Deer Forage Response to Herbicide and Fire in Mid-Rotation Pine Plantations

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ABSTRACT Mid-rotation management practices for pine (*Pinus* spp.) plantations enrolled in cost-share programs have not been widely evaluated for wildlife. Mid-rotation pine plantations often have a substantial hardwood mid-story that limits growth of desirable understory forage species important to white-tailed deer (*Odocoileus virginianus*; deer). We treated with imazapyr herbicide and prescribed burning (HB) 11 thinned, 13–22-year-old loblolly pine (*P. taeda*) plantations in the Upper Coastal Plain (UCP; $n = 5$) and the Lower Coastal Plain (LCP; $n = 6$) of Mississippi, USA, enrolled in cost-share programs. We then sampled these plantations for production of important deer forages during July of 2003 and 2004, years 1 and 2 posttreatment. Deer foraging habitat was clearly improved by the HB treatment in both regions by year 2. Forb species of annual importance to deer increased in percent cover and biomass in the UCP and in biomass in the LCP. We estimated nutritional carrying capacity using a target diet quality of 14% crude protein; estimates in HB plots were 3 times greater than controls in the UCP and 19 times greater in the LCP. Although UCP sites had baseline carrying capacities nearly 8 times greater than LCP sites, the greater relative response to HB in the LCP eliminated the regional difference. Our results indicate that imazapyr herbicide treatment followed by prescribed fire is a beneficial tool for deer management in mid-rotation pine plantations. (JOURNAL OF WILDLIFE MANAGEMENT 73(5):663–668; 2009)

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Enrollments in federal cost-share programs designed to create and maintain wildlife habitat have increased steadily throughout the life of the Conservation Reserve Program (CRP), with nearly 15 million ha enrolled in 2007 (Farm Service Agency 2008). Management practices creating grassland cover have been evaluated for their impact on grassland birds (McCoy et al. 1999, Haroldson et al. 2006), northern bobwhite (*Colinus virginianus*; Greenfield et al. 2002), and waterfowl (Reynolds et al. 2001). In the southern United States, establishing pine (*Pinus* spp.) plantations is a more popular practice, and many plantations are at or near an age where mid-rotation management is essential to maintain productivity. However, in spite of concerns regarding the perceived lackluster performance of these plantations in providing habitat (Allen et al. 1996, Carmichael 1997), there is as yet little information evaluating the habitat potential of these plantations.

Pine plantations can be managed using thinning, selective herbicides, and prescribed fire to alter the understory plant community. Within mature pine stands, ground-level production of forage plants important to white-tailed deer (*Odocoileus virginianus*; deer) is increased by thinning (Blair and Enghardt 1976, Peitz et al. 2001) and mid-story removal (Blair and Feduccia 1977, Masters et al. 1996). Use of selective herbicide and prescribed fire can increase high-quality forages in mature pine stands (Edwards et al. 2004, Jones and Chamberlain 2004, Welch et al. 2004). Edwards et al. (2004) reported that a treatment combination of imazapyr, prescribed fire, and fertilizer increased deer nutritional carrying capacity 38-fold in mature pine stands by removing the hardwood mid-story and enhancing growth of understory plants.

Cost-share programs such as the CRP defray costs of establishing timber stands on lands that were once marginal crop land. Because plant communities in pine plantations established on retired agricultural land may differ substantially from those in stands established on previously forested sites (Hedman et al. 2000), results from previous studies may be of limited application to plantations enrolled in cost-share programs. In the coastal states from Virginia to Texas, USA, >126,000 ha were established in CRP pine tree plantings from 1996 to 2008, meaning an average of nearly 10,000 ha/year will become eligible for mid-rotation management cost-share programs in coming years (Farm Service Agency 2008). Program administrators need information on mid-rotation management impacts to facilitate promotion of wildlife habitat quality.

Determining worth of a pine plantation as wildlife habitat must include species-specific habitat needs (Allen et al. 1996). The treatment combination of imazapyr and prescribed burning is authorized as a mid-rotation cost-share by the United States Department of Agriculture (USDA) Natural Resource Conservation Service and the Mississippi Forestry Commission (USDA 2003). Our goal was to determine if the positive effects of the selective herbicide imazapyr and prescribed fire on deer foraging habitat reported in mature natural pine stands (Edwards et al. 2004) was applicable for habitat quality enhancement during mid-rotation in plantations established on retired

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agricultural land and in other soil physiographic regions in Mississippi.

STUDY AREA

We studied plant communities and deer forage production on 11 mid-rotation loblolly pine (*Pinus taeda*) plantations of $\geq$18.2 ha located in the Upper Coastal Plain (UCP; $n = 5$) and Lower Coastal Plain (LCP; $n = 6$) of Mississippi, USA, areas known to differ in mineral soil richness (Pettry 1977). The climate was subtropical, with long-term annual means of 17.5° C and 148 cm rainfall (National Oceanic and Atmospheric Administration 2008). All stands were enrolled in either the CRP or Forest Incentives Program, were 13–22 years old, and had been thinned 1–6 years prior to treatment. Dominant woody competitors were sweetgum (*Liquidambar styraciflua*) on the UCP sites and Chinese privet (*Ligustrum sinense*) in the LCP. Previous agricultural uses in both regions included a mixture of row-cropping (wheat, corn, sorghum, and soybeans) and pasture. One LCP site was altered by wildfire prior to the second field season and we excluded it from analysis for that year. Pretreatment stand conditions (trees/ha; $\bar{x}$, min., max. dbh; mean total ht; basal area and vol/ha) were similar between treated and control sites (Sladek et al. 2008).

METHODS

We treated stands as blocks and established 2 8-ha plots within each stand to which we randomly assigned treatment. We left one plot as an undisturbed control; treatment to the second plot consisted of imazapyr application followed by prescribed burning (hereafter, HB). We applied imazapyr by skidder during October–December 2002 as Arsenal AC® (BASF Corp., Research Triangle Park, NC; 1.2 L) mixed with Red River Forestry Oil® (Red River Specialties, Inc., Shreveport, LA; 0.85 L) in 187 L of solution per treated ha. We applied prescribed fire during January–March 2003. We conducted burns under the following conditions: temperature of 4–18° C, 40–60% relative humidity, wind speed of $\leq$8 km/hour, and a mixing height $\geq$500 m.

We composed a list of potential deer forages 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). We recorded coverage of moderate to high use (i.e., rank of 3 or 4) understory herbaceous and woody forage plants during June 2003–2004 using 12 randomly placed 30-m line transects (Canfield 1941) in each experimental unit, then grouped species into 5 forage classes (nonleguminous forbs, grasses, legumes, vines, and woody species) for analysis. We estimated growing season production of moderate- to high-use deer forages during July 2003 and 2004 using 18 1-m^2 exclosures (Harlow 1977) in each experimental unit. Exclosures were located at a random distance (1–40 m) and azimuth from 9 plot centers located in a 3 $\times$ 3 grid with a spacing of 81 $\times$ 101 m. We clipped and weighed leaves and growing stem tips from 0 m to 1.5 m above ground to represent consumable plant portions for each species. We collected and dried known-weight field samples of each species in a forced-air oven at 60° C for 72 hours, then we reweighed them to determine wet:dry mass. We assigned species to forage classes and extrapolated dry weight forage biomass on a kg/ha basis. We compiled composite samples of each forage species for each region $\times$ treatment combination and analyzed them for nitrogen content using the Kjeldahl procedure to determine percent crude protein (CP) on a dry-matter basis (Jurgens 2002). We assumed that leaf biomass accurately represented the amount of forage potentially consumable by deer, and estimated carrying capacity (deer-days/ha) using the explicit nutritional constraints model (Hobbs and Swift 1985). We assumed a daily dry matter intake of 1,360 g (Edwards et al. 2004), which is within the range of intake rates of white-tailed deer in the southern United States (Fowler et al. 1967, Asleson et al. 1996, Campbell and Hewitt 2005). Lactating females experience the greatest nutritional demands among adult deer during the growing season, and July–August represents the peak lactation period for females in Mississippi (Jacobson et al. 1979). Although energy may be a limiting factor, endogenous fat reserves may be used to bridge the gap between lactation requirements and actual diet quality. However, milk production may be more directly tied to current protein intake (Bahnak et al. 1979), and low N intake by the dam reduces neonatal viability in deer (Sams et al. 1995). We therefore selected a target diet quality of 14% CP, which is considered the minimum requirement to support a lactating female with one fawn (Verme and Ullrey 1984). We assumed that CP content of forages accurately compared relative plant quality between treatments, in spite of the potential effects of plant secondary compounds such as condensed tannin (Hanley et al. 1992).

To quantify a treatment's capacity to produce important deer forage regardless of nutritional quality, we calculated a total forage value (TFV) by multiplying coverage $\times$ use rating for each forage species rated 3 or 4, then summing the products within each experimental unit to yield one value, similar to Edwards (2004) and Jones et al. (2009). We compared these values with the nutritional carrying capacity estimates to compare treatment rankings between the 2 methods.

We used a repeated-measures, mixed-model analysis of variance to test for main effects of treatment and year and treatment $\times$ year interactions for percent coverage by forage type, leaf biomass by forage type, nutritional carrying capacity, and TFV. We compared means between treatments ($n = 2$) and years ($n = 2$) in SAS PROC MIXED (SAS Institute Inc., Cary, NC). We treated stands (i.e., block; $n = 5$ in the UCP, $n = 6$ in LCP_{2003}, and $n = 5$ in LCP_{2004}) as the random effect, years as the repeated effect, and treatment $\times$ stand as the subject. We chose a first-order autoregressive covariance structure because there was one time interval between sampling periods (Littell et al. 2006). We considered differences significant if $P < 0.05$. We used LSMEANS SLICE to identify a treatment effect within years following a significant interaction (Littell et al. 2006).

Table 1. White-tailed deer understory forage classes that differed between treatment with imazapyr herbicide followed by prescribed fire and an untreated control in thinned, mid-rotation loblolly pine plantations at years 1 and 2 posttreatment in the Upper Coastal Plain of Mississippi, USA, 2003–2004.[a]

Understory forage classes	Treatment		Control		
	$\bar{x}$	SE	$\bar{x}$	SE	P[b]
% cover (yr)					
Forb (1 and 2)	16.3	1.5	7.2	0.7	≤0.001
Grass (2)	13.1	1.7	3.2	0.8	≤0.001
Vine (1 and 2)	17.5	1.8	46.5	2.9	≤0.001
Woody (1 and 2)	2.3	0.4	11.1	1.3	0.048
Biomass (kg/ha)					
Forb (1 and 2)	112.4	15.8	48.6	7.8	0.016
Vine (1)	44.9	10.5	138.0	21.9	0.003
Woody (1 and 2)	12.3	3.8	63.0	14.0	0.038

[a] Actual means presented. We performed some analyses using square-root–transformed data.
[b] P-values correspond to least-square means.

Table 2. White-tailed deer understory forage classes that differed between treatment with imazapyr herbicide followed by prescribed fire and an untreated control in thinned, mid-rotation loblolly pine plantations at years 1 and 2 posttreatment in the Lower Coastal Plain of Mississippi, USA, 2003–2004.[a]

Understory forage classes	Treatment		Control		
	$\bar{x}$	SE	$\bar{x}$	SE	P[b]
% cover (yr)					
Grass (2)	27.2	2.5	1.8	0.5	≤0.001
Vine (1 and 2)	21.5	2.0	31.5	2.1	0.046
Woody (1 and 2)	8.3	1.1	25.5	1.9	0.003
Biomass (kg/ha)					
Forb (2)	171.6	40.4	15.3	5.2	0.005
Grass (2)	216.7	35.1	19.7	8.4	≤0.001

[a] Actual means presented. We performed some analyses using square-root–transformed data.
[b] P-values correspond to least-square means.

When main effects were significant, we conducted pair-wise tests using Fisher's protected least significant difference with the LSMEANS PDIFF option (Littell et al. 2006). We tested normality and equal variance assumptions prior to each analysis and square-root–transformed variables with nonequal variances (Zar 1999). For ease of interpretation, we present actual means although we often conducted analyses on transformed data.

RESULTS

Biomass and coverage of forage classes responded similarly to HB in the UCP (Table 1). Biomass and coverage of forbs increased by >2-fold and those of woody species decreased by 80%. Vine coverage was reduced in both years by 62%, and vine biomass was reduced by 67% in year 1. Grass coverage in HB plots increased nearly 3-fold between years ($P = 0.017$) and was 4 times greater in HB plots than in controls in year 2. Coverage of both vines and woody species increased 3-fold between years 1 and 2 posttreatment ($P \leq 0.001$).

Forage classes in the LCP (Table 2) responded similarly to those in the UCP. Grass coverage and biomass in HB plots increased between years ($P \leq 0.001$) by 15- and 94-fold, respectively, whereas controls remained unchanged. In year 2, grass coverage and biomass were 15 and 11 times greater, respectively, in HB plots than in controls. Treatment with HB reduced vine coverage by 10% and woody coverage by 17% but did not affect biomass in either class. Although forb coverage was similar regardless of treatment, biomass in HB plots was 11 times greater than controls in year 2. Coverage of vines ($P = 0.015$) and biomass of woody species ($P \leq 0.001$) more than doubled between years regardless of treatment, and biomass of vines in HB plots tripled between years ($P \leq 0.001$).

We estimated nutritional carrying capacity using biomass and nutritional parameters from 35 forage species or species groups, including 12 forbs, 1 grass (*Dicanthelium* spp.), 1 legume, 10 vines, and 11 woody species. Crude protein values ranged from 6.9% to 22.4%. Treatment effects on deer foraging habitat varied depending on estimation method. In the UCP, nutritional carrying capacity was 3 times greater in HB plots ($\bar{x} = 115$ deer-days/ha, SE = 20; $P = 0.023$) than in controls ($\bar{x} = 38$ deer-days/ha, SE = 11); TFV did not vary with treatment ($P = 0.300$). In the LCP, TFV again did not vary with treatment ($P = 0.989$); however, nutritional carrying capacity was 18 times greater in HB plots ($\bar{x} = 97$ deer-days/ha, SE = 34; $P \leq 0.001$) versus control plots ($\bar{x} = 5$ deer-days/ha, SE = 3).

DISCUSSION

The selective herbicide and prescribed fire treatment effectively increased forages of annual importance to white-tailed deer in both soil resource regions. Treatment reduced mid-story hardwood coverage from 25% to 1% in the UCP and from 59% to 4% in the LCP (Sladek 2006), increasing available sunlight at ground level. Other studies in mid-rotation southern pines have also reported reduced hardwood mid-story and enhanced herbaceous growth following selective herbicide and prescribed fire treatment (Harrington et al. 1998, Harrington and Edwards 1999, Woodall 2005).

Greater presence of nutritious forbs in the imazapyr–prescribed-fire treatment improved deer foraging habitat in both regions, providing both similar forage quantity and increased forage quality compared to controls. Although forage grasses and vines were abundant, their contribution to nutritional carrying capacity was limited by their low CP content. Ten of 13 forb and legume species had >14% CP; conversely, only 1 of 23 grass, woody, or vine species had >14% CP. Furthermore, 7 of the 9 forb species in the LCP were found only in HB plots. Forb species occurrence was more similar between controls and HB plots in the UCP, but greater forb biomass in HB plots allowed more, lower quality forages to be included in carrying capacity models. Forb response was similar to a reported 2.5-fold increase following imazapyr and prescribed fire in mature pine stands (Welch et al. 2004). A similar treatment consisting of imazapyr, prescribed fire, and fertilizer in 45-year-old to 50-

year-old naturally regenerated pine stands increased nutritional carrying capacity 38-fold (Edwards et al. 2004); however, that increase was nearly evenly attributable to greater biomass of legume, vine, and shrub species, rather than increased forb biomass alone.

Strickland and Demarais (2000) reported that deer from the LCP weighed less and had smaller antlers than deer from the UCP. Similar associations have been reported between deer body and antler size and specific soil nutrients (Jacobson 1984). The inherent habitat quality difference between the LCP and UCP can be visualized by comparing their respective untreated nutritional carrying capacity estimates: the LCP is roughly one-eighth of the UCP. However, the HB treatment reduced that difference, producing roughly equal posttreatment nutritional carrying capacity estimates in each region. Although there may be inherent regional variations in forage quality (Jones et al. 2008), effective habitat management may ameliorate these effects.

The nutritional constraints model is limited in that it considers only one dietary nutrient, selected due to its potential as a limiting factor. Although energy may be a limiting factor for deer under some circumstances (Parker et al. 1999), research in Mississippi has shown that protein is potentially more limiting in pine stands and that typically lower soil fertility in the LCP reduces CP content of forages relative to other soil regions without affecting energy content (Jones et al. 2008, 2009; S. Demarais, Mississippi State University, unpublished data). A second limitation is that our samples represent only one season, although nutritional requirements vary seasonally, with age, and with reproductive status. Seasonal differences in CP are common among deer forages (Smith et al. 1956, Thorsland 1966, Fuller 1980, Meyer and Brown 1985, Jones et al. 2008) and reflect predictable seasonal growth cycles (Chapin 1980, Mattson 1980). Jones et al. (2008) reported CP in important deer forages throughout Mississippi averaged 6.4% greater in April than in July. Applying that as a constant to our July results suggests that treated stands would be more likely to meet springtime nutritional demands for growing yearlings (Holter et al. 1979). Because adult deer have lower protein requirements for both body and antler growth (French et al. 1956, Magruder et al. 1957, Robbins 1993, Asleson et al. 1996), springtime carrying capacity would likely be correlated with forage biomass. Because there is no way to infer the presence and thus the impact of winter annuals, winter forage conditions are more difficult to predict. However, seasonal variation in deer nutrient requirements would likely best be served by the treated stands, which provided a combination of high-quality forbs available throughout the growing season with a moderate amount of autumn and winter browse species.

Incorporating forage quality using the nutritional carrying capacity model prevents overestimations of carrying capacity by explicitly addressing diet quality, not just nutrient availability (Hobbs and Swift 1985). Forage surveys are commonly used in management of ungulates because of an assumed relationship between forage measurement(s) and carrying capacity, and deer habitat has been assessed using variables such as percent cover or biomass (Blair and Enghardt 1976, Mackie 2000, Rooney 2001, Horsley et al. 2003, Higgins et al. 2005). Previous studies comparing habitat rankings from nutritional carrying capacity and TFV in the LCP failed to show correlation between the 2 methods at diet-quality levels of 12–14% CP, but did find correlations using a maintenance diet of 6% CP (Edwards 2004, Jones et al. 2009). Because all forages we evaluated had CP >6%, nutritional carrying capacity at a maintenance level would also have correlated with TFV. Thus it appears that the utility of forage survey methods such as TFV may in general be limited to lower levels of target diet quality.

The potential duration of the improved foraging habitat will be influenced by future stand management. Without periodic disturbance, woody browse will grow beyond reach of deer and a fire-resistant hardwood mid-story will gradually reemerge. Haywood et al. (2001) found that a long-term regime of biennial burns eliminated development of hardwood mid-story trees in longleaf pine (*Pinus palustris*) stands while increasing understory herbaceous plant production by 90 times over unburned stands. Harrington and Edwards (1999) noted that a prescribed fire 3 years after thinning and herbicide application stimulated further herbaceous response to woody control. These results accord with recommendations of a 2–5-year burn cycle for maintaining deer forages in southern pine forests (Lewis and Harshbarger 1976, Wade and Lunsford 1989, Main and Richardson 2002). Increasing pine basal area may also reduce understory productivity and thus lower carrying capacity through time. Carrying capacity in our study was unrelated to pine basal area, which ranged from 14.3 m^2/ha to 21.0 m^2/ha. However, nutritional carrying capacity in northern Mississippi loblolly plantations more than doubled in plots with 11.5 m^2/ha pine basal area compared with plots averaging 25.3 m^2/ha (B. Strickland, Mississippi State University, unpublished data). Additional periodic thinning may be necessary to maintain understory light penetration requirements for continued forage production.

Mid-rotation management with imazapyr and prescribed fire should be an attractive option to many landowners, both for wildlife management and improved tree growth. Control of woody competition using herbicides at mid-rotation has been shown to substantially improve pine growth, making such treatments financially viable over a broad spectrum of market conditions, particularly when the practice is approved for cost-share status (Fortson et al. 1996, Caulfield et al. 1999, McInnis et al. 2004). In addition to improved deer foraging environment, we found improved habitat for avian species of conservation concern (Singleton 2007). Similar studies in Mississippi pine forests have shown that mid-story removal and restoration of a 2-layered vegetation structure (i.e., overstory and early succession understory) benefit species traditionally associated with pine forests (Burger et al. 1998, Woodall 2005).

MANAGEMENT IMPLICATIONS

Allen et al. (1996) criticized CRP and other USDA cost-share programs that use tree-planting practices as being ineffectively managed and poor wildlife habitat and recommended that the USDA require periodic management. Our results support use of selective herbicide and prescribed fire to improve deer foraging habitat in mid-rotation pine plantations enrolled in cost-share programs. The imazapyr–burn treatment effectively combined the advantages of each action, reducing the mid-story hardwood component and creating a 2-tiered habitat structure favorable to understory forages important to deer. Because the method encouraged growth of highly nutritious forbs, the imazapyr–burn treatment should be especially encouraged in areas where low soil fertility may otherwise limit carrying capacity.

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