. I also tested the utility of an index to CC based on forage species biomass and deer use rating. Quantifying relationships between pine plantation management intensity and vegetative characteristics that affect habitat quality will allow resource managers to make land management decisions that optimize timber production while giving consideration to socially and economically important wildlife species.

STUDY AREA

I studied deer forage on loblolly pine plantations established at 4 industrial forest sites in George, Lamar, and Perry counties in the Mississippi Lower Coastal Plain (LCP). Stands were harvested during summer 2000 – winter 2001 and averaged 66 ha in size. Vegetation at all sites was representative of the Outer Coastal Plain Mixed Forest Province (Bailey 1980). Two soil associations occurred on the 4 stands (United States Department of Agriculture 1995). The McLaurin-Heidel-Prentiss soil association was common to 2 stands and comprised of gently sloping, moderately well-drained sandy and loamy soils. The Prentiss-Rossella-Benndale soil association occurred on 2 stands and was characterized by loamy and fine sandy loam soils.

METHODS

Study Design

Treatments were combinations of mechanical site preparation (MSP), chemical site preparation (CSP), and herbaceous weed control (HWC) designed to reflect the range of operational intensities used on industrial forest lands in the southeastern U.S. Intensive management is generally associated with chemical competition control (McCullough et al. 2005), so I correlated treatment number with the amount of herbicide used during stand establishment to assign treatments ranging from least (treatment 1) to most (treatment 5) intensive. I assigned randomly each of the 5 treatments to an area ≥8 ha, each treatment occurring once per stand, for 4 replications per treatment in a randomized complete block design. Chemical site preparation was performed at all sites during July – August 2001; MSP was performed during September – December 2001. Herbaceous weed control was applied during March – April 2002 (year 1) and March – May 2003 (year 2).

Treatment 1 consisted of MSP using a combination plow to subsoil, disk, and bed, pulled behind a tractor with a V-blade attached to the front to clear debris. Herbaceous weed control consisting of 0.9 kg/ha of Oustar® (E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware; sulfometuron methyl and hexazinone; 13 oz./acre) was applied in a band of 1.5 m width over the tops of pine seedlings, resulting in 50% total coverage.

Treatment 2 consisted of CSP using a mixture of 2.4 L/ha Chopper® Emulsifiable Concentrate (BASF Corp., Research Triangle Park, North Carolina; 32 oz/acre), 3.5 L/ha Accord® (Dow AgroSciences LLC, Indianapolis, Indiana; 48 oz/acre), 3.5 L/ha Garlon 4® (Dow AgroSciences LLC, Indianapolis, Indiana; 48 oz/acre), and 1% volume to volume ratio of Timberland 90® surfactant (UAP Timberland LLC, Monticello, Arkansas) in a broadcast spray solution of 93.6 L/ha. Banded HWC was applied as per treatment 1.

Site preparation for treatment 3 consisted of MSP as described for treatment 1 combined with CSP as per treatment 2. Banded HWC was applied identically to treatments 1 and 2. Treatment 4 consisted of both MSP and CSP followed by a year 1 broadcast HWC using 0.9 kg/ha of Oustar. Treatment 5 was identical to treatment 4 with the addition of a second broadcast HWC treatment in year 2.

Apart from these treatments, management was standardized across all plots. Loblolly pines were planted on each site during the winter of 2001 – 2002 on a 3.0 × 2.1-m spacing (1,551 trees/ha), with each participating company using its own seedlings. Two sites were machine planted, and 2 sites were hand planted due to high debris loads. Although seedling sources and planting methods differed among sites, they were consistent within sites (i.e., blocks). All stands were fertilized with a broadcast application of diammonium phosphate at 280 kg/ha in April 2002.

Sampling

I composed a list of potential deer forages using input from the literature (Warren and Hurst 1981, Miller and Miller 1999) and Mississippi Department of Wildlife, Fisheries and Parks biologists, ranking forages from 1 (limited use) to 4 (high use). I sampled forages with rankings of 3 or 4 within each experimental unit using 20 randomly placed 1-m^2 exclosures (Harlow 1977) during July 2002 – 2006, excluding a 30-m buffer zone along treatment boundaries to ensure uniformity. I clipped and weighed leaves and growing stem tips to represent consumable plant portions for each species and collected 3 known- weight field samples ≥30 g of each species for further processing. I dried these forage samples in a forced-air oven at 60º C for 72 hours, averaged resulting wet:dry ratios, and used the result to extrapolate dry weight biomass on a kg/ha basis for each species across sampling units. I assigned species to forage classes and calculated dry weight forage biomass for forbs (non-leguminous), legumes, vines, woody, grasses, and total forage.

Composite samples of each forage species were processed by the Mississippi State University Animal Nutrition Laboratory for crude protein (CP) and digestible energy (DE). Crude protein was determined using the Kjeldahl procedure (Helrich 1990). Gross energy was determined using a bomb calorimeter and digestibility by *in vitro* dry matter disappearance (Cherney et al. 1997) using rumen fluid from a fistulated steer. I calculated DE by multiplying gross energy × digestibility. All nutritional values were established on a dry matter basis.

I used an explicit nutritional constraints model (Hobbs and Swift 1985) to determine treatment effects on nutritional CC by estimating deer-days of foraging capacity during the growing season at a given level of diet quality. I computed CC assuming a daily dry matter intake (DMI) of 1360 g (Edwards et al. 2004), which is within the range of intake rates of southern deer (Fowler et al. 1967, Asleson et al. 1996, Campbell and Hewitt 2005). For each treatment, I calculated an energy-based maintenance-level CC (DEM), an energy-based lactation-level CC (DEL), a protein-based maintenance-level CC (CPM), and a protein-based lactation-level CC (CPL). To calculate DEM, I used a target diet quality of 2.2 kcal DE/g DMI, based on a requirement of 159 kcal/kg$^{0.75}$/day (Hellickson and DeYoung 1997, McCall et al. 1997) for a 50 kg deer. I calculated DEL using a requirement of 3.25 kcal DE/g DMI as sufficient for a lactating doe with one fawn (Campbell et al. 2002, adjusted for DMI); I assumed that this level was more than sufficient for antler growth in bucks (Robbins 1993). I set the target diet quality for CPM at 6% CP (French et al. 1956, McEwen et al. 1957, Asleson 1996). The CPL requirement of 14% CP would likely support lactation for a doe with one fawn (Verme and Ullrey 1984), and be more than adequate for antler growth in bucks (Asleson

1996). I assumed that CP and DE content of forages provided an accurate relative comparison of plant quality among treatments. Although plant secondary compounds such as tannins can influence digestibility (Hanley et al. 1992), I assumed that any such effects were consistent among treatments and study areas.

To quantify a treatment's capacity to produce preferred deer forage, I calculated a total forage value (TFV) by multiplying projected biomass × use rating for each forage species rated 3 or 4, then summing the products within each experimental unit to yield a single value (Jones et al. 1993). This value was used to test determine whether this less labor-intensive method could substitute as a CC index in place of the more complex nutritional constraints model.

Data Analysis

I used a repeated measures, mixed model ANOVA to test for main effects of year and treatment and year × treatment interaction for species diversity, species richness, and coverage of forbs, graminoids, shrubs, vines, trees, and total vegetation. I compared means among treatments ($n = 5$) and years ($n = 5$) in SAS PROC MIXED (SAS Institute 2000). I treated stands (i.e., blocks, $n = 4$) as the random effect, years as the repeated effect, and treatment × stand as the subject. For each analysis, I selected the best combination of data transformation, use of the random statement, and covariance structure, choosing the combination that minimized AIC_C (Akaike's Information Criterion corrected for small sample size; Littell et al. 2006, Gutzwiller and Riffell 2007). This is not a case of mixing analytical paradigms as warned against in Anderson et al. (2001); only one *a priori* model is analyzed, and the AIC_C is not used to rank models, but rather to determine which analysis procedure makes the best use of the data. I determined if log or square root transformation improved AIC_C and used it accordingly. I then selected the best covariance structure from among: autoregressive covariance with treatment as a group, autoregressive covariance without treatment as a group, and unstructured covariance. I then assessed the utility of the random statement, and chose whether to retain it based on lesser AIC_C value. I used the Kenwardroger adjustment in denominator degrees of freedom for repeated measures and small sample sizes (Littell et al. 2006, Gutzwiller and Riffell 2007). I considered differences significant if $P < 0.10$ (Tacha et al. 1982). I used LSMEANS SLICE to identify a treatment effect within years following a significant interaction (Littell et al. 2006). I compared means using Fisher's least significant difference with the LSMEANS PDIFF option (Littell et al. 2006). For ease of data interpretation, I present actual means although I conducted most analyses on transformed data.

RESULTS

Forage Biomass

I detected treatment differences in 3 of 5 forage classes and in total forage biomass (Table 4.1). Across all years, broadcast HWC reduced biomass of forage grasses by 87% compared to treatments with banded HWC. Similarly, total forage biomass was 2 times greater in treatments with banded HWC than in treatment 5, which received 2 broadcast HWC applications. Year × treatment interactions in forb and vine forage biomass indicated treatment effects varied in relation to time since treatment.

Differences in forb biomass were detected for years 1 and 2. Broadcast HWC reduced forage biomass of forbs by 89% compared to banded HWC during the first growing season following establishment. During year 2, forb biomass was 1.9 times greater in treatments 3 and 4 than in treatments 1, 2, and 5.

Vine biomass tended to reflect the treatment intensity gradient. Treatment 1, which received no CSP, exhibited the greatest biomass in years 1 – 4 due to retention of residual vines from the pre-harvest stand and greater volumes of blackberry and dewberry (*Rubus* spp.). During year 1, treatment 1 had 4 times more forage vine biomass than treatments 2, 4, and 5, with treatment 3 intermediate. Following the second broadcast HWC application, year 2 vine biomass in treatment 1 was 62 times greater than in treatment 5 and nearly 3 times greater than treatments 2 – 4. These differences gradually decreased through years 3 and 4 until all treatments were at parity in year 5.

Carrying Capacity Estimators and Total Forage Value

I estimated CC using biomass and nutritional parameters from 71 forage species, including 30 forbs, 2 grasses, 9 legumes, 12 vines, and 18 woody species. Crude protein values ranged from 3.4 – 19.4%, and DE ranged from 0.81 – 3.73 kcal/g. Protein-based estimators expressed more treatment differences than energy-based estimators at maintenance and lactation levels.

Response of CPM followed the treatment gradient, indicating a gradual accretion of effects as treatment intensity increased (Table 4.2). Treatment 1 exhibited 2 times greater CPM than treatments 4 and 5, with treatments 2 and 3 intermediate. Broadcast HWC was primarily responsible for reduced CPM, though only treatment 1 differed from treatments 4 and 5, indicating that CSP was also a factor. The second broadcast HWC in treatment 5 did not prevent a large increase in CPM from year 1 to year 2; however, the increase was not as great as in treatment 4, which did not receive the additional HWC application. Similarly, broadcast HWC appeared to be the primary factor influencing the year 4 treatment difference in DEM (Table 4.3), where treatment 1 expressed 2.3 times greater DEM than treatments 4 and 5. Because CPM calculations used >95% of available forage biomass, the response of TFV was identical to that of CPM, with response following the treatment gradient (Table 4.4).

Unlike maintenance-level estimators, lactation-level CC estimates were generally greater in moderate-intensity treatments, indicating that these treatments produced more nutritious forage than did treatments 1 and 5. Within treatments 2 – 4, production of these species was delayed by increasing management intensity, so that CPL peaked earlier in less intensive treatments (Table 4.5). In year 1, CPL was 5 times greater in treatment 2 than in other treatments. In year 2, treatment 3 expressed CPL 16 times greater than treatments 1, 4, and 5. In year 3, CPL in treatment 4 was 7 times greater than treatments 1, 2, and 5. Estimates for DEL during year 1 were 13 times greater in treatments 2 and 3 than in other treatments (Table 4.6).

DISCUSSION

Forage Development

Treatment design facilitates comparisons between treatments with 1 differing component, elucidating effects of individual treatment elements. Forage development patterns were influenced by herbicide use. Mechanical site preparation worked with chemical site preparation to suppress woody forages in year 1. Chemical site preparation is applied primarily to control remnant woody vegetation that may compete with planted pines; however, suppression of this woody component also may release the site for herbaceous plants (Miller et al. 1995, Edwards 2004, Mihalco 2004), increasing the opportunity establish nutritious forbs and legumes.

Broadcast herbaceous weed control appeared to impact total forage biomass more than other treatment elements, but impacts were mostly confined to the year of application (Blake et al. 1987, Keyser et al. 2003, Keyser and Ford 2006). It is likely that banded HWC also reduced total forage production in year 1 compared to no HWC (Blake et al. 1987), but I had no opportunity to make this comparison. Broadcast HWC virtually eliminated forage grasses from treatments 4 and 5; forbs were similarly affected, but recovered the year following the application, similar to results from Blake et al. (1987). Because forage vines included both lianas and early seral species such as Japanese honeysuckle (*Lonicera japonica*) and *Rubus* spp., they were sensitive to the combination of broadcast HWC and chemical site preparation.

The establishment regimes in this study may not be a complete substitute for practices investigated in previous research. Intensive MSP as practiced in the southern U.S. during the 1960's and '70's often involved 3 or more treatment elements (Fox et al. 2007). This high level of soil disturbance created plant communities dominated by graminoids and forbs such that forage yields in the growing season following site preparation were equal to or greater than those in subsequent years (Stransky and Halls 1978, Stransky et al. 1986, Blake et al. 1987). Treatments in this study yielded total forage production that was lower the season following site preparation than in subsequent years, thereby reducing the window of high forage production available in regenerating plantations.

Carrying Capacity Estimators

In estimating nutritional CC, presence of high-quality forage increases CC by allowing the subject to consume a larger proportion of lower quality forage while maintaining target diet quality, thus increasing the total proportion of forage biomass used in the model. As long as the distribution of forage quality is comparable among treatments, CC will be correlated closely with forage biomass. In my study, total forage biomass was correlated negatively with treatment intensity. Maintenance-level CC estimators responded similarly, because diet requirements were low enough to include most forage biomass in the CC models. Conversely, differences in lactation-level CC were primarily attributable to differences in the proportion of high-quality forage biomass among treatments.

Previous studies of stand establishment impacts on deer forage production focused on biomass without considering diet quality. Consequently, they should be most comparable to my maintenance-level CC estimates, which were less sensitive to variations in plant quality. The pattern of CPM and DEM estimates was nearly identical across treatments, peaking on average in years 2 – 3, similar to other studies of forage development in pine plantations whether treated with mechanical site preparation (Lewis et al. 1984, Johnson 1987), chemical site preparation (Blake et al. 1987, Gassett et al. 2000), or HWC (Keyser and Ford 2006). Lactation-level CC estimates were less comparable. Energy-based estimates tended to be greater in years 4 and 5. Protein-based estimates in moderately intensive treatments expressed increasing delays in maximum CC as management intensity increased, so peak CC ranged from year 1 – 3. Managers should take these differences into account when formulating expectations for forage provision in establishing pine plantations.

Direct comparisons among 6 CC estimation methods in Texas found that, while each method produced different absolute results, all methods provided consistent relative rankings (McCall et al. 1997). I found roughly similar relative results between CP- and DE-based methods for estimating maintenance-level CC. However, results from lactation-level estimates were less comparable between methods. This may have been at least partly attributable to the low level of soil fertility in the LCP (Pettry 1977, Jacobson 1984), which reduces the overall nutritional value of individual forage species relative to more fertile regions (P. Jones, Mississippi State University, unpublished data). In regions with more fertile soils, I would expect more species and a greater proportion of biomass to enter into CC models with high nutritional requirements than occurred in this study, perhaps improving the correlation between the CP- and DE-based methods.

Deer have been shown to select forest clearings with greater biomass of high-quality forage (Beckwith 1964) even if overall forage biomass is less than other areas (Stewart et al. 2000). Treatment 1 produced the most forage biomass, but the lack of CSP reduced its capacity to produce high-quality forage plants, particularly forbs. Treatments 4 and 5 suffered reduced utility due to broadcast HWC, which eliminated most forb coverage in the year applied. In this region of limited soil nutrients, nutritional needs for lactating does were better served by treatments 2 and 3, both of which combined CSP with banded HWC.

The nutritional constraints model has the benefit of preventing overestimation of CC by considering diet quality, not just nutrient availability (Hobbs and Swift 1985). In my study, lactation-level CC estimates averaged only 7% those of maintenance-level CC, emphasizing the discrepancy between ability of these sites to produce bulk forage and high-quality forage. Had I required even marginally greater levels for lactation support, those CC estimates would have approached 0. Previous work comparing stand establishment regimes in the South has focused on production of forage quantity (Stransky and Halls 1978, Blake et al. 1987, Chamberlain and Miller 2006, Keyser and Ford 2006). My results show that such a focus may be misleading and potentially detrimental for deer in the LCP.

Total Forage Value

The relatively simple vegetation sampling procedure used in the biomass-based TFV makes this approach easier than the more intensive process of gathering data to calculate the nutritional constraints model CC estimate. Forage surveys are used commonly in management of ungulates because of an assumed relationship between forage measurement(s) and carrying capacity (Mackie 2000, Higgins et al. 2005). However, CC estimates based on biomass measurements without consideration of nutritional value will be inaccurate in areas where forage quality is limiting (Hobbs and Swift 1985, Miller and Wentworth 2000). Edwards (2004) found neither forage coverage nor species richness were reliable indicators of differences in CC calculated using a diet quality of 12% CP in the Mississippi LCP. In this study, protein-based maintenance-level CC estimates were successfully indexed by TFV because the CP values of most forage species met or exceeded the target diet quality of 6% CP. However, the wide range of forage digestibility sharply reduced the correlation of TFV with DEM. Furthermore, high-quality forage did not represent a constant proportion of overall forage across treatments, and consequently TFV was not correlated with lactation-level CC estimates. With the exception of protein-based maintenance-level CC, it seems unlikely that measures of forage biomass can be used as an accurate index of CC in the LCP.

MANAGEMENT IMPLICATIONS

Consideration of seasonal nutritional demands for deer in young pine stands of the LCP resulted in different management preferences than consideration of forage quantity alone. Nutrient poor soils may limit access to high-quality forage in the LCP and early seral stage pine plantations may represent a significant foraging option for deer. As such, managers should attempt to meet the requirements of the greatest seasonal demand, which is lactation. Thus, managers in the LCP should consider providing high-quality forage, even, if necessary, at the expense of quantity. While management options may be somewhat limited on ownerships where wood production is the primary objective, this study has shown that there is enough latitude in operational intensive pine management strategies to allow biologists a considerable range of potential outcomes. Strategies that depend on producing bulk rather than quality forage may reduce the value of young plantations for deer in the LCP. Superior levels of lactation-level and maintenance-level CC were provided in chemically site-prepared stands followed by banded HWC. Therefore, I recommend combining CSP or CSP and MSP with at most banded HWC during pine plantation establishment in the LCP to maximize the value of young plantations for deer forage production. Because of the generally lower soil quality in this region, production of the few plant species capable of meeting the peak nutritional demands of deer may be vital to maintaining healthy populations with consistent recruitment.

Although young plantations potentially provide better quality forage than surrounding forests (Thill et al. 1990), none of the treatments in this study provided sustained high-quality foraging options for deer, and managers should not depend on any of the tested treatments to provide a sufficient foraging environment for deer. While the period before crown closure could provide an opportunity for substantial forage production in southern pine plantations, the low absolute lactation-level CC estimates in this study reveal only a limited temporal availability for high-quality foraging above maintenance requirements. Treatments which provided superior CPL did so for only one to 2 years, and DEL was generally low in years 1 – 3. Managers should therefore incorporate landscape-scale considerations to enable deer to maintain a nutritional plane adequate for seasonal needs, especially in the LCP. Traditional management techniques, such as prescribed fire, retention of mast-producing hardwoods, and supplemental forage production should be implemented to create and maintain diverse foraging habitat (Yarrow and Yarrow 1999). Within pine stands, thinning increases ground-level production of important forage plants (Peitz et al. 1999), and use of selective herbicide and prescribed fire can increase availability of high-quality forage in both mid-rotation (Iglay et al. 2006, Ragsdale and Demarais 2006) and mature pine stands (Edwards et al. 2004).

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Table 4.1. Consumable biomass (kg/ha) of moderate- to high-use white-tailed deer (*Odocoileus virginianus*) forages available in 5 loblolly pine (*Pinus taeda*) plantation establishment treatments in the Lower Coastal Plain of Mississippi, 2002 – 2006.[a]

		Treatment[b]												
Forage		1		2		3		4		5		*P*-values[c]		
class	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[d]	Yr*Trt
Forb	1	110 A	42	106 A	69	138 A	111	3 B	2	23 B	16	0.002	0.004	0.019
	2	76 B	53	80 B	61	178 A	60	211 A	87	150 B	122		0.011	
	3	67	45	99	64	45	27	88	40	85	62		0.769	
	4	65	20	62	37	92	35	56	12	29	11		0.659	
	5	22	6	36	23	47	13	29	6	15	6		0.802	
Grass	1	9	6	80	59	120	57	3	3	3	3	0.174	0.049	0.241
	2	28	17	39	26	14	9	0	0	0	0			
	3	114	57	79	61	32	23	2	1	7	7			
	4	42	23	40	19	30	24	17	13	14	14			
	5	63	40	24	10	22	12	6	3	10	8			
	All	51 A	16	52 A	17	44 A	15	6 B	3	7 B	3			
Legume	1	4	3	2	0	4	3	1	1	0	0	0.369	0.772	0.910
	2	2	1	5	3	9	4	11	9	4	3			
	3	1	1	4	4	10	7	15	9	2	2			
	4	4	3	3	3	8	7	9	8	5	5			
	5	9	7	4	3	2	1	6	4	3	2			
Vine	1	152 A	34	64 BC	30	92 AB	49	26 C	21	32 BC	17	≤0.001	0.013	≤0.001
	2	448 A	26	159 B	36	222 B	78	122 B	40	7 C	5		≤0.001	
	3	511 A	128	280 B	66	282 B	72	183 B	58	73 C	22		≤0.001	
	4	395 A	65	243 B	16	258 AB	28	177 B	37	155 B	35		0.034	
	5	199	30	132	11	156	25	144	27	98	15		0.532	

Table 4.1, Continued.

Forage class	Year	Treatment[b] 1 $\bar{x}$	1 SE	2 $\bar{x}$	2 SE	3 $\bar{x}$	3 SE	4 $\bar{x}$	4 SE	5 $\bar{x}$	5 SE	*P*-values[c] Yr	Trt[d]	Yr*Trt
Woody	1	59	28	68	26	12	9	16	10	7	6	≤0.001	0.153	0.035
	2	47	14	54	23	93	36	92	40	82	41		0.872	
	3	50	12	88	35	119	68	56	22	77	31		0.829	
	4	154	36	99	35	75	24	101	50	112	29		0.613	
	5	80	22	83	28	92	16	96	28	136	51		0.900	
Total	1	335	71	319	156	366	222	48	23	66	16	≤0.001	0.021	0.268
	2	601	76	337	73	516	131	436	88	242	97			
	3	744	163	550	122	487	146	344	67	244	62			
	4	659	96	447	86	464	39	360	48	315	47			
	5	373	54	280	42	318	29	281	22	261	58			
	All	542 A	54	367 AB	47	430 AB	56	294 BC	38	226 C	31			

[a] Actual means presented; analysis performed on square-root transformed data.
[b] Within-year treatment means followed by the same upper case letter do not differ significantly (α=0.10). Treatment differences correspond to least square means.
[c] *P*-values correspond to least square means. Degree of freedom were as follows: $\mathrm{Yr}_{\mathrm{Forb}}{}^{\backprime} = 4{,}54.7$; $\mathrm{Trt}_{\mathrm{Forb}} = 4{,}20$; $\mathrm{Yr} \times \mathrm{Trt}_{\mathrm{Forb}} = 16{,}55.4$; $\mathrm{Yr}_{\mathrm{Grass}}{}^{\backprime} = 4{,}30.5$; $\mathrm{Trt}_{\mathrm{Grass}} = 4{,}7.28$; $\mathrm{Yr} \times \mathrm{Trt}_{\mathrm{Grass}} = 16{,}31.6$; $\mathrm{Yr}_{\mathrm{Legume}}{}^{\backprime} = 4{,}60.3$; $\mathrm{Trt}_{\mathrm{Legume}} = 4{,}21.2$; $\mathrm{Yr} \times \mathrm{Trt}_{\mathrm{Legume}} = 16{,}59.9$;$\mathrm{Yr}_{\mathrm{Vine}}{}^{\backprime} = 4{,}59.8$; $\mathrm{Trt}_{\mathrm{Vine}} = 4{,}18.4$; $\mathrm{Yr} \times \mathrm{Trt}_{\mathrm{Vine}} = 16{,}59.2$; $\mathrm{Yr}_{\mathrm{Woody}}{}^{\backprime} = 4{,}60.3$; $\mathrm{Trt}_{\mathrm{Woody}} = 4{,}19.6$; $\mathrm{Yr} \times \mathrm{Trt}_{\mathrm{Woody}} = 16{,}59.7$; $\mathrm{Yr}_{\mathrm{Total}}{}^{\backprime} = 4{,}12$; $\mathrm{Trt}_{\mathrm{Total}} = 4{,}15$; $\mathrm{Yr} \times \mathrm{Trt}_{\mathrm{Total}} = 16{,}17.9$.
[d] When Yr*Trt is significant, Trt *P*-values are for within-year comparisons.

Table 4.2. Estimates of white-tailed deer (*Odocoileus virginianus*) carrying capacity (deer-days/ha) based on a mean diet quality of 6% crude protein in 1- to 5-yr-old loblolly pine (*Pinus taeda*) plantations in the Mississippi Lower Coastal Plain, 2002 – 2006.[a]

		Treatment[b]					*P*-values[c]		
Year		1	2	3	4	5	Yr	Trt	Yr*Trt
1	$\bar{x}$	245	230	261	31	49	<0.001	0.021	0.257
	SE	52	111	162	16	10			
2	$\bar{x}$	440	248	377	321	176			
	SE	56	54	96	64	72			
3	$\bar{x}$	547	405	358	253	179			
	SE	120	89	108	49	46			
4	$\bar{x}$	484	329	340	264	231			
	SE	70	63	28	36	34			
5	$\bar{x}$	272	200	232	205	191			
	SE	39	27	22	16	43			
All	$\bar{x}$	397A	282 ABC	313 AB	215 BC	165 C			
	SE	40	34	41	28	23			

[a] Actual means presented; analysis performed on square-root transformed data.

[b] Treatment means followed by the same upper case letter do not differ significantly ($\alpha=0.10$). Treatment differences correspond to least square means.

[c] *P*-values correspond to least square means. Degrees of freedom were 4,12 for year, 4,15 for treatment, and 16,17.9 for interaction.

Table 4.3. Estimates of white-tailed deer (*Odocoileus virginianus*) carrying capacity (deer-days/ha) based on a mean diet quality of 2.2 kcal/g digestible energy in 1- to 5-yr-old loblolly pine (*Pinus taeda*) plantations in the Mississippi Lower Coastal Plain, 2002 – 2006.[a]

		Treatment[b]					*P*-values[c]		
Year		1	2	3	4	5	Yr	Trt[d]	Yr*Trt
1	$\bar{x}$	117	162	88	11	33	<0.001	0.145	0.066
	SE	58	77	48	7	12			
2	$\bar{x}$	99	125	198	178	82		0.392	
	SE	32	55	73	42	17			
3	$\bar{x}$	185	293	197	130	103		0.654	
	SE	54	124	112	33	45			
4	$\bar{x}$	428 A	305 AB	315 A	191 B	179 B		0.055	
	SE	79	74	30	54	42			
5	$\bar{x}$	197	198	212	167	158		0.701	
	SE	61	37	27	24	59			

[a] Actual means presented; analysis performed on log-transformed data.

[b] Treatment means followed by the same upper case letter do not differ significantly (α=0.10). Treatment differences correspond to least square means.

[c] *P*-values correspond to least square means. Degrees of freedom were 4,12 for year, 4,15 for treatment, and 16,17.9 for interaction.

[d] Treatment values are within-year, year and interaction values are overall.

Table 4.4. Mean total forage value of white-tailed deer (*Odocoileus virginianus*) forage plants for 5 levels of establishment intensity in 1- to 5-yr-old loblolly pine (*Pinus taeda*) plantations in the Mississippi Lower Coastal Plain, 2002 – 2006.

		Treatment[a]					*P*-values[b]		
Year		1	2	3	4	5	Yr	Trt	Yr*Trt
1	$\overline{x}$	1189	1080	1190	158	232	<0.001	0.038	0.201
	SE	236	568	729	70	53			
2	$\overline{x}$	2126	1131	1754	1492	804			
	SE	273	241	415	296	291			
3	$\overline{x}$	2693	1958	1695	1146	827			
	SE	620	431	517	196	211			
4	$\overline{x}$	2395	1597	1608	1272	1121			
	SE	343	291	141	202	170			
5	$\overline{x}$	1292	986	1097	984	909			
	SE	175	156	94	70	212			
All	$\overline{x}$	1939 A	1350 ABC	1469 AB	1010 BC	779 C			
	SE	199	169	188	129	105			

[a] Treatment means followed by the same upper case letter do not differ significantly (α=0.10). Treatment differences correspond to least square means.

[b] *P*-values correspond to least square means. Degrees of freedom were 4,12 for year, 4,15 for treatment, and 16,17.9 for interaction.

Table 4.5. Estimates of white-tailed deer (*Odocoileus virginianus*) carrying capacity (deer-days/ha) based on a mean diet quality of 14% crude protein in 1- to 5-yr-old loblolly pine (*Pinus taeda*) plantations in the Mississippi Lower Coastal Plain, 2002 – 2006.[a]

		Treatment[b]					*P*-values[c]		
Year		1	2	3	4	5	Yr	Trt[d]	Yr*Trt
1	$\bar{x}$	5.3 B	32.2 A	3.2 B	3.2 B	14.6 B	0.542	0.070	0.025
	SE	4.1	19.1	2.0	2.9	14.4			
2	$\bar{x}$	2.0 BC	18.2 AB	26.6 A	2.7 BC	0.3 C		0.072	
	SE	1.5	16.5	2.7	2.4	0.3			
3	$\bar{x}$	3.7 B	5.5 B	11.7 AB	27.8 A	2.8 B		0.078	
	SE	1.6	4.9	6.0	10.1	2.6			
4	$\bar{x}$	4.0	9.7	13.1	15.7	4.8		0.655	
	SE	2.0	8.0	7.0	7.1	3.5			
5	$\bar{x}$	8.1	5.3	1.2	7.4	4.1		0.842	
	SE	4.7	4.3	0.5	3.4	1.8			

[a] Actual means presented; analysis performed on square-root transformed data.

[b] Treatment means followed by the same upper case letter do not differ significantly (α=0.10). Treatment differences correspond to least square means.

[c] *P*-values correspond to least square means. Degrees of freedom were 4,55.6 for year, 4,14.8 for treatment, and 16,55.9 for interaction.

[d] Treatment values are within-year, year and interaction values are overall.

Table 4.6. Estimates of white-tailed deer (*Odocoileus virginianus*) carrying capacity (deer-days/ha) based on a mean diet quality of 3.25 kcal/g digestible energy in 1- to 5-yr-old loblolly pine (*Pinus taeda*) plantations in the Mississippi Lower Coastal Plain, 2002 – 2006.[a]

		Treatment[b]					*P*-values[c]		
Year		1	2	3	4	5	Yr	Trt[d]	Yr*Trt
1	$\bar{x}$	0.5 C	15.9 A	13.0 AB	0.1 C	3.1 BC	<0.001	0.014	0.091
	SE	0.3	8.0	8.7	0.1	2.9			
2	$\bar{x}$	5.4	1.0	2.8	0.3	3.8		0.614	
	SE	4.8	0.7	2.0	0.3	2.1			
3	$\bar{x}$	27.1	25.4	21.5	5.4	5.3		0.276	
	SE	13.2	21.5	13.7	0.4	2.5			
4	$\bar{x}$	90.6	23.1	44.9	19.6	19.0		0.152	
	SE	38.8	8.6	13.6	8.9	7.4			
5	$\bar{x}$	54.2	33.1	41.3	15.3	20.3		0.684	
	SE	40.0	13.6	16.4	4.8	5.6			

[a] Actual means presented; analysis performed on log-transformed data.

[b] Treatment means followed by the same upper case letter do not differ significantly (α=0.10). Treatment differences correspond to least square means.

[c] *P*-values correspond to least square means. Degrees of freedom were 4,57.5 for year, 4,18.6 for treatment, and 16,57.3 for interaction.

[d] Treatment values are within-year, year and interaction values are overall.

CHAPTER 5

HABITAT SUITABILITY OF INTENSIVELY ESTABLISHED LOBLOLLY PINE PLANTATIONS FOR NORTHERN BOBWHITE (*Colinus virginianus*) IN SOUTHERN MISSISSIPPI

ABSTRACT

Stand establishment techniques involving multiple herbicide applications are becoming standard procedure on industrial pine plantations. Declines in northern bobwhite (*Colinus virginianus*) populations in the Southeast have been attributed to loss of early successional plant cover associated with changing forest management practices. I tested effects of 5 levels of operational stand establishment intensity on vegetation communities and structure important for bobwhite in 1 – 5-yr-old loblolly pine (*Pinus taeda*) plantations (*n* = 4) in the Lower Coastal Plain of Mississippi. Treatments were combinations of mechanical site preparation, chemical site preparation, and herbaceous weed control (HWC), and were ranked by level of intensity from low (treatment 1) to high (treatment 5). Chemical site preparation reduced coverage of woody plants across all years, and pines dominated woody coverage on most chemically prepared stands. Broadcast HWC reduced coverage of herbaceous plants during the year when it was applied; herbaceous coverage recovered to levels similar to treatments receiving banded HWC the next year. Mechanical site preparation produced greater coverage of bare ground in year 1 compared with chemical site preparation; broadcast HWC maintained

greater bare ground than banded HWC for 1 year following application. Debris coverage was increased by greater management intensity; herbicide applications created more dead material in years 1 and 2, and increased pine dominance in more intensive treatments yielded greater pine litter coverage in years 4 and 5. Visual obscurity was decreased by greater treatment intensity from 0.0 – 0.9 m height in years 1 and 2. Coverage of fall and winter food plants in treatment 1 was more than double that in treatment 5; however, differences in a winter food suitability index occurred only in years 1 and 2 due to superior accessibility in more intensive treatments. I assessed vegetation community composition and structure to determine suitability of treatments across all 5 years for nesting, loafing, and brood-rearing habitat. Two years of optimal nesting habitat was provided by treatments 1, 3, and 4, 1 year by treatment 2, and none by treatment 5. Loafing cover reached optimal levels in all treatments by year 3, and dropped below optimum in treatment 1 in year 5. Brood-rearing habitat was inadequate in all treatments in all years due to lack of combined bare ground and forb coverage requirements. Intensively managed pine plantations are likely inadequate for brooding bobwhite, and efforts to provide brood-rearing habitat may have to rely on thinned mid-rotation stands and permanent landscape features such as rights-of-way. Newly established plantations may be increased in value for bobwhite by increasing spacing between planting rows, thus increasing time before crown closure and providing opportunity for understory manipulations to diversify habitat and increase useable space.

INTRODUCTION

Intensively managed pine plantations will play an important role in providing wood products for the foreseeable future (Prestemon and Abt 2002). Industrial forest management strategies change in response to silvicultural, economic, and social issues, and future strategies likely will include increased use of herbicides (Wigley 2000). Rather than a single herbicide application at stand initiation, management strategies will likely include tank mixes of multiple herbicides prior to planting to reduce competition with crop trees, followed by one or more herbaceous weed control (HWC) treatments. In 2002, approximately 286,000 ha of southern pine plantations received applications of HWC, and 433,000 ha received chemical site preparation (Dubois et al. 2003), mostly relying on tank mixes of 2 or 3 herbicides (Shepard et al. 2004).

A trade-off exists between timber yield and competing vegetation. Control of competing vegetation with herbicides typically produces increases of up to 150% in volume for pine species in the southeastern United States (Wagner et al. 2004). However, increasing intensity of site preparation can reduce abundance and diversity of woody and herbaceous plant species. Magnitude of effects depends on herbicide type (Miller et al. 1999), rate (Zutter and Zedaker 1988), proportion of the area receiving treatment (Schabenberger and Zedaker 1999), and the additive effects of mechanical site preparation (Harrington and Edwards 1996).

As northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) populations have declined in the southeastern U.S., much of the cause has been attributed by some authors to intensive plantation management practices and decreasing use of prescribed fire (Brennan 1991, Burger 2002). Use of prescribed fire has declined in the face of increasing costs (Dubois et al. 2003) and restricted use (Haines et al. 2001), and selective herbicide use has emerged as a silvicultural alternative (Wigley et al. 2002). In addition to site preparation, forest herbicides are used after planting to reduce herbaceous competition with crop trees (Shepard et al. 2004, Wagner et al. 2004). Given the widespread use of intensive forest management on large, pine-dominated parcels, it is imperative to understand the impacts of such management on vegetation communities vital to bobwhite.

Options for improving bobwhite habitat have been explored in mature pine forests under intensive management (Welch et al. 2004, Jones and Chamberlain 2004, Kitts 2004, Burke 2006). Although several studies have documented effects of herbicide use during stand establishment on food plants important to bobwhite (McComb and Hurst 1987, Miller et al. 1989, Witt et al 1993, Feken 1995, Hawkes 1995, Keyser et al. 2003, Keyser and Ford 2006), most have been of short duration, and little information is available on impact of tank mixtures of herbicides, multiple herbicide applications, and combinations of mechanical and chemical site preparation (Miller and Miller 2004). Furthermore, there is as yet no comprehensive assessment of the multiple habitat values potentially found in young, intensively established pine plantations.

My study investigated effect of 5 intensive establishment regimes on vegetation communities in loblolly pine (*Pinus taeda*) plantations during a 5-yr period following site preparation and planting in southern Mississippi. I compared the results with ranges and combinations of coverage reported in the scientific literature as consistent with bobwhite use or preference. Guthery et al. (2005) recommended evaluating annual dynamics in usable space, as cover on a given area might express temporal availability. My goal was to determine when requirements for suitable fall and winter foraging habitat, nesting habitat, brood-rearing habitat, and loafing cover might best be met by each establishment regime. Results from this study might be combined with research of intensively managed mature pine stands to yield a more complete picture of bobwhite habitat availability and potential voids across landscapes dominated by intensive pine silviculture.

STUDY AREA

I studied bobwhite habitat on loblolly pine stands established at 4 industrial forest sites in George, Lamar, and Perry counties in southern Mississippi. Stands were harvested during summer 2000 – winter 2001 and averaged 66 ha in size. Vegetation at all sites was representative of the Mississippi Lower Coastal Plain (Pettry 1977). Two soil associations occurred on the 4 stands (United States Department of Agriculture 1995). The McLaurin-Heidel-Prentiss association was common to 2 stands and was comprised of gently sloping, moderately well-drained, sandy and loamy soils. The Prentiss-Rossella-Benndale association occurred on 2 stands and was characterized by loamy and fine sandy loam soils.

METHODS

Study Design

Treatments were combinations of mechanical site preparation (MSP), chemical site preparation (CSP), and herbaceous weed control (HWC) designed to reflect the range of operational intensities used on industrial forest lands in the southeastern U.S. Intensive management is generally associated with chemical competition control

(McCullough et al. 2005), so I correlated treatment intensity with the herbicide amount used during stand establishment to assign treatments ranging from least (treatment 1) to most (treatment 5) intensive. I assigned randomly each of the 5 treatments to an area ≥ 8 ha, each treatment occurring once per stand, for 4 replications per treatment in a randomized complete block design. Chemical site preparation was performed during July-August 2001; MSP was performed during September-December 2001. Herbaceous weed control was applied during March-April 2002 (year 1) and March-May 2003 (year 2).

Treatment 1 consisted of MSP using a combination plow to subsoil, disk, and bed, pulled behind a tractor with a V-blade attached to the front to clear debris. Herbaceous weed control consisting of 0.9 kg/ha of Oustar® (E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware; sulfometuron methyl and hexazinone; 13 oz/ac) was applied in a band of 1.5 m width over the tops of pine seedlings.

Treatment 2 consisted of CSP using a mixture of 2.4 L/ha Chopper Emulsifiable Concentrate® (BASF Corp., Research Triangle Park, North Carolina; 32 oz/ac), 3.5 L/ha Accord® (Dow AgroSciences LLC, Indianapolis, Indiana; 48 oz/ac), 3.5 L/ha Garlon 4® (Dow AgroSciences LLC, Indianapolis, Indiana; 48 oz/ac), and 1% volume to volume ratio of Timberland 90® surfactant (UAP Timberland LLC, Monticello, Arkansas) in a broadcast spray solution of 93.6 L/ha. Banded HWC was applied as per treatment 1.

Site preparation for treatment 3 consisted of CSP as described for treatment 2 followed by MSP as per treatment 1. Banded HWC was applied identically to treatments 1 and 2. Treatment 4 consisted of both CSP and MSP followed by a year 1 broadcast

HWC using 0.9 kg/ha of Oustar. Treatment 5 was identical to treatment 4 except for a second broadcast HWC application in year 2.

Apart from these treatments, management was standardized across all plots. All stands were fertilized with a broadcast application of diammonium phosphate at 280 kg/ha in April 2002. Loblolly pines were planted on each site during the winter of 2001 – 2002 on a 3.0 × 2.1-m spacing (1,551 trees/ha), with each participating company using its own genetically improved seedlings. Two sites were machine planted, and 2 sites were hand planted due to high debris loads. Although seedling sources and planting methods differed among sites, they were consistent within sites (i.e., blocks).

Sampling

I measured coverage of ferns, forbs, graminoids, vines, woody plants, litter, and bare ground along 10 randomly placed 30-m line transects in each experimental unit during June 2002 – 2006. Multiple layering of plants often resulted in total coverage >100%. Bare ground and debris were tabulated only when there was a minimum distance of 50 cm from ground level to any overhead canopy.

Landers and Johnson (1976) assigned importance values of 1 – 16 to fall and winter food plant species based on percentage occurrence and percentage volume in diet of bobwhites throughout the Southeast. Brazil (1993) followed the same methodology to assign importance values to fall and winter bobwhite food plants in Mississippi. I used species with IV ≥ 4 to calculate a winter food suitability index (WFSI; Schroeder 1985) from coverage of important food plants and coverage of bare ground and debris. This index, which ranges from 0 – 1, considers agricultural crops as necessary to provide onethird of the index value (Schroeder 1985). Because no agricultural land was included in my study, I calculated only the non-agricultural portion of the index, yielding a possible range of 0 – 0.67. The non-agricultural component of the index is optimized across the range of 25 – 75% canopy coverage of preferred bobwhite herbaceous food plants combined with 30 – 60% coverage of bare ground or light litter (Schroeder 1985).

I measured visual obstruction at 40 randomly placed points using a 1.8-m Nudds density board (Nudds 1977) stratified into 6 0.3-m sections. The board was viewed at a distance of 10 m in each cardinal direction by a standing observer from a standardized height of 1.5 m and obstruction of each section was estimated in 20% increments. I analyzed estimates using the mid-point of each range as the estimated coverage, yielding maximum obstruction of 90%.

Data Analysis

I used a repeated measures, mixed model ANOVA to test for main effects of year, treatment, and year × treatment interaction for: coverage of preferred fall and winter food plants; WFSI; coverage of bare ground, debris, forbs, graminoids, herbaceous plants, and woody plants; and coverage of each Nudds board section. I compared means among treatments ($n = 5$) and years ($n = 5$) in SAS PROC MIXED (SAS Institute 2000). I treated stands (i.e., blocks, $n = 4$) as the random effect, years as the repeated effect, and treatment × stand as the subject. For each analysis, I selected the best combination of data transformation, covariance structure, and use of the random statement, choosing the combination that minimized AIC_C (Akaike's Information Criterion corrected for small sample size; Littell et al. 2006, Gutzwiller and Riffell 2007). This is not a case of mixing analytical paradigms as warned against in Anderson et al. (2001); only one *a priori* model is analyzed, and the AIC_C is not used to rank models, but rather to determine which analysis procedure makes the best use of the data. I first determined if log transformation improved AIC_C and used it accordingly. I then selected the best covariance structure from among: autoregressive covariance with treatment as a group, autoregressive covariance without treatment as a group, and unstructured covariance. I then assessed the utility of the random statement, and chose whether to retain it based on lesser AIC_C value. I used the Kenwardroger adjustment in denominator degrees of freedom for repeated measures and small sample sizes (Littell et al. 2006, Gutzwiller and Riffell 2007). I considered differences significant if $P < 0.05$. I used LSMEANS SLICE to identify treatment effects within years and year effects within treatments following a significant interaction (Littell et al. 2006). I compared means using Fisher's least significant difference with the LSMEANS PDIFF option (Littell et al. 2006). For ease of data interpretation, I present actual means although I conducted most analyses on transformed data.

RESULTS

Treatment 1 averaged 8.2% more woody coverage than other treatments across all 5 years (Table 5.1). Woody coverage increased on all treatments across years, reaching 67 – 82% by year 5. Coverage of forbs, graminoids, herbaceous plants, debris, and bare ground all exhibited year × treatment interactions, yielding treatment and year differences that reflected the impact of herbicide applications on plant succession.

Broadcast HWC in treatments 4 and 5 reduced herbaceous coverage and its primary components of forbs and graminoids in the years it was applied. Coverage in those treatments increased the year following broadcast HWC application to levels equivalent with treatments receiving banded HWC. Herbaceous coverage peaked in year 3, averaging 65.5%, then declined steadily to 24.0% in year 5. Graminoid coverage responded similarly, averaging 44.8% at its peak in year 3, then declining to 16.3% in year 5. Increasing management intensity increasingly delayed maximum forb production such that treatments 1 and 2 peaked in year 2, treatments 3 and 4 peaked in years 2 and 3, and treatment 5 in years 3 and 4.

Coverage of bare ground in treatments receiving MSP averaged 18.4% in year 1, compared with 2.1% in treatment 2, which received only CSP. Treatments with broadcast HWC maintained greater bare ground levels than those with banded HWC for 1 year following the last application. Bare ground decreased quickly in treatments receiving banded HWC, falling from an average of 10.4% in year 1 to 1.1% in years 2 – 5. Debris coverage was more complex. In year 1, greater intensity treatment produced 67.4% debris coverage in treatments 3 – 5 compared with 44.0% in treatment 1. In year 2, broadcast HWC maintained greater debris levels in treatment 5, while coverage in remaining treatments decreased by an average of 40.8 to 17.4%. All treatments were equivalent in year 3, the same year that herbaceous cover peaked across all treatments. Treatment 5 again had greater debris coverage in years 4 and 5, this time due to increasing pine coverage, which shaded out competitors and increased the area covered by pine litter.

Coverage of fall and winter food plants decreased with increasing management intensity (Table 5.2). Across all years, coverage averaged 50.1% in treatment 1, 35.4% in treatments 2 – 4, and 18.3% in treatment 5. Coverage increased from a treatment average of 7.5% in year 1 to a peak of 52.4% in year 3, then declined to 37.3% by year 5. Treatment differences in WFSI values occurred in years 1 and 2, when more intensive HWC applications reduced food plant coverage. In year 1, WFSI averaged 0.27 in treatments with banded HWC versus 0.02 for treatments with broadcast HWC (Table 5.3). Treatment 4 recovered from the effects of broadcast HWC in year 2, whereas the second application in treatment 5 continued to suppress food plant coverage and reduce WFSI. Mean WFSI values in treatment 1 were similar across all 5 years ($F_{4,15} = 2.65$), averaging 0.35; values in treatments 2 – 4 differed among years ($F_{4,15} = 3.67 – 15.05$), peaking in years 2 – 4 (mean = 0.43), then declining in year 5 (mean = 0.21). Treatment 5 exhibited an annual increase in WFSI to year 4 ($F_{4,15} = 16.21$), followed by a decrease in year 5.

Visual obstruction increased across years at all heights (Table 5.4). Less intensive treatments expressed greater coverage in the bottom 3 sections in years 1 and 2, and obstruction 0.0 – 0.9 m above ground leveled out near maximum by year 3. Board sections from 0.9 – 1.8 m were unaffected by treatment, and coverage in those sections leveled out in year 4.

DISCUSSION

Historically, regenerating and newly established pine plantations in southeastern U.S. pine forests have provided 2 – 4 years of early successional habitat suitable for bobwhites (Shultz and Wilhite 1974, Burger 2001). Mechanical site preparation during the 1960s and '70s often involving raking and windrowing followed by broadcast disking and burning (Fox et al. 2007), resulting in a canopy of forbs with abundant bare ground suitable for brood-rearing and winter foraging (Burger 2001). As succession proceeded into the grassy and shrub stages, brood-rearing and winter food habitat deteriorated, while nesting and escape cover improved until eliminated by crown closure. Stands in today's intensively managed pine forests are often managed on ≤ 30-yr rotations; pre-crown closure plantations may compose 15 – 25% of such landscapes, making the utility of young plantations especially important. Maximizing usable space (Guthery 1997) in young plantations necessitates providing habitat sufficient to meet the needs of as many life processes as possible within the stand.

When rating habitat in each treatment, it is important to remember that the results reported are means, and that stands are rarely homogenous. It is likely that pockets of suitable habitat can be found within a stand even when the overall average for a particular feature falls outside of the known range of use. However, averages outside those ranges can be taken to represent a general deterioration in habitat quantity or quality, either of which might result in lower utility for bobwhite.

Fall and Winter Food Plants

Although food may not be a limiting factor for most bobwhite populations (Guthery 2002), important food plants may be characteristic of plant communities that provide habitat structure and species composition to which bobwhites are adapted. Bobwhite densities in regenerating pine plantations have been correlated with abundance of important food plants (Brunswig and Johnson 1972). Previous researchers also have observed a correlation between decreasing use of young pine stands by bobwhite and increasing vegetation thickness (Brunswig and Johnson 1972, Sweeney et al. 1981). The WFSI acknowledges this relationship, requiring 30 – 60% coverage of bare ground or light litter and 25 – 75% canopy coverage of preferred bobwhite herbaceous food plants for optimal suitability (Schroeder 1985). Given this range, lower than optimal accessibility began limiting WFSI in the year following the last HWC application even as food plant coverage increased into optimal range.

Mechanically site-prepared pine plantations provide pulses of bobwhite food plants 1 – 3 years following treatment (Brunswig and Johnson 1972, Sweeney et al. 1981, Felix et al. 1986, Witt et al. 1993). Chemical treatment of plantations targeting woody competitors can enhance growth of herbaceous plants (Knowe et al. 1992, Miller et al. 1995, Mihalco 2004) and promote species (e.g., legumes) with known resistance to particular herbicides during site preparation or release operations (Hurst 1987, Witt et al. 1993, Shaw et al. 2001). The CSP tank mix used in this study was formulated to provide broad spectrum control of woody plants, opening the way for a strong herbaceous response. This potential asset was limited by broadcast HWC, which greatly reduced herbaceous plant coverage during the year in which it was applied. Banded HWC typically reduces herbaceous coverage along planting beds (Mihalco 2004), but it is possible that bobwhite may have benefited from improved access to untreated strips between beds. Despite its negative impact on forage production, broadcast HWC improved accessibility such that WFSI values did not differ among treatments beyond year 2.

Impacts on Cover

Schroeder (1985) described optimal loafing cover as having 40 – 80% coverage of woody vegetation ≤ 2 m in height. Mechanical site preparation typically suppresses non-crop woody vegetation for 1 – 2 years (Stransky et al. 1986, Miller et al. 1995, Lauer and Zutter 2001), whereas chemical treatment may substantially control non-crop woody cover for ≥ 10 years (Quicke et al. 1996, Miller et al. 1999). In this study, woody plant coverage (including planted pines) was greater in the mechanically prepared treatment. Even so, all treatments reached the 40% threshold for optimal loafing cover simultaneously (year 3). Pine trees were the primary source of woody coverage in treatments 3 – 5 due to more complete competition control and consequent superior growth rate. Although pine height was > 2.0 m by this time, self-pruning of lower limbs did not occur during this study. Furthermore, pines in treatments 3 – 5 closed ranks along rows by year 4, providing access to long swaths of cover with relatively low ceilings. Therefore, pines at these ages may have provided adequate loafing cover for bobwhite. Treatment 1 surpassed 80% woody cover in year 5, potentially becoming less suitable for loafing than other treatments.

Optimal nesting cover has been described as 40 – 60% coverage of herbaceous plants, 40 – 60% of which are grasses, with visual obstruction of 40 – 60 cm (Schroeder 1985). Measurements of mean vegetation coverage and structure at bobwhite nests in Mississippi fell within these ranges (Taylor and Burger 2000); somewhat greater percentages of grassy cover have been reported at nest sites in Kansas (Taylor et al. 1999) and Missouri (Burger et al. 1994), with concomitant reductions in forb cover. This combination of cover composition and visual obstruction occurred sporadically across my treatments (Table 5.5). Although a single year of broadcast HWC had no greater impact than banded HWC, 2 years of broadcast HWC prevented development of nesting cover and promoted faster dominance of pine trees, which in turn shaded out understory vegetation in years 4 and 5. The second broadcast HWC also delayed development of adequate visual obstruction until year 3, while obstruction in the remaining treatments was adequate beginning in year 2.

Recent studies of habitat selection by brood-rearing bobwhite have determined typical, if not necessarily preferred, ranges for several vegetation characteristics. Visual obstruction requirements for brood-rearing habitat may approach 60 cm (Taylor and Burger 2000). By this measure, obstruction was lacking in all treatments in year 1, and also was likely too low in treatment 5 in year 2. Bare ground is important to allow accessibility by bobwhite chicks that might become exhausted in thick vegetation or debris (Hurst 1972). Reported coverage of bare ground at brooding sites ranges from 14 – 25% (Speake and Sermons 1986, Burger et al. 1994, Taylor et al. 1999, Taylor and Burger 2000, Carver et al. 2001). Observed vegetation densities have ranged from 33 – 51% grass coverage, 34 – 47% forb coverage, and 37 – 44% woody coverage (Burger et al. 1994, Taylor et al. 1999, Taylor and Burger 2000). Comparison of these combinations of habitat characteristics with my data shows that brood-rearing conditions would not have been considered favorable in any of my treatments during any portion of this study due to lack of conjoint occurrence of bare ground and forb coverage requirements (Figure 1). Sites receiving MSP did achieve adequate bare ground in year 1, primarily within the strips created by the combination plow; however, HWC applications in spring of year 1 prevented development of adequate forb cover in those strips. Chemical site preparation used alone never provided sufficient bare ground. Similarly low levels of bare ground were noted in 2-year-old loblolly pine plantations released with imazapyr in South Carolina (Feken 1995) and in tall fescue fields treated with herbicide (Gruchy 2007), indicating that herbicide in general may need to be supplemented with additional mechanical disturbance to provide brood-rearing habitat. Burke (2006) found that a single prescribed burn following herbicide treatment did not create adequate bare ground for brood-rearing bobwhite in mature pine stands, indicating the necessity for multiple applications to restore and maintain such habitat following years of litter build-up.

In areas dominated by intensive pine management, the overall lack of open canopy may be the greatest barrier to providing suitable habitat conditions for bobwhite. One goal of intensive pine plantation establishment is to shorten the open-canopied phase and allow crop trees to shade out interspecific competitors. Increasing the spacing of planted pines can be a financially acceptable alternative under certain conditions (Huang and Kronrad 2004, VanderSchaaf and South 2004), increasing the length of time newly established plantations maintain an open canopy (Radtke and Burkhart 1999) and allowing opportunities for understory manipulations. Interspersed blocks or strips of between-row vegetation treated with periodic disking could provide a patchwork of early vegetation conditions targeting different life requirements, increasing and extending the value of young intensively managed pine plantations for bobwhite. Mature stands may offer opportunities to manage groundstory vegetation with herbicide and fire (Jones and Chamberlain 2004, Welch et al. 2004), particularly after thinning (Grelen and Enghardt 1973, Cram et al. 2002). However, most thinning regimes on commercial timberland do not result in long-term open-canopied conditions.

Overall, intensively established loblolly pine plantations differed somewhat in the timing and level of habitat provision for bobwhite, with broadcast HWC the most limiting factor. Combining these results with those from intensively managed mature pine stands may be an appropriate step toward building models that enable managers to maximize usable space on plantation forests. The stand establishment treatments presented here are by no means exhaustive, and examination of other regimes, particularly those including prescribed fire and greater mechanical soil disturbance, may provide better options for bobwhite management on intensively managed pine plantation forests.

MANAGEMENT IMPLICATIONS

The intensive establishment regimes for loblolly pine plantations in this study generally provided moderate levels of winter food, nesting, and loafing cover for bobwhite, but inadequate brood-rearing cover. Moderate intensity treatments involving CSP or CSP and MSP combined with one year of banded HWC produced the most suitable habitat among my treatments. Because early succession habitat in plantation forests is of an ephemeral nature, management of permanent landscape features in close juxtaposition to open-canopied pine stands will likely be necessary to provide the full complement of bobwhite habitat, particularly brood-rearing habitat. Managing permanent landscape features such as rights-of-way with strip disking (Greenfield et al. 2003) may improve structural characteristics for brooding bobwhite and provide a vital habitat component. Timing and distribution of regeneration cuts may be critical to providing available early succession areas for bobwhite in areas dominated by even-aged management (Sweeney et al. 1981). Landscape-scale management that ensures interspersion of early seral communities, whether in young plantations or recently thinned stands, will be necessary to provide adequate habitat for bobwhites (White et al. 2005).

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Table 5.1. Percent coverage of ground cover types in 5 loblolly pine (*Pinus taeda*) plantation establishment treatments in the Lower Coastal Plain of Mississippi, 2002 – 2006.[a]

		Treatment												
Ground		1		2		3		4		5		*P*-values[b]		
cover	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[c]	Yr*Trt
Forbs	1	11.9 A[d]	2.2	18.6 A	9.3	11.3 A	3.3	1.6 B	0.3	1.4 B	0.5	≤0.001	0.004	≤0.001
	2	22.5 A	7.1	27.8 A	9.9	26.8 A	9.1	27.7 A	5.3	6.7 B	5.3		0.009	
	3	14.3	3.8	20.2	7.9	23.7	6.6	28.8	8.8	13.6	7.0		0.109	
	4	8.6	2.2	14.2	5.7	15.6	3.2	13.5	3.7	11.6	3.3		0.455	
	5	6.3	1.6	7.3	4.1	10.8	2.9	10.3	3.4	5.7	1.9		0.684	
Graminoids	1	15.0 A	3.4	18.0 A	5.8	8.8 A	1.8	1.9 B	0.7	1.1 B	0.4	≤0.001	≤0.001	0.009
	2	28.7 AB	6.7	32.9 A	4.9	22.1 AB	6.4	21.3 BC	7.0	10.4 C	2.9		0.003	
	3	38.4	5.6	47.2	9.3	45.1	8.2	43.3	6.6	50.0	11.4		0.791	
	4	28.4	2.7	37.0	8.1	33.6	4.8	36.4	5.8	22.1	1.2		0.476	
	5	16.7	2.2	15.1	1.4	17.6	2.0	15.3	2.4	16.7	2.8		0.866	
Debris	1	44.0 A	4.4	58.7 AB	12.6	58.9 B	4.2	71.0 B	7.0	72.4 B	6.2	≤0.001	0.004	≤0.001
	2	13.0 A	3.6	22.0 B	4.2	14.9 AB	6.5	19.6 AB	2.6	65.9 C	8.8		≤0.001	
	3	17.4	2.0	20.5	0.7	17.2	2.4	13.3	2.1	18.8	3.4		0.509	
	4	12.7 A	2.6	18.2 AB	3.3	15.5 A	1.6	18.5 AB	2.5	27.9 B	3.0		0.024	
	5	20.5 A	2.3	35.9 BC	2.8	26.0 AB	2.1	33.9 BC	3.2	44.4 C	3.6		0.002	
Herbaceous[e]	1	27.0 AB	4.0	36.9 A	15.0	20.2 B	3.4	3.4 C	0.9	2.5 C	0.9	≤0.001	≤0.001	≤0.001
	2	51.2 A	0.9	60.1 A	5.2	49.2 A	7.9	49.0 A	8.7	17.3 B	4.5		≤0.001	
	3	53.0	6.1	68.0	5.6	69.8	13.7	72.8	8.2	63.7	11.6		0.259	
	4	38.2	4.1	51.5	2.7	51.7	5.3	50.2	4.4	37.0	4.1		0.134	
	5	23.4	3.7	22.7	3.0	29.6	3.4	26.1	2.8	18.4	3.0		0.374	

Table 5.1. Continued.

Vegetation type	Year	Treatment 1		Treatment 2		Treatment 3		Treatment 4		Treatment 5		P-values[b]		
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[c]	Yr*Trt
Woody	1	7.2	1.3	3.7	1.5	2.6	0.3	2.4	0.5	2.2	0.6	≤0.001	0.014	0.286
	2	21.6	2.9	14.5	2.3	14.6	3.7	16.0	2.7	8.3	1.4			
	3	48.2	10.2	34.0	7.2	29.6	4.6	40.0	3.9	37.2	5.3			
	4	58.7	3.5	46.8	8.2	45.0	4.1	52.8	7.2	64.9	7.8			
	5	82.3	4.1	71.5	9.5	67.4	6.4	78.7	11.7	75.5	4.5			
	All	43.6 A	6.5	34.1 B	6.1	31.8 B	5.5	38.0 B	6.8	37.6 B	7.0			
Bare ground	1	14.7 A	2.1	2.1 B	0.3	14.4 A	2.6	22.4 A	7.9	22.2 A	7.2	≤0.001	≤0.001	≤0.001
	2	1.1 A	0.8	0.2 A	0.1	1.7 AB	0.7	5.7 B	2.6	6.9 B	4.0		0.044	
	3	0.5	0.1	0.2	0.0	1.2	0.5	1.9	0.6	7.8	3.2		0.085	
	4	2.0	0.4	1.7	0.2	2.1	0.8	2.3	1.2	3.5	0.9		0.960	
	5	1.1	0.1	0.8	0.3	1.0	0.3	1.2	0.4	1.4	0.3		0.982	

[a] Actual means presented; analysis performed on square-root transformed data. *P*-values and treatment differences correspond to least square means.

[b] Degrees of freedom were as follows: $\text{Yr}_{\text{Forb}`}$ = 4,40; $\text{Trt}_{\text{Forb}}$ = 4,5.45; Yr × $\text{Trt}_{\text{Forb}}$ = 16,30.8; $\text{Yr}_{\text{Graminoid}`}$ = 4,56.4; $\text{Trt}_{\text{Graminoid}}$ = 4,16.6; Yr × $\text{Trt}_{\text{Graminoid}}$ = 16,57.2; $\text{Yr}_{\text{Debris}`}$ = 4,54.8; $\text{Trt}_{\text{Debris}}$ = 4,18.3; Yr × $\text{Trt}_{\text{Debris}}$ = 16,55.8; $\text{Yr}_{\text{Herbaceous}`}$ = 4,53.4; $\text{Trt}_{\text{Herbaceous}}$ = 4,15; Yr × $\text{Trt}_{\text{Herbaceous}}$ = 16,54.5; $\text{Yr}_{\text{Woody}`}$ = 4,56.6; $\text{Trt}_{\text{Woody}}$ = 4,19.1; Yr × $\text{Trt}_{\text{Woody}}$ = 16,57.3; $\text{Yr}_{\text{Bare ground}`}$ = 4,44.6; $\text{Trt}_{\text{Bare ground}}$ = 4,3.95; Yr × $\text{Trt}_{\text{Bare ground}}$ = 16,28.3.

[c] When Yr*Trt is significant, Trt *P*-values are for within-year comparisons.

[d] Within-year treatment means followed by the same upper case letter do not differ significantly (α=0.05).

[e] Includes ferns, forbs, and graminoids.

Table 5.2. Percent coverage of important fall and winter northern bobwhite (*Colinus virginianus*) food plants in 1 – 5-yr-old loblolly pine (*Pinus taeda*) plantations under 5 regimens of establishment intensity varying from low (1) to high (5) in the Lower Coastal Plain of Mississippi, 2002 – 2006.[a]

		Treatment					*P*-values [b]		
Year		1	2	3	4	5	Yr	Trt	Yr*Trt
1	$\bar{x}$	16.4	7.7	9.5	2.1	1.6	<0.001	<0.006	0.248
	SE	1.5	2.9	2.7	0.5	0.3			
2	$\bar{x}$	53.6	31.0	49.6	34.4	5.4			
	SE	6.9	9.0	16.1	9.5	2.8			
3	$\bar{x}$	74.6	51.5	58.7	53.5	23.7			
	SE	10.7	11.6	14.7	8.5	7.7			
4	$\bar{x}$	57.8	43.4	44.5	34.3	32.2			
	SE	2.5	9.0	6.5	4.9	3.8			
5	$\bar{x}$	48.0	40.3	37.1	32.6	28.7			
	SE	5.1	3.7	2.2	3.7	2.5			
All	$\bar{x}$	50.1 A [c]	34.8 B	40.0 AB	31.4 BC	18.3 C			
	SE	5.0	4.7	5.6	4.5	3.3			

[a] Actual means presented; analysis performed on log transformed data. *P*-values and treatment differences correspond to least square means.

[b] df were 4,12 for year, 4,13.8 for treatment, and 16,17.9 for interaction.

[c] Treatment means followed by the same upper case letter do not differ significantly (α=0.05).

Table 5.3. Estimates of winter food suitability index[a] for northern bobwhite (*Colinus virginianus*) in 1 – 5-yr-old loblolly pine (*Pinus taeda*) plantations under 5 regimens of establishment intensity varying from low (1) to high (5) in the Lower Coastal Plain of Mississippi, 2002 – 2006.[b]

		Treatment					*P*-values [c]		
Year		1	2	3	4	5	Yr	Trt [d]	Yr*Trt
1	$\overline{x}$	0.44 A[e]	0.18 A	0.20 A	0.02 B	0.01 B	<0.001	<0.001	≤0.001
	SE	0.04	0.06	0.06	0.00	0.00			
2	$\overline{x}$	0.35 AB	0.41 AB	0.33 B	0.51 A	0.15 C		0.008	
	SE	0.06	0.03	0.09	0.05	0.08			
3	$\overline{x}$	0.39	0.46	0.40	0.37	0.46		0.806	
	SE	0.07	0.03	0.07	0.05	0.12			
4	$\overline{x}$	0.36	0.46	0.42	0.47	0.63		0.116	
	SE	0.05	0.06	0.02	0.06	0.02			
5	$\overline{x}$	0.19	0.23	0.19	0.22	0.30		0.725	
	SE	0.02	0.07	0.03	0.06	0.11			

[a] Index values range from 0 – 0.67.

[b] Actual means presented; analysis performed on log transformed data. *P*-values and treatment differences correspond to least square means.

[c] Degrees of freedom were 4,60 for year, 4,15 treatment; 16,60 for interaction.

[d] Treatment values are within-year, year and interaction values are overall.

[e] Within-year treatment means followed by the same upper case letter do not differ significantly (α=0.05).

Table 5.4. Visual obstruction (%) of Nudds' density board in 5 loblolly pine (*Pinus taeda*) plantation establishment treatments in the Lower Coastal Plain of Mississippi, June 2002 – 2006.

		Treatment												
		1		2		3		4		5		*P*-values[b]		
Height	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[c]	Yr*Trt
0.0 – 0.3	1	64.6 A	2.4	60.7 A	3.8	48.0 B	2.5	32.2 C	1.8	31.3 C	2.1	≤0.001	≤0.001	≤0.001
	2	83.6 A	1.5	75.4 A	2.2	79.8 A	1.7	75.4 A	2.2	53.4 B	3.0		≤0.001	
	3	89.2	0.3	83.7	1.4	84.6	1.2	86.3	0.9	84.8	1.0		0.705	
	4	89.9	0.1	87.8	1.0	89.2	0.4	88.7	0.5	89.3	0.4		0.991	
	5	89.1	0.3	88.8	0.5	89.3	0.5	87.8	0.6	85.1	1.4		0.990	
0.3 - 0.6	1	38.1 A	2.6	36.4 A	4.3	20.0 B	2.3	9.9 C	1.6	10.1 C	1.6	≤0.001	≤0.001	≤0.001
	2	78.0 A	2.1	65.2 B	3.1	71.1 AB	2.4	64.8 B	2.6	44.3 C	3.0		≤0.001	
	3	87.9	0.5	79.6	1.8	81.4	1.5	82.4	1.5	80.2	1.7		0.334	
	4	89.9	0.1	86.1	1.5	87.3	1.0	87.3	0.7	88.2	0.7		0.942	
	5	88.1	0.5	86.8	0.7	86.9	0.7	83.9	1.2	81.2	1.9		0.942	
0.6 - 0.9	1	12.9 AB	1.9	19.3 A	3.5	4.8 BC	1.0	2.1 C	0.6	4.0 BC	1.1	≤0.001	0.036	0.035
	2	64.5 A	3.3	54.0 A	3.6	58.4 A	3.0	55.4 A	2.9	37.3 C	2.7		≤0.001	
	3	84.1	1.2	73.7	2.2	75.8	1.9	79.1	1.9	72.5	2.6		0.262	
	4	89.6	0.2	82.8	2.0	85.5	1.4	86.4	1.0	86.7	0.7		0.905	
	5	86.4	0.9	83.8	1.0	83.1	1.1	80.7	1.5	77.9	2.1		0.905	
0.9 – 1.2	1	4.1	1.0	8.9	2.2	1.9	0.6	0.7	0.2	2.2	0.9	≤0.001	≤0.071	0.402
	2	51.0	3.7	41.0	3.4	44.5	3.1	42.3	2.9	30.3	2.1			
	3	78.8	1.9	65.7	2.7	68.6	2.3	72.5	2.5	66.8	3.1			
	4	88.3	0.8	80.7	2.2	84.6	1.4	84.6	1.0	84.9	1.1			
	5	85.6	1.1	82.2	1.2	80.7	1.4	78.4	1.8	77.5	2.1			

Table 5.4. Continued.

		Treatment												
		1		2		3		4		5		*P*-values[b]		
Height	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Yr	Trt[c]	Yr*Trt
1.2 - 1.5	1	1.9	0.6	4.5	1.7	0.8	0.4	0.2	0.1	1.6	0.7	≤0.001	0.062	0.738
	2	40.8	3.3	28.9	2.8	33.3	2.9	33.1	2.5	25.2	1.8			
	3	73.9	2.3	58.5	3.1	62.3	2.6	67.1	3.2	62.4	3.5			
	4	86.9	1.0	77.6	2.7	82.9	1.7	82.3	1.3	83.4	1.5			
	5	85.3	1.0	80.4	1.6	78.5	1.7	76.2	1.7	75.6	2.5			
1.5 - 1.8	1	1.4	0.5	3.2	1.5	0.7	0.4	0.1	0.1	1.1	0.6	≤0.001	0.213	0.492
	2	32.5	3.0	20.4	2.1	25.6	2.8	27.4	2.3	21.4	1.7			
	3	69.3	2.7	51.4	3.5	55.4	2.8	62.5	3.6	60.1	3.6			
	4	85.2	1.3	75.8	2.9	81.7	2.0	81.6	1.6	82.3	1.6			
	5	84.9	1.1	80.0	1.7	77.6	2.0	75.9	1.7	76.2	2.3			

[a] Means within rows followed by the same letter do not differ significantly (α=0.05).

[b] Degrees of freedom for each section were: Yr$_{0.0-0.3}$ = 4,50.2, Trt$_{0.0-0.3}$ = 4,15.9, Yr × Trt$_{0.0-0.3}$ = 16,52.3; Yr$_{0.3-0.6}$ = 4,40.5, Trt$_{0.3-0.6}$ = 4,5.86, Yr × Trt$_{0.3-0.6}$ = 16,30.2; Yr$_{0.6-0.9}$ = 4,43.5, Trt$_{0.6-0.9}$ = 4,7.33, Yr × Trt$_{0.6-0.9}$ = 16,30.1; Yr$_{0.9-1.2}$ = 4,58.3, Trt$_{0.9-1.2}$ = 4,24.3, Yr × Trt$_{0.9-1.2}$ = 16,59.1; Yr$_{1.2-1.5}$ = 4,58.6, Trt$_{1.2-1.5}$ = 4,23.8, Yr × Trt$_{1.2-1.5}$ = 16,59.2; Yr$_{1.5-1.8}$ = 4,12, Trt$_{1.5-1.8}$ = 4,15, Yr × Trt$_{1.5-1.8}$ = 16,17.9.

[c] When Yr*Trt is significant, Trt *P*-values are for within-year comparisons.

Table 5.5. Occurrence of suitable habitat conditions for northern bobwhite (*Colinus virginianus*) in intensively established loblolly pine (*Pinus taeda*) plantations 1 – 5 years post-treatment in the Mississippi Lower Coastal Plain, 2002 – 2006.

	Year				
Treatment[a]	1	2	3	4	5
1	F[b]	F, N	F, L, N	F, L	F
2	F	F	F, L	F, L, N	F, L
3	F	F, N	F, L	F, L, N	F, L
4		F, N	F, L	F, L, N	F, L
5		F	F, L	F, L	F, L

[a] Treatments consisted of: 1 – mechanical site preparation (MSP) and 1 yr of banded herbaceous weed control (HWC); 2 – chemical site preparation (CSP) and 1 yr of banded HWC; 3 – MSP, CSP, and 1 yr banded HWC; 4 – MSP, CSP, and 1 yr broadcast HWC; and 5 – MSP, CSP, and 2 yrs broadcast HWC.

[b] Letters indicate habitat suitability of the treatment for winter food (F), loafing (L), or nesting (N). No treatment produced suitable brood-rearing habitat at any time during years 1 – 5.

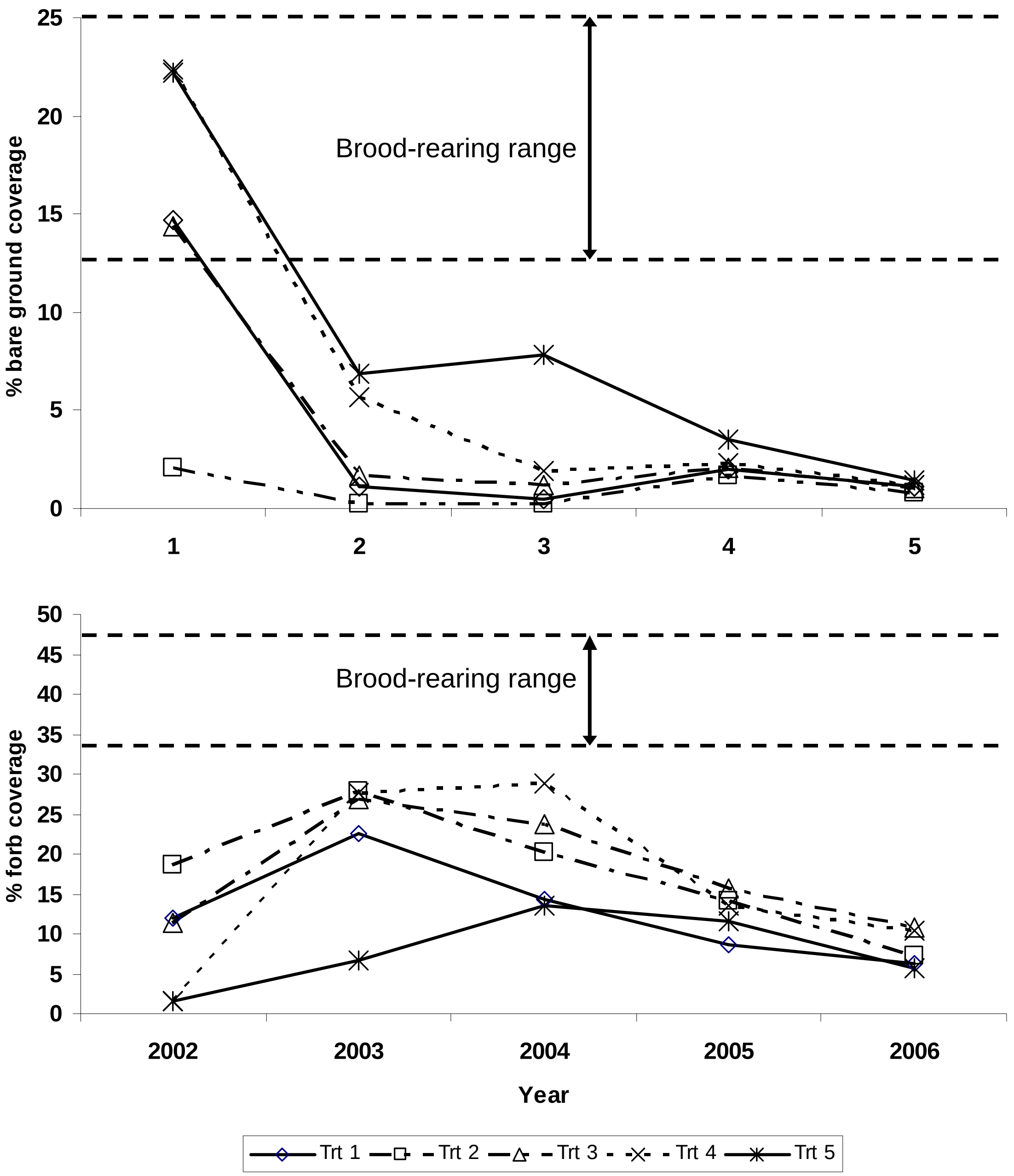

Figure 5.1. Coverage of bare ground and forbs in 5 establishment intensities of loblolly pine (*Pinus taeda*) plantations ranging from low (treatment 1) to high (treatment 5) 1 – 5 years post-treatment in southern Mississippi, 2002 – 2006, compared with ranges of these elements associated with brood-rearing northern bobwhite (*Colinus virginianus*). Combined lack of forb and bare ground coverage within reported ranges for brood-rearing bobwhite indicated that all treatments provided inadequate brood-rearing habitat across all years studied.

CHAPTER 6

FINANCIAL VIABILITIES OF 5 INTENSITIES OF LOBLOLLY PINE (*Pinus taeda*) PLANTATION ESTABLISHMENT IN THE LOWER COASTAL PLAIN OF MISSISSIPPI

ABSTRACT

Intensively managed pine plantations may provide greater returns on investment than unmanaged or lightly managed stands, although with added costs. Financial comparisons of intensive plantation establishment regimes are lacking in the literature. I measured tree growth in 5-year-old loblolly pine (*Pinus taeda*) plantations established using 5 levels of management intensity common to commercial forestry in the southeastern U.S., and used a growth and yield program to project fiber production under scenarios of identical or optimal management. I analyzed financial performance using real discount rates of 5, 7, 9, and 11%, with and without a 50% cost-share payment for site preparation and planting costs. Under identical management, financial metrics were associated negatively with increasing treatment intensity. Net present value (NPV) was positive in the 4 less intensive treatments at the 5, 7, and 9% discount rates; NPV in the most intensive treatment was positive only at 5 and 7%. The addition of cost-share payments improved internal rate of return (IRR) by 1.56 – 2.44% and yielded positive NPVs for the 3 less intensive treatments at the 5 – 11% discount rates; NPVs in the 2 more intensive treatments were positive at the 5 – 9% discount rates. Because optimal management resulted in greater growth in intensive treatments, NPVs were positive for all treatments at the 5 – 9% discount rates. Cost-share payments improved IRR by 1.41 – 2.30% and yielded positive NPVs for all treatments at all discount rates. While increasingly intensive management yielded greater returns from these sites, land managers should avoid instituting actions that do not have a foreseeable positive impact on pine growth or survival on their particular site. Monetary returns may be further enhanced by management actions in mid- and late rotation, and by taking advantage of additional cost-share programs and tax benefits. Educational programs targeting nonindustrial private forest (NIPF) landowners should emphasize monetary incentives available for defraying stand establishment costs and the role of intensive management in producing non-timber products.

INTRODUCTION

Because demand for wood product is projected to remain strong for the foreseeable future, intensively managed pine plantations on private land will continue to be a significant component of the landscape in the southeastern U.S. (Prestemon and Abt 2002). Intensive management includes such actions as mechanical site preparation, herbicide application(s), fertilization, and use of genetically improved seedlings (Siry 2002). Growth response to elements of intensive management have been incorporated into growth and yield models, allowing for financial analyses based on growth projections under varied scenarios. Such analyses have been performed for decisions regarding various elements of intensive management, such as chemical site preparation or herbaceous weed control (HWC) (Busby 1992, Busby et al. 1998), mid- to late-rotation fertilization (Stearns-Smith et al. 1992, Williams and Farrish 2000), improved genetics (McKeand et al. 2006), and thinning (Huang and Kronrad 2002). However, financial analyses involving the use of multiple management elements during the stand establishment phase are lacking.

Nonindustrial private forest (NIPF) landowners control 71% of the 81 million ha of timberland in the South and are responsible for 67% of annual timber harvest (Conner and Hartsell 2002). Intensive pine plantation management is not practiced widely by NIPF landowners relative to industry and timber investment management organizations (Siry 2002, Arano and Munn 2006). This may be attributable to a number of factors: 1) differences in priorities held by NIPF landowners (Siry 2002, Wicker 2002, Conway et al. 2003); 2) smaller ownership sizes (Conner and Hartsell 2002) which may reduce the economic efficiency of management actions (Cubbage 1983, Greene et al. 1997); 3) a lack of knowledge or technical expertise (Zhang et al. 2005), or 4) lack of available capital (Arano et al. 2004).

Intensive management strategies have been shown to drastically increase pine growth (Miller et al. 1995, Borders and Bailey 2001). Gains from separate management actions, such as fertilization and weed control, are often additive in effect (Zutter and Miller 1998, Jokela et al. 2000, Miller et al. 2003), making greater intensity management more economically feasible. Despite greater costs, monetary returns for intensively managed plantations are consistently greater than those from unmanaged, small, or lightly managed stands (Yin and Sedjo 2001, Siry 2002, Allen et al. 2005).

Greater regeneration costs reduce the likelihood that NIPF landowners will actively regenerate harvested stands (Kline et al. 2002, Beach et al. 2005), whereas cost sharing tends to increase planting by NIPF landowners (Alig et al. 1990, Kline et al. 2002). Establishment costs have the longest wait for return on investment of any stand management action, and cost-share programs shift risk away from the landowner. Federal programs such as the Forestry Incentive Program and the Stewardship Incentive Program make cost-share funds available for reforestation, afforestation, or improved forest management; in addition, 8 of 13 southern states offer cost-share programs (Granskog et al. 2002). The monetary benefit associated with available cost-share programs is therefore an important consideration if NIPF landowners are to be fully informed of their management options. The purpose of this study was to investigate the monetary returns associated with financial investments in alternative management regimes used commonly to establish pine plantations in the southern U.S. Given the high percentage of NIPF landowners eligible for cost-share programs, I included cash-flow analyses with and without a cost-share payment for site preparation and planting costs to expand the range of application.

STUDY AREA

I measured loblolly pine (*Pinus taeda*) growth on 5-yr-old stands established at 4 industrial forest sites owned by 3 timber companies in southern Mississippi. Stands were harvested between June 2000 to February 2001, averaged 66 ha in size, and treatment plots were delineated such that each was influenced uniformly by topography and drainages. Residual vegetation communities in post-harvest stands were characterized by

39% coverage of herbaceous plants, 15% coverage of vines, and 19% coverage of woody plants (Edwards 2004). Two soil associations common to the Mississippi Lower Coastal Plain (Pettry 1977) occurred on the 4 stands (United States Department of Agriculture 1995). The McLaurin-Heidel-Prentiss soil association was common to 2 stands and comprised of gently sloping, moderately well-drained sandy and loamy soils. The Prentiss-Rossella-Benndale soil association occurred on 2 stands and was characterized by loamy and fine sandy loam soils.

Treatments were designed to reflect the range of operational intensities used by forest industry, and consisted of combinations of mechanical site preparation, chemical site preparation, and banded or broadcast herbaceous weed control (HWC). Intensive management is often associated with chemical competition control (McCullough et al. 2005), so I correlated treatment number with amount of herbicide used during stand establishment to assign treatments ranging from least (treatment 1) to most (treatment 5) intensive. I assigned randomly each of the 5 treatments to an area ≥8 ha, each treatment occurring once per stand, for a total of 4 replications per treatment in a randomized complete block design. Chemical site preparation was performed during July - August 2001, mechanical site preparation during September - December 2001, and HWC during March - April 2002 (year 1) and March - May 2003 (year 2).

Treatment 1 consisted of mechanical site preparation using a combination plow to subsoil, disk, and bed, pulled behind a bulldozer with a V-blade attached to the front to clear debris. Year 1 HWC consisting of 0.9 kg/ha of Oustar® (E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware; sulfometuron methyl and hexazinone; 13 oz/ac) was applied in a band of 1.5 m width centered on rows of planted pines.

Treatment 2 consisted of chemical site preparation using a mixture of 2.4 L/ha Chopper® Emulsifiable Concentrate (BASF Corp., Research Triangle Park, North Carolina; imazapyr; 32 oz/ac), 3.5 L/ha Accord® (Dow AgroSciences LLC, Indianapolis, Indiana; glyphosate; 48 oz/ac), 3.5 L/ha Garlon 4® (Dow AgroSciences LLC, Indianapolis, Indiana; triclopyr; 48 oz/ac), and 1% volume to volume ratio of Timberland 90® surfactant (UAP Timberland LLC, Monticello, Arkansas) in a broadcast spray solution of 93.6 L/ha (10 gal/ac). Year 1 banded HWC was applied as per treatment 1.

Site preparation for treatment 3 consisted of mechanical site preparation as described for treatment 1 combined with chemical site preparation as per treatment 2. Additionally, banded HWC was applied in year 1 identically to treatments 1 and 2. Treatment 4 consisted of mechanical and chemical site preparation followed by a year 1 broadcast HWC using 0.9 kg/ha of Oustar. Treatment 5 was identical to treatment 4 except for an additional broadcast HWC treatment in year 2.

Apart from these treatments, management was standardized across all plots. Loblolly pines were planted on each site during winter of 2001 – 2002 on a 3.0 × 2.1-m spacing (1,551 trees/ha), with each timber company using its own 1-0 bare root seedlings. Two sites were machine planted, and 2 sites hand planted due to prohibitive amounts of coarse woody debris. Although seedling sources and planting methods differed among sites, they were consistent within sites (i.e., blocks). All stands were fertilized with a broadcast application of 280 kg/ha diammonium phosphate in April 2002.

METHODS

I measured diameter at breast height (dbh) of pines and competing hardwoods in 5 0.01-ha plots within each experimental unit in January 2007. From these data I calculated composite dbh distributions for pines, basal area (BA) estimates of hardwoods, and number of crop trees/ha for each treatment. I entered these data, along with information regarding stand establishment actions, into the PTAEDA3.1 growth and yield program (Burkhart et al. 2004) and projected growth to the end of the rotation (21 – 26 years) for all 5 treatments. I selected PTAEDA3.1 because it is based on data from sites throughout the southeastern U.S., the development of the program in its various iterations is well-documented in the literature, and because earlier versions of the program have been used widely in research on environmental issues (e.g., Schroeder 1991, Luxmoore et al. 1997, Baldwin et al. 2001) and economic projections (e.g., Reisinger 1985, VanderSchaaf and South 2004, Huang et al. 2005). I used a site index of 21.33 m (base age 25), which was equivalent to the average site index on my study sites. The program provided data on yields of pulpwood, chip-n-saw (CNS), and sawtimber from each harvest event. I selected the option to include tops of CNS and sawtimber trees as pulpwood. Due to potential concerns regarding juvenile wood, I classified all material <18 years of age as pulpwood.

I divided the analysis into 2 scenarios. Under the first scenario, I managed all treatments identically after stand establishment. Stands were commercially thinned at age 12 using a fifth row removal and low thinning to reach a target BA of 16.1 m^2/ha. Stands were thinned again at age 18 using a low thin to 16.1 m^2/ha BA, then clearcut harvested at age 25. Under the second scenario, I attempted to maximize land expectation value (LEV; Bullard and Straka 1998) for each combination of treatment and discount rate by allowing some latitude in management strategy and harvesting the stand when it reached financial maturity, potentially resulting in different management regimes. Under this scenario, stands were commercially thinned during the first year in which removals would be ≥56 Mg/ha using a fifth row removal and low thinning to a residual BA of 16.1 m^2/ha. The second thinning was performed when the stand was ≥18 years old and had adequate volume to support removals ≥56 Mg/ha using a low thinning to a residual BA of 16.1 m^2/ha. I calculated LEVs for harvest scenarios at 1-year intervals following the second thinning. Alternatively, I eliminated the second thinning and tested harvest scenarios annually beginning at age 18. In all cases, I mandated final harvest when BA ≥32.2 m^2/ha.

I entered treatment costs and projected revenues into a cash flow model by task and year of occurrence. Costs included stand establishment, fire protection, property taxes, and an opportunity cost based on the alternative land use of pasture rent in Mississippi (National Agricultural Statistics Service 2006); returns included income from harvest events and from a generic hunting lease (Table 6.1). I used regional market data from 2006, averaging across quarters, to determine values for timber products (Timber Mart-South 2007). The value of the hunting lease was a conservative estimate based on a web-based survey of leases offered by 2 corporations with large land holdings in the U.S. South, and lease rates reported for NIPF landowners in Mississippi (Munn et al. 2007) and Alabama (Zhang et al. 2006). Property taxes were a weighted average of rates within the 3 counties which contained my study sites. I estimated establishment costs from Smidt et al. (2005), input from industry foresters, and price lists from a major distributor of forestry chemicals in southern Mississippi. I based fire protection costs on a South-wide average from Smidt et al. (2005). All costs and prices were adjusted to 2006 dollars.

Several financial metrics are available to compare scenarios for potential investors who may consider disparate alternatives to timber management (Bullard and Straka 1998). Net present value (NPV) is calculated by subtracting the present value of rotation costs from the present value of project revenues, using a discount rate representing the desired minimum rate of return. A negative NPV would indicate that the investment did not meet minimum return requirements. Equivalent annual income (EAI) allows direct comparison of longer-term investments with alternative forms of annually realized income, such as agriculture or leasing, through conversion of NPV into an annual income. Internal rate of return (IRR) is the interest rate that equalizes the present values of costs and returns; allowing accept/reject decisions through direct comparison with discount rates. Land expectation value (LEV) is a special case of NPV that does not consider land costs, operating on the assumption that land will be used for growing timber at a set rotation age in perpetuity. For investors buying land for forest management, LEV is equivalent to the maximum price that will allow the landowner to have a rate of return equal to the declared discount rate. I calculated NPV, EAI, IRR, and LEV in the program FORVAL (Straka and Bullard 2006) using real, before-tax discount rates of 5, 7, 9, and 11%. To account for the potential effect of cost-share programs, I conducted all analyses with and without a 50% cost-share payment for site preparation and planting, including the payment as a return in year 1.

RESULTS

Identical Post-establishment Management

Generally, financial outcomes were associated negatively with increasing intensity of stand establishment practices (Table 6.2). Treatment 5 yielded negative NPVs at the 9 and 11% discount rates, while treatments 1 – 4 expressed negative NPVs only for the 11% rate. Greater site preparation costs caused LEVs, NPVs, and EAIs for treatments 1 and 2 to exchange rank as discount rate increased; treatment 1 expressed more desirable results than treatment 2 at a 5% discount rate, and was less desirable than treatment 2 at 7 – 11%. Treatment 2 exhibited the greatest IRR, with the remaining treatments declining in order of intensity level.

Addition of 50% cost-share resulted in a positive NPV for all situations except treatments 4 and 5 at an 11% discount rate (Table 6.3). Treatment 1 ranked greatest in all categories and at all rates. Treatment 2 exhibited a greater IRR than treatments 3 – 5, but greater cost-share payments elevated LEVs, NPVs, and EAIs in treatments 3 and 4 above treatment 2 at the least discount rate. Cost-share improved the IRR from 1.56 – 2.44% across treatments.

Harvest yields averaged across years ranged from 12.3 – 13.9 Mg/ha; they were least in treatment 2, then increased with treatment intensity (Table 6.4). Proportions of product classes were nearly identical across treatments, except that treatment 2 projected slightly lesser proportions of pulpwood and sawtimber than other treatments.

Stands Managed for Financial Maturity

Managing stands for financial maturity allowed for superior growth rates of the more intensive treatments to substantially improve monetary returns when compared with stands under identical management (Table 6.5). More intensive treatments expressed greater improvements in LEVs and shorter rotation lengths than did less intensive treatments. All treatments expressed negative NPVs and EAIs at the 11% discount rate only. Treatment 5 bypassed a second thinning at all discount rates, whereas most other treatment-rate combinations performed better with a second thinning. Treatment 2 yielded greater IRRs than other treatments across all discount rates.

Addition of cost-share resulted in positive NPVs for all evaluations (Table 6.6). Optimal management schedules were altered only slightly in treatments 4 and 5, while management in treatments 1 – 3 remained unchanged. Improvements in IRR ranged from 1.41 – 2.30%, and averaged highest in treatments 3 and 4.

DISCUSSION

Treatment Elements

Given the incremental increases in establishment intensity, it is possible to examine the financial efficacy of individual management actions used in the establishment phase by comparing treatments which differ in one management element. Mechanical site preparation cost $84.34/ha more than chemical (treatment 1 vs. 2), yet provided roughly equivalent returns by producing greater wood volume through improvement of site-specific soil physical properties , and was made superior over chemical site preparation by the inclusion of cost-share payments. The combination of chemical and mechanical site preparation again increased production over either single site preparation method (treatment 3 vs. 1 and 2), but with the additional cost of either \$286.32 or \$370.65/ha. This disadvantage was improved by cost-share payments alone, and overcome using either the optimal management strategy or the combination of optimal management and cost-share.

Increasing establishment intensity by moving from banded to broadcast HWC (treatment 3 vs. 4) was beneficial only under optimal management regimes. Single-year broadcast HWC showed consistently better returns than the 2-year application (treatment 4 vs. 5). The comparative ease with which increases in site preparation costs were overcome compared with increased HWC costs can be attributed to the lack of cost-share payments for HWC applications. However, cost-share for HWC is commonly available and, if used, would likely make the second broadcast application at least cost-neutral.

Financial Considerations

No single management regime will be appropriate for all potential site conditions. For example, plantations in this study were established on recently harvested sites with a large residual component of woody plants that was largely controlled by the chemical site preparation (Edwards et al. 2006). However, plantations established on retired agricultural fields or pastures are unlikely to benefit substantially from chemical site preparation targeting woody competitors, and application under such scenarios would be wasteful. Mechanical site preparation may be most appropriate on sites where managers need to address site-specific issues related to soil properties. Soils on my study sites were prone to compaction, yielding poor drainage and potentially increasing seedling mortality and inhibiting root system development. Mechanical site preparation was designed to break the compacted layer and create raised beds, improving both drainage and rooting environment. Regardless of initial conditions, even the least intensive management regime was sufficient to successfully establish a fully stocked plantation on my sites. Increasing establishment intensity beyond that point may still be financially advantageous, as long as growth is improved enough to justify additional investment.

Across all treatments, the rate of wood production generally improved enough with increasing management intensity to more or less keep pace with rising costs, especially when site preparation and planting received cost-share payments. However, financial restrictions, or aversion to risk, may prevent some NIPF landowners from meeting the greater capital demands of more intensive regimes, in which case viable alternatives were still afforded by less costly treatments. For example, optimal management for both treatments 1 and 4 without a cost-share payment yielded an average IRR of 9.9%, though stand establishment costs were $351.18/ha less in treatment 1. Land managers should therefore be careful to avoid increasing intensity where additional management actions have no foreseeable positive impact on pine growth or survival.

Costs associated with intensive management are in constant flux. Increasing natural gas prices have resulted in fertilizer costs greater than when these stands were originally fertilized in 2002 (Huang 2007), and increasing fuel costs will likely result in greater application costs for machine-applied treatments (Bair and Alig 2006). Conversely, costs for some chemicals may decrease as generic forms become available following the loss of patent protection. Given that herbicide costs accounted for 74% of the cost of chemical site preparation, a substantial drop in herbicide price may increase the financial attractiveness of chemical site preparation or early rotation release treatments.

Cost sharing may be an important incentive for NIPF landowners to actively regenerate harvested stands (Alig et al. 1990, Kline et al. 2002). Costs of stand establishment in my study were high, ranging from \$606.67 - \$1,188.60/ha over years 1 - 3. Several federal and state cost-share programs exist which may provide 40 – 60% of the cost of site preparation, tree planting, and stand improvement activities such as HWC (Granskog et al. 2002). Federal tax law allows for the deduction of reforestation costs for qualifying timber property up to \$10,000/year with amortization of remaining costs over the following 8 years, thereby increasing after-tax LEVs (Straka and Greene 2007). Tax incentives for reforestation also may be available from various states; for example, Mississippi currently offers an income tax credit of up to \$10,000 for reforestation under appropriate conditions (Gaddis 1999). While I only considered the benefits of cost-share payments for site preparation and planting, NIPF landowners who use additional cost-share opportunities and tax incentives should be able to further improve their monetary returns.

Economies of scale dictate that highly mechanized harvest crews will be less efficient as harvest units become smaller (Cubbage 1983, Toms et al. 2001). Average tract size of private forest land is decreasing as more ownerships are created from a relatively static forest land base (DeCoster 1998, Mehmood and Zhang 2001). As a result, smaller tracts, such as those typically owned by NIPFs, may receive less interest in the marketplace (Greene et al. 1997). Small-scale equipment may suffer from lower productivity, but can be more cost-efficient than large-scale equipment on smaller tracts

(Updegraff and Blinn 2000). The success of intensive management on small tracts may hinge on the availability of low-capital harvesting systems to serve this niche in an economically efficient fashion. Harvesting firms in other portions of the U.S. have adapted to serving NIPF landowners (Rickenbach and Steele 2005, 2006), and mechanized systems specializing in smaller tract harvest are in development and testing (Wilhoit and Rummer 1999). Some NIPF landowners also have been served by companies using animal-powered logging (Toms et al. 2001) or modified agricultural or construction equipment (Office of Technology Assessment 1983).

Landowner expectations of return drive investment in forest management. Mississippi landowners who had harvested timber on their properties within the previous 5 years stated 8.9% as a minimum acceptable real rate of return for a 15-year investment in forest management, roughly equivalent to their minimum acceptable real rate of return for investment in stocks, bonds and mutual funds (Bullard et al. 2002). Minimum acceptable rates for 25-year forest management were 10.7% (Bullard et al. 2002). I chose to use discount rates that would bracket these and thus allow for a broad array of landowner expectations.

Stand Management Considerations

Although I considered treatment 2 as more intensive than treatment 1, year 5 stand measurements used for input into PTAEDA3.1 yielded a superior diameter distribution and mean dbh for treatment 1. Mechanical site preparation is used commonly in the Coastal Plain to improve rooting environments (Miwa et al. 2004), and it had a greater impact on early growth in this study than did chemical site preparation (Edwards et al. 2006).

The strictures I placed on managing for financial maturity were designed to be a realistic reflection of management and market realities facing NIPF landowners. While lesser tonnage thresholds would have allowed for earlier thinnings, I considered the 56 Mg/ha requirement, roughly equivalent to 1 truckload/0.4 ha, a reasonable threshold for making logging operations financially attractive to prospective bidders on smaller properties (Johnson et al. 2003). Although intensively managed loblolly pine quickly reaches sawtimber dimensions, such wood often exhibits inferior structural qualities due to high proportions of juvenile wood (Kretschmann and Bendtsen 1992, Ying et al. 1994). Consequently, I imposed delaying the second thinning to ≥18 years to ensure that most mills would treat trees 20.5 – 31.0 cm dbh as CNS, rather than relegating them to pulpwood status with the consequent loss of 70% in value. I considered the upper BA limit of 32.2 m^2/ha reasonable, as such a stand would probably be considered overstocked and subject to increased risk from diseases and insect pests (Hedden 1978, Brown et al. 1987). During growth projection without a second thinning, the BA limit was reached in all treatments during a period where CNS-sized trees were rapidly progressing to more valuable sawtimber. If allowed to continue beyond this limit, LEVs would have been slightly greater in all treatments for the 5 and 7% discount rates, resulting in more optimal management regimes without a second thinning.

I used a site index based on the average of my study sites. Stands with a lesser SI would almost certainly produce lower returns if managed identically to my treatment sites, and stands with a higher SI might well produce high-value products earlier in rotation, improving their rate of return (Huang et al. 2005).

The generalized management strategies I used following the initial differences in stand establishment allow for further management actions to improve returns on investment. Mid- or late-rotation fertilization may improve the growth rate of greater value sawtimber, effectively increasing NPV (Williams and Farrish 2000, Fox et al. 2007). Chemical removal of substantial hardwood competition in post-thinning stands also may increase pine growth (Clason 1984, Shelton and Murphy 1997, Caulfield et al. 1999), and might have proved beneficial in treatments 1 and 2, which had 10 and 8% hardwood BA, respectively, at age 5. Also, I did not test across different planting densities, which could alter thinning regimes and development of different timber products (Huang et al. 2005).

Non-timber Forest Products

Timber and non-timber forest products (NTFP) are produced by NIPF landowners (Newman and Wear 1993, Pattanayak et al. 2002, Kendra and Hull 2005), who commonly mention such benefits as wildlife habitat, aesthetics, and a sense of stewardship as important reasons for owning their property (Haymond 1988, Kluender and Walkingstick 2000, Kendra and Hull 2005). Intensive management may be perceived as negatively impacting such ecosystem services (Gan et al. 2000), especially given the general public perception of herbicide use as environmentally unsound. However, NTFP values can be provided by intensively managed stands (Miller and Miller 2004). By reducing land area needed to produce a given income, intensive management may enable landowners to manage smaller portions of their holdings primarily for timber, leaving the remainder available for other management objectives (Allen et al. 2005). Additionally, many intensive management techniques focus on vegetation control, and can be used to improve timber yield while simultaneously targeting wildlife habitat improvements (Edwards et al. 2004, Wagner et al. 2004).

The period between stand establishment and crown closure is important for wildlife species dependent on early seral stages, and stand establishment procedures used in this study resulted in a wide range of habitat structures (Hanberry 2007, Jones 2008). Retention of snags and remnant unmerchantable trees in stands with chemical preparation only (e.g., treatment 2) may provide vital habitat structure for many bird species, increasing avian species richness and abundance compared with mechanically prepared sites (Darden 1980, O'Connell and Miller 1994, Hanberry 2007). In this study, banded HWC provided very nearly equivalent tree growth to broadcast treatment, but also exhibited a better winter foraging environment for northern bobwhite (*Colinus virginianus*) comparable to results from less intensively established stands (Jones 2008). Nutritional carrying capacity for white-tailed deer (*Odocoileus virginianus*) benefited from chemical site preparation, which allowed nutritious forbs to develop in treatments limited to banded HWC (treatments 2 and 3); by contrast, treatment 1 promoted the quick reestablishment of low quality browse, with consequently lesser nutritional carrying capacity (Edwards 2004, Jones 2008).

MANAGEMENT IMPLICATIONS

Intensive pine plantation management has the potential to be a financially viable source of income for forest landowners in the Mississippi Lower Coastal Plain. The addition of widely available cost-share assistance and thoughtful management made even the most intensive stand establishment regime financially viable. Selection of appropriate methods for stand establishment will vary in accordance with landowner objectives, site characteristics, and capital availability. Lower intensity treatments may be more appropriate for those with concerns over wildlife habitat and biodiversity, but should still provide substantial returns competitive with higher intensity establishment methods.

Measells et al. (2005) found that NIPF landowners in 4 southern states were underserved and recommended comprehensive outreach programs targeting landowners within reasonable distances of educational programs. Programs emphasizing the potential non-timber benefits of intensive management could help eliminate misconceptions as to its impacts on characteristics important to NIPF landowners. The availability of cost-share programs and tax benefits for defraying regeneration costs and improving financial performance should also be stressed (Greene et al. 2004).

New technologies are needed to serve the growing numbers of small forest landowners (DeCoster 1998). Technical progress toward efficient harvesting systems for small tracts should be pursued to provide financially attractive alternatives to conventional high-capital options. Logging contractors and entrepreneurs should be encouraged to invest in equipment and training that will enable them to compete in this growing market. Increasing interest in cellulosic biofuels may provide greater incentives for harvesting smaller tracts and consequent investment in appropriate equipment.

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Table 6.1. Costs and revenues ($/Mg or $/ha) for forest management activities used to project monetary returns from intensively established loblolly pine (*Pinus taeda*) plantations in the Mississippi Lower Coastal Plain (2006 dollars).

Source	Cost ($/ha)	Net revenue ($/ha)	Net revenue ($/Mg)	Timing
Cost-share				
Treatment 1		263.66		Year 1
Treatment 2		221.49		Year 1
Treatments 3 - 5		406.81		Year 1
Fertilizer	74.13			Year 1
Fire protection	1.85			Annually
Harvest				
Chip-n-Saw			22.14	Variable
Pulpwood			6.56	Variable
Sawtimber			38.25	Variable
Hunting lease		22.00		Annually
Opportunity cost	40.77			Annually
Planting	156.66			Year 0
Property tax	10.18			Annually
Site preparation				
Mechanical	370.65			Year 0
Chemical	286.31			Year 0
Weed control				
Banded	89.57			Year 1
Broadcast (Yr 1)	154.44			Year 1
Broadcast (Yr 2)	146.41			Year 2

Table 6.2. Financial results from projected growth of 5 loblolly pine (*Pinus taeda*) plantations managed identically[a] following establishment under different levels of intensity ranging from low (1) to high (5) in southern Mississippi, without cost-share (2006 dollars).

		Discount rate			
Treatment	Metric[b]	5%	7%	9%	11%
1	LEV ($/ha)	3,277.40	1,591.50	738.44	253.85
	NPV ($/ha)	1,723.50	816.13	248.00	-110.89
	EAI ($/ha)	122.29	70.03	25.25	-13.17
	IRR (%)	10.28%	10.28%	10.28%	10.28%
2	LEV ($/ha)	3,255.49	1,610.55	778.98	307.19
	NPV ($/ha)	1,708.06	831.67	283.84	-61.48
	EAI ($/ha)	121.19	71.37	28.90	-7.30
	IRR (%)	10.57%	10.57%	10.57%	10.57%
3	LEV ($/ha)	3,143.33	1,402.63	519.56	16.34
	NPV ($/ha)	1,629.02	662.06	17.46	-330.92
	EAI ($/ha)	115.58	56.81	5.55	-39.29
	IRR (%)	9.23%	9.23%	9.23%	9.23%
4	LEV ($/ha)	3,112.48	1,364.93	477.65	-28.37
	NPV ($/ha)	1,607.28	631.30	17.46	-372.34
	EAI ($/ha)	114.04	54.17	1.78	-44.21
	IRR (%)	9.07%	9.07%	9.07%	9.07%
5	LEV ($/ha)	2,974.85	1,240.55	360.77	-140.16
	NPV ($/ha)	1,510.29	529.84	-85.87	-475.90
	EAI ($/ha)	107.16	45.47	-8.74	-56.51
	IRR (%)	8.66%	8.66%	8.66%	8.66%

[a] All stands were commercially thinned at age 12 and 18, clearcut harvested at age 25.

[b] Abbreviations are: LEV – land expectation value; NPV – net present value; EAI – equivalent annual income; IRR – internal rate of return.

Table 6.3. Financial results from projected growth of 5 loblolly pine (*Pinus taeda*) plantations managed identically[a] following establishment under different levels of intensity ranging from low (1) to high (5) in southern Mississippi (2006 dollars), with cost-share.[b]

Treatment	Metric[c]	Discount rate			
		5%	7%	9%	11%
1	LEV ($/ha)	4,037.70	2,142.41	1,176.80	623.70
	NPV ($/ha)	2,259.28	1,265.54	635.52	231.74
	EAI ($/ha)	160.30	108.60	64.70	27.52
	IRR (%)	12.72%	12.72%	12.72%	12.72%
2	LEV ($/ha)	3,554.83	1,864.30	1,008.83	522.58
	NPV ($/ha)	1,919.00	1,038.67	487.04	138.06
	EAI ($/ha)	136.16	89.13	49.58	16.39
	IRR (%)	12.13%	12.13%	12.13%	12.13%
3	LEV ($/ha)	3,693.12	1,868.70	941.74	411.95
	NPV ($/ha)	2,016.46	1,042.26	427.72	35.57
	EAI ($/ha)	143.07	89.44	43.55	4.22
	IRR (%)	11.23%	11.23%	11.23%	11.23%
4	LEV ($/ha)	3,662.28	1,831.00	899.83	367.25
	NPV ($/ha)	1,994.72	1,011.50	390.68	-5.84
	EAI ($/ha)	141.53	86.80	39.77	-0.69
	IRR (%)	10.96%	10.96%	10.96%	10.96%
5	LEV ($/ha)	3,524.64	1,706.62	782.95	255.46
	NPV ($/ha)	1,897.73	910.04	287.35	-109.40
	EAI ($/ha)	134.65	78.09	29.25	-12.99
	IRR (%)	10.35%	10.35%	10.35%	10.35%

[a] All stands were thinned at age 12 and 18, clearcut harvested at age 25.

[b] Cost-share amounts were 50% of site preparation and planting cost.

[c] Abbreviations are: LEV – land expectation value; NPV – net present value; EAI – equivalent annual income; IRR – internal rate of return.

Table 6.4. Commodity production (Mg/ha) and value ($/ha) from projected growth of 5 loblolly pine (*Pinus taeda*) plantations managed identically[a] following establishment under different levels of intensity ranging from low (1) to high (5) in southern Mississippi.

		Commodity				
Treatment	Age	Pulpwood	Chip-n-Saw	Sawtimber	Value	Trees/ha[b]
1	12	66.3	0.0	0.0	479.81	1,227
	18	7.8	46.8	0.0	1,200.13	439
	25	29.3	2.5	162.3	7,126.81	257
2	12	56.3	0.0	0.0	406.86	1,234
	18	9.0	47.1	0.0	1,213.71	463
	25	30.9	13.2	150.8	6,907.38	267
3	12	79.1	0.0	0.0	572.20	1,232
	18	7.2	51.1	0.0	1,299.21	413
	25	26.9	0.0	172.4	7,462.78	238
4	12	82.9	0.0	0.0	599.76	1,230
	18	6.5	53.8	0.0	1,360.00	396
	25	25.3	0.0	172.6	7,460.88	231
5	12	89.9	0.0	0.0	650.01	1,239
	18	5.8	53.1	0.0	1,338.72	382
	25	24.0	0.0	174.1	7,517.31	224

[a] All stands were commercially thinned at age 12 and 18, clearcut harvested at age 25.
[b] Pre-harvest.

Table 6.5. Financial results from projected growth of 5 loblolly pine (*Pinus taeda*) plantations managed for financial maturity following establishment under different levels of intensity ranging from low (1) to high (5) in southern Mississippi, without cost-share (2006 dollars).

Treatment	Harvest[b]	Rate (%)	Metric[a]			
			LEV ($/ha)	NPV ($/ha)	EAI ($/ha)	IRR (%)
1	12, **26**	5	3,215.87	1,714.44	119.26	9.56
	12, 19, **24**	7	1,513.19	740.40	64.55	10.02
	12, 19, **23**	9	690.30	199.45	20.82	10.07
	12, 19, **22**	11	221.38	-137.93	-16.87	10.06
2	12, 18, **26**	5	3,288.88	1,766.91	122.91	10.49
	12, 18, **24**	7	1,612.11	819.17	71.42	10.66
	12, 18, **24**	9	791.14	290.67	29.95	10.66
	12, 18, **22**	11	324.48	-45.21	-5.53	10.65
3	11, **23**	5	3,319.86	1,676.44	124.29	9.38
	11, 18, **23**	7	1,517.83	730.16	64.78	9.60
	11, 18, **21**	9	619.99	133.53	14.37	9.64
	11, 18, **21**	11	111.50	-234.28	-29.01	9.64
4	11, 18, **24**	5	3,588.81	1,901.43	137.80	9.82
	11, 18, **22**	7	1,686.53	846.29	76.51	9.95
	11, 18, **21**	9	724.74	221.14	23.80	9.99
	11, 18, **21**	11	165.33	-187.47	-23.09	9.99
5	11, **23**	5	3,481.48	1,785.44	132.37	9.17
	11, **23**	7	1,506.81	721.35	63.99	9.17
	11, **23**	9	510.47	44.40	4.63	9.17
	11, **21**	11	-38.74	-367.74	-45.54	9.12

[a] Abbreviations are: LEV – land expectation value; NPV – net present value; EAI – equivalent annual income; IRR – internal rate of return.

[b] Numbers indicate age of stand at harvest. **Bolded** numbers indicate age at final harvest.

Table 6.6. Financial results from projected growth of 5 loblolly pine (*Pinus taeda*) plantations managed for financial maturity following establishment under different levels of intensity ranging from low (1) to high (5) in southern Mississippi (2006 dollars), with cost-share.[a]

			Metric[b]			
Treatment	Harvest[c]	Rate (%)	LEV ($/ha)	NPV ($/ha)	EAI ($/ha)	IRR (%)
1	12, **26**	5	3,565.23	1,965.55	136.73	10.97
	12, 19, **24**	7	1,820.91	986.81	86.04	11.65
	12, 19, **23**	9	970.85	441.34	46.07	11.75
	12, 19, **22**	11	485.50	99.61	12.18	11.80
2	12, 18, **26**	5	3,597.03	1,977.86	137.59	12.00
	12, 18, **24**	7	1,869.94	1,026.17	89.47	12.27
	12, 18, **24**	9	1,023.75	493.88	50.88	12.27
	12, 18, **22**	11	546.36	154.33	18.88	12.38
3	11, **23**	5	3,894.33	2,063.88	153.01	11.38
	11, 18, **23**	7	1,999.67	1,110.36	98.5	11.75
	11, 18, **21**	9	1.066.27	506.75	54.54	11.94
	11, 18, **21**	11	524.10	132.21	16.37	11.94
4	11, 18, **24**	5	4,150.37	2,288.87	165.88	11.82
	11, 18, **21**	7	2,178.03	1,203.45	111.07	12.18
	11, 18, **21**	9	1,169.06	594.36	63.96	12.18
	11, 18, **20**	11	581.94	180.54	22.67	12.22
5	11, **23**	5	4,055.95	2,172.88	161.09	10.87
	11, **23**	7	1,988.65	1,101.54	97.72	10.87
	11, **22**	9	947.22	414.38	43.88	10.95
	11, 18, **22**	11	375.61	0.78	0.09	11.00

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[a] Cost-share payments were 50% of site preparation and planting cost.

[b] Abbreviations are: LEV – land expectation value; NPV – net present value; EAI – equivalent annual income; IRR – internal rate of return.

[c] Numbers indicate age of stand at harvest. **Bolded** numbers indicate age at final harvest.

CHAPTER 7

SYNTHESIS AND RECOMMENDATIONS

Pine plantations are an important part of timber management in the South, with over 500,000 ha planted annually (Siry 2002). At least half of these plantations receive herbaceous weed control, and >80% receive chemical site preparation (Dubois et al. 2003). This widespread use of multiple herbicide applications substantiates the need for research to quantify and qualify impacts of such standardized methods. Because forest land is expected to meet objectives beyond mere fiber production, forest landowners have an interest in understanding the varied results of potential management options.

Although treatments used in this study were designed to be incrementally more or less intensive, there were 2 sets of comparisons that appeared to account for most of the observed differences. The choice of site preparation method(s) was of vital importance due to its impact on the plant community as a whole and cost. Broadcast versus banded herbaceous weed control (HWC) was less of a financial issue, except for double application, but had substantial impact on habitat metrics.

Pine growth in years 1 – 5 was improved through increased establishment intensity, via control of herbaceous competition and improved rooting environment provided by mechanical site preparation (MSP). Chemical site preparation (CSP) reduced long-term woody competition and increased projected volume. Though greater intensity improved yield, the greatest monetary returns were realized through CSP with banded HWC due to lesser establishment cost. However, all treatments produced financially viable results, and differences were small. It seems that management intensity properly tailored to site conditions should be capable of producing a profitable stand of timber under current market conditions.

While growth and yield models are useful tools, there is still uncertainty as to the response of trees past crown closure, when interspecific competition becomes more intensive than intraspecific. Growth gains realized through HWC may or may not be retained through mid-rotation (Lauer et al. 1993, South et al. 2006). This study provides an opportunity to investigate the long-term impact of stand establishment management by continuing to measure tree performance throughout rotation, especially if identical management regimes continue to be used at all sites.

Vegetation diversity and richness were decreased by herbicide use. Chemical site preparation particularly impacted woody species and vines, and pushed succession back to an earlier seral stage than did MSP. By eliminating a substantial portion of the resulting herbaceous community, broadcast HWC reduced diversity and richness relative to banded HWC in the years it was applied, and promoted faster dominance by the pines. Residual vines and woody plants were prominent in treatments with MSP only, which served to reduce the presence of herbaceous plants. Though CSP reduced plant diversity and richness at the stand level, the resulting early seral community it produces may serve to increase gamma diversity in pine plantation landscapes so long as HWC is limited to banded applications. By year 5, community differences were decreasing. However, because treatments were approaching crown closure at different speeds, differences may increase briefly as more intensive treatments shade out understory plants before less intensive treatments. Vegetation monitoring should therefore continue until crown closure occurs on all sites.

Among treatments tested in my study, northern bobwhites were best served by combined MSP and CSP, followed by banded HWC. While this treatment exhibited a fairly typical progression of providing various types of habitat during succession, brood-rearing habitat was not supplied by this or any other treatment. Although the stand establishment regimes tested in my study had the advantage of providing information from incremental increases in management intensity, they did not represent all possible scenarios. Prescribed burning is still used commonly in some regions as a site preparation tool, and may provide seed scarification and bare ground necessary to produce better brood-rearing habitat for northern bobwhite than any of the methods applied in this study. Broadcast disking likewise increases bare ground exposure and promotes early herbaceous communities. Both methods should be investigated in factorial experiments with chemical site preparation and, at most, banded HWC application, to examine possible benefits to northern bobwhite.

Lactating does exhibit the greatest growing season demand of any class of deer. Treatments 2 and 3, both of which applied CSP and banded HWC, provided the greatest levels of nutritional support to meet this demand. Even so, forage quality necessary for lactating does was limited across all treatments, possibly due to the generally low soil fertility found in the Lower Coastal Plain resulting in only a small number of plants capable of supplying substantial crude protein or digestible energy. Given the relatively low nutritional plane and the short-term value of the treatments, it is apparent that supplying adequate nutrition for deer in pine plantation-dominated landscapes will require a larger-scale approach. Results from this study should be combined with those from studies performed in mid- and late-rotation pines under intensive management to model nutritional carrying capacity across the managed forest landscape.

Forage plants in other soil resource regions of Mississippi have shown greater levels of crude protein (P. Jones, Mississippi State University, unpublished data). Total forage value (TFV) was intended as a potential index for nutritional carrying capacity that would reduce the effort necessary to evaluate the forage resource in a given area. However, TFV results were not correlated with carrying capacity estimates for lactating does, and are therefore of limited use in this region. Analysis of similar data from other soil regions may determine whether and when such an index might prove accurate, and therefore useful.

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