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Research Article

Forage Availability for White-Tailed Deer Following Silvicultural Treatments in Hardwood Forests

MARCUS A. LASHLEY, *Graduate Research Assistant, Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, TN 37996, USA*

CRAIG A. HARPER,[1] *Professor, Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, TN 37996, USA*

GARY E. BATES, *Professor, Department of Plant Sciences, University of Tennessee, Knoxville, TN 37996, USA*

PATRICK D. KEYSER, *Associate Professor, Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, TN 37996, USA*

ABSTRACT Closed-canopy upland hardwood stands often lack diverse understory structure and composition, limiting available nutrition for white-tailed deer (*Odocoileus virginianus*) as well as nesting and foraging structure for other wildlife. Various regeneration methods can positively influence understory development; however, non-commercial strategies are needed to improve available nutrition in many stands, as some contain timber that is not ready to harvest and others are owned by landowners who are not interested in harvesting timber. Applications of herbicide and prescribed fire have improved availability of food and cover for deer and other wildlife in pine (*Pinus* spp.) systems. However, this strategy has not been evaluated in hardwood systems. To evaluate the influence of fire and herbicide treatments on available deer forage in upland hardwood systems, we measured forage availability and calculated nutritional carrying capacity (NCC) at 14% crude protein mixed diet, following 7 silvicultural treatments, including controls, in 4 mixed upland hardwood stands July–September 2007 and 2008. We compared NCC among forest treatments and within 4 paired warm-season forage food plots to evaluate the usefulness of food plots in areas where forests are managed. Nutritional carrying capacity estimates (deer days/ha) were greatest following canopy reduction with prescribed fire treatments in both years. Understory herbicide application did not affect species composition or NCC 1 year or 2 years post-treatment. Production of forage plantings exceeded that of forest treatments both years with the exception of early-maturing soybeans and retention cut with fire 2 years post-treatment. We encourage land managers to use canopy reducing treatments and low-intensity prescribed fire to increase available nutrition and improve available cover where needed in upland hardwood systems. In areas where deer density may limit understory development, high-quality forage food plots may be used to buffer browsing while strategies to reduce deer density and stimulate the forest understory are implemented. © 2011 The Wildlife Society.

KEY WORDS food plots, forage availability, prescribed fire, silviculture, understory herbicide applications, upland hardwoods, white-tailed deer.

Forest understory structure and composition influence presence and abundance of several wildlife species (Casey and Hein 1983, de Calesta 1994). Closed-canopy forests often lack food and cover resources for many species that require a well-developed forest understory (de Calesta 1994, Johnson et al. 1995, Edwards et al. 2004, Jackson et al. 2007). Chronic overbrowsing by white-tailed deer (*Odocoileus virginianus*; hereafter deer) can decimate a forest understory and reduce available nutrition for body maintenance and productivity. Overbrowsing also degrades habitat quality for other species (Casey and Hein 1983, Tilghman 1989, de Calesta 1994, Rossell et al. 2005). A reduction in deer density is often recommended to ameliorate the situation, but even after population reduction, restoration of the forest understory is limited until sufficient sunlight is available to stimulate the seedbank and support vegetation response (Anderson and Katz 1993, Webster et al. 2005, Rossell et al. 2007, Shaw et al. 2010).

Silviculture can have a profound effect on forest understory structure and composition and the associated nutritional carrying capacity (NCC) for white-tailed deer (Beck and Harlow 1981, Masters et al. 1993, Edwards et al. 2004, Mixon et al. 2009). Regeneration methods, such as clearcutting and shelterwood harvest, alter the forest canopy, allow increased light to the forest floor, and stimulate increased forage availability. Stand improvement practices, or improvement cuttings, remove trees of less desirable species, poor form, and poor condition to favor better trees and

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[1]*E-mail: charper@utk.edu*

improve stand quality, composition, structure, health, and growth (Smith 1986, Nyland 2002). Improvement cuttings are often implemented to improve conditions for wildlife as well as tree growth and may produce a response similar to regeneration methods, depending on the intensity of treatment (Beck and Harlow 1981, Peitz et al. 2001). These treatments can be especially important where deer density has exceeded NCC and negatively altered the forest understory (de Calesta 1994, Edwards et al. 2004).

The historical role and occurrence of fire in the Appalachian region has been documented (Abrams 1992, Delcourt and Delcourt 1997, Signell et al. 2005, Cohen et al. 2007). Frequent low-intensity fires burned much of the southern Appalachians except protected coves and drains. Although much of the published work has focused on the effects of fire exclusion and wildfire, documentation of the effects of prescribed fire in upland hardwoods has focused primarily on oak (*Quercus*) regeneration and non-game wildlife (Brose et al. 1999, Ford et al. 2002, Greenberg et al. 2007*a*, 2007*b*). Interestingly, there is little documentation on the effects of prescribed fire in Appalachian hardwoods following partial canopy removal (Pack et al. 1988, Jackson et al. 2007), and none as related to available nutrition for deer. Wildlife managers and private landowners could benefit from this information, especially given the impact of deer and fire on the structure and composition of the forest understory and that much of the eastern United States is dominated by upland hardwood forests.

Along with canopy reduction and prescribed fire, herbicide treatments have been used in pine (*Pinus*) systems to improve the forest understory for deer and other species. Edwards et al. (2004) reported herbicide release encouraged better-quality forages and increased forage availability in intensively managed open-canopy pine plantations by retarding woody regeneration, eliminating the mid-story stratum, and allowing sunlight to the forest floor to encourage increased herbaceous growth. Mixon et al. (2009) found fire and herbicide treatment in mid-rotation loblolly pine (*Pinus taeda*) stands exponentially increased NCC, especially on poor sites. Similar data evaluating the effects of canopy reduction in conjunction with prescribed fire and broadcast understory herbicide applications on forage availability for deer in hardwood systems have not been reported.

Considering the importance of the forest understory to support deer and other wildlife species in upland hardwood systems and the potential for such application in the Appalachian region, information on the effect of various regeneration and stand improvement practices on forage availability for deer is needed. Consideration for stand improvement practices is particularly important in stands that do not contain merchantable timber or that are owned by landowners who have no interest in harvesting timber but are willing to improve existing stand conditions for wildlife (English et al. 1997, Guo and Hodges 2009).

Forage food plots are commonly promoted to provide supplemental nutrition for deer (Koerth and Kroll 1998, Yarrow and Yarrow 2005, Harper 2008). Supplemental nutrition may sustain a high deer density even after forage availability in adjacent forests has been depleted (Doenier et al. 1997, Cooper et al. 2002, Brown and Cooper 2006). However, a well-managed forest should support the nutritional requirements of deer at low-to-moderate densities without the need of food plots. Edwards et al. (2004) reported forage availability for deer following thinning, herbicide release, and prescribed fire in loblolly pine stands was similar to that within food plot plantings, which is an important consideration for land managers, given the expense and time commitment with planting and managing food plots. Appropriately managed upland hardwood stands could produce similar results and reduce the need for planting food plots.

Our objectives were to evaluate the effect of understory disturbance (prescribed fire and broadcast understory herbicide applications) following commercial (shelterwood harvest) and non-commercial (retention cutting) overstory reduction on forage availability for deer in upland hardwoods. We hypothesized NCC for deer would be increased following fire and herbicide treatments and that herbicide application would transition species composition of the understory from being dominated by woody species to herbaceous species.

STUDY AREA

We conducted our study across 4 upland hardwood stands on the Chuck Swan State Forest and Wildlife Management Area (CSF) in Union, Campbell, and Anderson counties, Tennessee within the Southern Appalachian Ridge and Valley physiographic province. The Tennessee Division of Forestry (TDF) and the Tennessee Wildlife Resources Agency (TWRA) jointly managed CSF. Chuck Swan State Forest and Wildlife Management Area encompassed 9,892 ha and was 92% forested with the remaining acreage in mowed fields, wildlife food plots, logging decks, and maintained roads. Hardwood stands were managed on an 80-year rotation with clearcutting the primary regeneration method. Stands ranged 0–200+ years in age. Sandstone ridges with 15–30% northwest-facing slopes 365–490 m in elevation characterize the topography of the oak (Quercus)-hickory (*Carya*) forest. Most soils on the study area were classified in the Clarksville Fullerton Claiborne association. Temperatures ranged from a yearly average high of 20.4° C to a yearly average low of 7.9° C. The area received approximately 1,200 mm of rain per year (National Oceanic and Atmospheric Administration 2008).

Common overstory trees included white oak (*Quercus alba*), chestnut oak (*Q. montana*), northern red oak (*Q. rubra*), black oak (*Q. velutina*), southern red oak (*Q. falcata*), scarlet oak (*Q. coccinea*), mockernut hickory (*Carya tomentosa*), pignut hickory (*C. glabra*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), yellow-poplar (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), and American beech (*Fagus grandifolia*), with scattered shortleaf pine (*Pinus echinata*). Sassafras (*Sassafras albidum*), dogwood (*Cornus florida*), pawpaw (*Asimina triloba*), and sourwood (*Oxydendrum arboreum*) were common in the midstory. Species common to the understory included greenbrier (*Smilax* spp.), lilies

(*Liliaceae* spp.), poison ivy (*Toxicodendron radicans*), Virginia creeper (*Parthenocissus quinquefolia*), wild grape (*Vitis* spp.), blackberry (*Rubus* spp.), blueberry (*Vaccinium* spp.), panicgrasses (*Dicanthelium* spp.), and violets (*Viola* spp.).

Surveys conducted by the TWRA estimated approximately 10–12 deer/km^2. Herd management included a draw hunt system following state regulations. The average annual deer harvest at CSF had been approximately 3–4 deer/km^2 since 2005 (Tennessee Wildlife Resources Agency 2009).

METHODS

Treatments

We used a randomized block design, blocking on forest stand to minimize variation caused by site differences. To ensure independence, stands selected for study were located in separate drainages and were 11–26 km apart. Stands were 9.6 ha each and divided into 12 0.8-ha treatment units. We randomly assigned 7 treatments to experimental units within each stand. Pre-treatment basal area ranged from 20 to 24 m^2/ha. Treatments included shelterwood (S), shelterwood with fire (SF), retention cut with fire (RF), retention cut with herbicide application (RH), retention cut with herbicide and fire (RHF), fire only (F), and control (C). We replicated S, SF, RF, F, and C treatments twice in each stand. Retention cut with herbicide application and retention cut with herbicide and fire treatments occurred only once in each stand because the herbicide was applied in experimental units that were formerly unburned retention cuts. We assigned treatment randomly to the previously unburned retention cuts to establish RH and RHF.

Shelterwood is an even-aged regeneration method characterized by a series of partial commercial harvests. Trees are left in the overstory to shelter developing regeneration and are removed usually 6–8 years after initial harvest (Smith 1986). We completed 4 S harvests in each stand, June through July 2001. The objective of the harvests was to reduce basal area to 13 m^2/ha and provide shelter for advance regeneration. Overstory trees were scheduled for harvest in 2010. Wildlife value was not a factor in harvest selection. In April 2005, we burned 2 S treatment units in each stand.

Retention cutting usually is a non-commercial stand improvement operation, where undesirable tree species are killed or felled. We completed a retention cut on 4 units in each stand during February 2001. We burned 2 units in each stand during early April 2001. Basal area was reduced to 13 m^2/ha in treatment units. We retained trees based on species, form, crown class, and size. We retained white and red oaks for acorn production, and we retained blackgum and black cherry (*Prunus serotina*) for soft mast production. We also retained scattered American beech for hard mast production. Red maple, sugar maple, sourwood, and yellow poplar were species commonly killed by girdling and hack-and-squirt using a 1:1 Garlon®-3A (5.2 kg triclopyr/L) (DowAgroSciences, Indianapolis, IN)–water mixture in the wound. We cut down undesirable <13 cm diameter at breast height and treated stumps with the herbicide mixture. We burned RF units again in April 2005 and 2007. A backpack-spray crew broadcast 11.7 L/ha of Garlon® 4 (6.9 kg triclopyr/L) (DowAgroSciences) to the understory of the unburned retention cut units in June 2006. We randomly selected one RH unit per stand and burned it (RHF) in April 2007.

We implemented fire treatments in April 2001, 2005, and 2007. We conducted all prescribed fire treatments under the following conditions: temperature 6–20° C, 20–40% relative humidity, wind speed of 5–10 km/hr, and a mixing height of >500 m. For all controlled burns, we initially set backing fires and burned the remainder of the units using short strip-heading fires to maintain low intensity. We used low-intensity strip-heading fires generating 15–45 cm flame heights during all prescribed burns. Damaging overstory hardwoods with fire is often a concern among forest managers. We used low-intensity early growing-season fire at CSF to consume the litter layer and set back succession without damaging valuable overstory trees. We took precautionary measures by removing large debris from the base of desirable trees prior to burning. Previous research has shown heat maintained in burning large debris adjacent to the base of a tree may damage the cambium and consequently decrease timber value or even kill the tree (Brose and Lear 1999).

For food plot treatments, we used 3 food plot plantings in each of 4 openings that were adjacent to one of the forest stands and that were similar in slope, aspect, size, and prior land use. Plantings consisted of 4.6 maturation soybeans (*Glycine max*), iron-and-clay cowpeas (*Vigna sinensis*), and lablab (*Lablab purpureus*), planted 11 June 2007, and 3 varieties of soybeans (4.6, 5.6, and 7.0 maturation), planted 7 June 2008. Maturation groups characterize the time required for soybeans to mature. Larger group numbers indicate longer duration to maturity. Each field was relatively square, 1.5–2 ha, and surrounded by woods on all sides. We amended sites with ag-lime to adjust pH and fertilized them to adjust phosphorus and potassium levels according to soil tests.

Sampling

We randomly placed 3 1.2-m × 1.2-m × 1.2-m woven-wire panel exclusion cages in each forest treatment unit. We collected forage—all leaf biomass from woody species and entire herbaceous plants (excluding large stems)—by species within cages and within 3 paired randomly placed un-caged plots. There were 2 sampling periods: early July through mid-August and late August through September in each 2007 and 2008. Sampling mimicked herbivory observed on site (i.e., we clipped only leaves and tender shoots and excluded mature plant parts). These methods allowed consistent sampling and comparison between forest plants and forage plantings. We moved and randomly placed each cage after each sampling period. We marked each sampled area to avoid re-sampling a plot.

We randomly placed 4 0.6-m × 0.6-m × 1.2-m exclusion cages in each food plot planting and collected all forage, except for large stems, for caged as well as 4 un-caged samples. We sampled in July, August, and September

2007 and July, August, September, and October 2008. We moved and randomly placed each cage after each sampling period. We marked each sampled area to avoid re-sampling a plot.

We dried all samples to constant mass in an air-flow dryer at 50° C, ground them using a 1-mm-mesh mill, and sent them to SURE-TECH™ Laboratories (Indianapolis, IN) for crude protein (CP) analysis using traditional chemical methods (wet chemistry) in 2007 and 2008. SURE-TECH™ Laboratories was certified by the National Forage Testing Association.

We calculated estimates of NCC using potential deer forages identified in the literature (Harlow and Hooper 1972, Warren and Hurst 1981) and from selected species determined by browse transects that recorded use of understory herbaceous and woody forage plants by deer (Table 1). We randomly placed one 50-m transect within each treatment unit at each site ($N = 48$). Three systematic plots were located along each transect with plots centered on 10 m, 25 m, and 40 m. We counted stems by species and noted evidence of deer herbivory within a 1.2-m × 1.5-m area around plot center (Shaw 2008). We ranked species as selected if they were selected by deer as or more than would be expected based on availability (Neu et al. 1974). We calculated NCC using the explicit nutritional constraints model (Hobbs and Swift 1985) to determine treatment effects on deer-days of foraging capacity during the growing season. We determined NCC per hectare based on a 14% CP mixed diet, which is considered the minimum requirement to support a lactating female with one fawn (Verme and Ullrey 1984, Jones et al. 2009). We considered CP the most appropriate metric to determine NCC during the growing season, as there is a large protein burden on females at this time that must be met through their diet rather than body reserves (Sadleir 1987). The protein requirement for lactation during the growing season is considered greater than the energy requirement (Barboza and Parker 2008) and the difference in digestible energy requirement between maintenance and lactation are of less magnitude (2.2 kcal/g vs. 3.25 kcal/g dry matter) than the difference in CP requirement (6% vs. 14% CP; Jones et al. 2009). We assumed deer eat about 1.36 kg dry weight of biomass per day (Holter et al. 1979). Because not all of the selected species were >14% CP content, we mixed the maximum amount of forage available from the selected species until the 14% threshold was met. We then calculated NCC by dividing each treatment total by 1.36 kg, which provided deer-days per hectare. It is important to note we did not use or consider our NCC estimate as an absolute estimate of carrying capacity, but rather a biologically sound relative comparison among treatments (Hobbs and Swift 1985).

Analysis

We calculated production for forest treatments and food plot plantings for comparison. We calculated production by adding the first period to the additional biomass produced in the subsequent period (current period caged sample minus previous period uncaged sample). We added the first period of caged production to the production of each additional period for an overall production estimate. There were no differences between caged and uncaged plots or periods in the forest treatments in either year of the study. Thus, we assessed cost per additional kilogram by dividing the total cost of the treatment by the average amount of dry matter forage avail-

Table 1. Crude protein (CP) values of species we included in the nutritional constraints model for white-tailed deer, Chuck Swan State Forest and Wildlife Management Area, Tennessee, USA, August 2007 and 2008.

Common name	Species	CP% 2007	CP% 2008
American pokeweed	*Phytolacca americana*	11.06	29.81
Tick-trefoil	*Desmodium* spp.	16.95	20.9
Grape	*Vitis* spp.	10.96	20.16
Virginia creeper	*Parthenocissus quinquefolia*	11.23	14.42
Wild yam	*Dioscorea villosa*	10.02	13.76
Blackberry	*Rubus* spp.	10.08	13.12
Greenbrier	*Smilax* spp.	10.85	12.65
Blackgum	*Nyssa sylvatica*	12.61	11.24
Strawberrybush	*Euonymus americana*	9.71	11.06
Mapleleaf viburnum	*Viburnum acerfolium*	7.23	7.23
Hogpeanut	*Amphicarpa bracteata*	[a]	[a]
Bedstraw	*Gallium* spp.	8.55	8.55
Flowering dogwood	*Cornus florida*	8.52	18.05
Yellow-poplar[b]	*Lireodendron tulipifera*	10.6	12.46
Sourwood[b]	*Oxydendron arboreum*	9.48	11.54
Japanese honeysuckle[b]	*Lonicera japonica*	12.86	12.86
Blueberry[b]	*Vaccinium* spp.	7.76	9.21
Maples[b]	*Acer* spp.	7.81	10.87
Oaks[b]	*Quercus* spp.	10.2	18.56
Sumac[b]	*Rhus* spp.	10.34	10.34
Poison ivy[b]	*Toxicodendron radicans*	10.52	10.52
Sassafras[b]	*Sassafras albidum*	11.34	13.78

[a] Data not collected because species contribution was negligible.
[b] Additional species noted in Harlow and Hooper (1972) and Warren and Hurst (1981).

able minus the average amount of dry forage available in C. We extrapolated cost per additional kilogram for forest treatments over 2 years using the same cost with combined means from both years because treatment cost was not recurring. We calculated cost per additional kilogram for total forage available and selected species. We assessed food plots by dividing production by the cost incurred from planting. Cost of food plots was recurring because forages were annuals, so each year of production was assessed separately.

For forest treatments, we conducted a repeated measures analysis of variance (ANOVA) using SAS 9.13 (SAS Institute, Cary, NC). The experiment was a randomized block design with incomplete replication in each stand. The only treatments that were not replicated in each stand were RH and RHF. We used the Tukey's Honestly Significant Difference multiple comparison test to compare means at $\alpha = 0.05$ when we detected a year by treatment interaction. The fixed effect was treatment × period × year. Site × treatment × period was the random effect. Data were normal in all analyses ($W = 0.95$ for total forage production, $W = 0.94$ for production of selected forage, $W = 0.96$ for NCC). Shapiro and Wilk's W-statistic is a test for normality in a dataset with 1.00 being perfectly normal. In both years, we pooled periods and caged and un-caged samples to calculate means after initial tests showed no differences ($P = 0.94$ and 0.90).

For food plot plantings, we conducted a repeated measures ANOVA. The experiment was a randomized block design with replication across fields. Fixed effects were species × cage × period. The random effect was species × replication × site. The data were normal both years ($W = 0.94$ and 0.98). Caged and un-caged samples were different in 2007 ($P = 0.032$) and similar in 2008 ($P = 0.713$); therefore, we did not pool them.

We conducted another repeated measures ANOVA to compare production of forested treatments to production with food plots. The data were normal in both years ($W = 0.93$ and 0.91). We calculated production of forested treatments and food plots to allow comparison in a single model.

RESULTS

Total forage available (standing crop) in the RF and SF treatments was >3× that in C in 2007 (Table 2). In 2008, total forage available in RF and SF increased and exceeded that in all other treatments. Total forage available in F also increased in 2008 and exceeded that available in C. Forage available from selected species during 2007 followed the same general pattern as total forage with >3× as much selected forage available in RF and SF than C (Table 2). In 2008, the selected forage available in RF was >8× that in C and exceeded that in all other treatments except SF. Following 3 fires, there was more than 3× the selected forage in F than C and the selected forage produced in F equaled that in S 7 years following the initial regeneration harvest (Table 2). Although there were differences among treatments in selected forage produced in 2007, there was little difference in NCC because CP levels were generally lower in 2007 than 2008 (Table 1); thus, there was less forage that met the 14% CP threshold in the model (Table 3). In 2008, the NCC of the selected forage available in RF and SF was at least twice as high as that available in all other treatments, and the NCC of S and F was >3× that of C (Table 3).

All of the warm-season forages we planted produced thousands of kilograms of forage during both years of the study (Table 4). Production of iron-and-clay cowpeas and lablab persisted longer than soybeans in 2007 with nearly 3× and 7× as much forage available, respectively, in caged samples during September. Caged estimates were greater than

Table 2. Forage available[a] for white-tailed deer following silvicultural treatments at Chuck Swan State Forest and Wildlife Management Area, Tennessee, USA, July–September 2007 and 2008.

	2007		2008	
Treatment	**kg/ha**	**SE**	**kg/ha**	**SE**
Total forage available[b]				
Control	193 E	53	129 E	22
Fire only	222 E	38	375 CD	62
Shelterwood	366 CD	54	334 CDE	57
Shelterwood with fire	581 BC	90	722 AB	113
Retention cut with fire	711 AB	90	940 A	120
Retention cut with herbicide	152 E	49	326 CDE	92
Retention cut with herbicide and fire	467 BCDE	326	329 CDE	84
Selected species[c]				
Control	150 DE	33	103 E	20
Fire only	212 CD	31	337 C	47
Shelterwood	274 C	52	259 CD	51
Shelterwood with fire	496 BC	72	651 AB	79
Retention cut with fire	591 B	74	844 A	91
Retention cut with herbicide	110 E	30	163 CDE	44
Retention cut with herbicide and fire	105 E	43	130 CDE	41

[a] Forage available represents average standing crop across sampling periods within each year.
[b] Treatment effect significant for total forage available ($F_{6,42} = 21.65$, $P < 0.001$) and selected species ($F_{6,42} = 4.65$, $P < 0.0010$). Means with the same letter are not different within respective forage groupings across years ($P < 0.05$).
[c] Includes only those species selected as forage by deer as identified in Table 1.

Table 3. Nutritional carrying capacity[a] following silvicultural treatments at 14% crude protein nutritional constraint at Chuck Swan State Forest and Wildlife Management Area, Tennessee, USA, July–September 2007 and 2008.

	2007		2008	
Treatment[b]	Deer days/ha	SE	Deer days/ha	SE
Control	18	12 E	67	21 D
Fire	30	14 DE	217	44 C
Shelterwood	20	11 E	151	43 C
Shelterwood and fire	30	13 DE	452	103 AB
Retention cut and fire	79	43 CDE	591	114 A
Retention cut and herbicide	21	18 E	74	27 CD
Retention cut with herbicide and fire	2	2 F	87	22 CD

[a] Means with the same letter are not different ($P < 0.05$).
[b] Includes only those species selected as forage by deer as identified in Table 1. Treatment effect significant ($F_{6,42} = 24.57$, $P < 0.001$).

Table 4. Forage availability for white-tailed deer following 3 warm-season plantings at Chuck Swan State Forest and Wildlife Management Area, TN, USA, July–September 2007.

		2007[a]						2008[a]					
		4.6 Soybeans		Cowpeas		Lablab		4.6 Soybeans		5.6 Soybeans		7.0 Soybeans	
Month		kg/ha	SE	kg/ha	SE	kg/ha	SE	kg/ha	SE	kg/ha	SE	kg/ha	SE
Jul	Caged	771	200 B	1,608	299 A	344	47 B	272	101 AB	379	206 AB	551	286 A
	Uncaged	645	361 B	2,376	1,099 A	469	104 B	184	84 AB	190	115 AB	170	103 AB
Aug	Caged	3,200	325 AB	3,443	147 AB	4,836	623 A	1,897	375 A	2,351	463 A	2,175	323 A
	Uncaged	2,303	327 C	2,447	216 BC	2,782	271 BC	1,757	258 A	1,883	344 A	2,045	386 A
Sept	Caged	633	242 DE	2,305	393 BC	4,036	389 A	1,872	184 B	3,392	459 A	2,993	255 A
	Uncaged	575	246 E	1,424	255 CD	2,747	242 ABC	1,796	351 B	2,895	497 A	3,092	570 A
Oct	Caged							17	33 C	995	349 AB	1,385	472 A
	Uncaged							13	27 C	819	314 B	756	194 B

[a] Treatment effect for 2007 was significant ($F_{1,50} = 5.12$, $P = 0.018$). Treatment effect for 2008 was significant ($F_{1,50} = 4.66$, $P = 0.022$). Means separated between forages within month and year. Means with same letter are not different ($P < 0.05$).

uncaged estimates for soybeans and lablab in August. There was no difference in deer use among forages in other months during 2007. In 2008, late-maturing soybeans persisted longer than 4.6 soybeans. There was no difference in deer use among soybean varieties. Total forage production in food plot plantings was >4× greater than the total forage produced in the SF and RF silvicultural treatments in 2007 (Table 5). In 2008, the later-maturing soybeans produced >3× the total forage available in the RF and SF silvicultural treatments. Production of 4.6 soybeans and total forage available in RF during 2008 was similar.

In our cost analysis, we included any cost incurred by implementing a treatment, such as labor ($8.00/hr), cost of herbicide and application, or prescribed burning. There were no costs associated with C or shelterwood treatments. The F treatment (prescribed fire) cost $37.00/ha, which was the rate charged by the TDF. The RF treatment cost $294.00/ha, including labor (to cut stems), herbicide

Table 5. Forage production[a] for white-tailed deer following silvicultural treatments and food plot plantings at Chuck Swan State Forest and Wildlife Management Area, Tennessee, USA, July–September 2007 and 2008.

	2007		2008	
Treatment[b]	kg/ha	SE	kg/ha	SE
Control	199	48 E	169	38 E
Fire only	271	69 E	510	56 DE
Shelterwood	437	54 E	497	55 DE
Shelterwood with fire	804	93 DE	1,009	102 DE
Retention cut with fire	729	108 DE	1,173	104 CDE
Retention cut with herbicide	156	55 E	660	83 DE
Retention cut with herbicide and fire	674	325 E	376	95 E
Lablab	5,309	249 A		
Cowpeas	2,381	361 ABC		
4.6 Soybeans[c]	2,959	252 ABC	1,869	158 BC
5.6 Soybeans			3,604	306 ABC
7.0 Soybeans			3,797	288 AB

[a] Production represents total forage produced during each growing season.
[b] Treatment effect significant ($F_{11,12} = 27.59$, $P < 0.001$). Means with the same letter are not different ($P < 0.05$).
[c] Soybean varieties are grouped according to time required for soybeans to mature. Larger group numbers indicate longer duration to maturity.

($98.00/ha to treat cut stems), and cost of prescribed fire ($37.00/ha). The RH treatment cost $652.00/ha, including labor (to cut stems), herbicide (for cut stems), and broadcast understory herbicide application ($198.00/ha). The RHF treatment cost $689.00/ha, including labor, herbicide, broadcast understory herbicide application, and prescribed fire. We assessed forage plantings similarly, considering costs for soil testing ($5.00/field), seed ($148.00/ha for soybeans, $203.00/ha for cowpeas, $178.00 for lablab), lime and fertilizer ($178.00/ha), pre-emergence imazethapyr application ($44.00/ha), and tractor-hours and labor ($74.00/ha).

Shelterwood harvests provided income. RH and RHF were least economical among treatments (Table 6). RF and F were more economical to implement and cost per kilogram of production was lower than treatments including understory herbicide application. The cost per kilogram of warm-season forage plantings varied. Cowpeas and 4.6 soybeans were less economical than lablab and later-maturing soybeans. RF was similar in cost per kilogram of total forage available to warm-season forage plantings.

DISCUSSION

Canopy reduction in combination with prescribed fire increased forage availability for deer over all other treatments at CSF. Increased availability of selected forages also led to increased NCC. Prescribed fire alone increased availability of selected species and increased NCC during the second year of sampling. Nutritional carrying capacity following S still exceeded that within C 7 years post-harvest. However, periodic prescribed fire following canopy reduction (RF) continued to disturb the understory and maintain a larger NCC than that provided 6 years and 7 years post S.

Table 6. Cost per additional kilogram of forage available[a] for white-tailed deer following silvicultural treatments and food plot plantings at Chuck Swan State Forest and Wildlife Management Area, Tennessee, USA, July–September 2007 and 2008.

	Cost (U.S. dollars)	
Treatment	**Total forage**	**Selected[b]**
Control (C)[c]	c	c
Fire only	0.13	1.85
Shelterwood	c	c
Shelterwood with fire	c	c
Retention cut with fire	0.22	1.20
Retention cut with herbicide	4.18	d
Retention cut with herbicide and fire	1.45	d
Lablab	0.10	
Cowpeas	0.23	
Soybeans 4.6[e]	0.20	
Soybeans 5.6	0.13	
Soybeans 7.0	0.13	

[a] Forage available minus forage available in C divided by cost of treatment.
[b] Includes only those species selected as forage by deer as identified in Table 1.
[c] No cost associated with control or shelterwood harvests.
[d] We could not calculate cost/additional kg because more forage was available in C.
[e] Cost was same in 2007 and 2008.

Our data suggest fire alone can increase NCC, but this effect was most likely influenced by multiple prescribed fires within a short fire-return interval (2–4 yr). Wood (1988) found one dormant-season prescribed fire did not increase forage availability in the following 3 growing seasons in closed-canopy stands. Shaw et al. (2010) detected a small increase in NCC following one dormant-season fire in closed-canopy hardwoods.

Repeated prescribed burning, as well as understory broadcast applications of triclopyr, did not reduce woody composition or increase herbaceous composition of the understory. Woody regeneration accounted for 55–79% of the available forage in all treatments (Table 7). Consideration for species composition is important when evaluating forage availability for deer because increased biomass does not necessarily equate to increased NCC. For example, burnweed (*Erechtites hieracifolia*), which was not eaten by deer, accounted for the majority of total forage available in RHF in 2007. Although available herbaceous forage increased following treatments that included fire and herbicide, relative woody composition remained large. Edwards et al. (2004), Jones et al. (2009), and Mixon et al. (2009) found imazapyr reduced undesirable woody growth and stimulated more desirable herbaceous forage for deer. However, imazapyr is not recommended for use in hardwoods because of soil activity and potential risk to valuable overstory species (BASF 2007).

Triclopyr, which has no residual soil activity, is safe to apply under hardwoods (DowAgroSciences 2005). Triclopyr effectively killed woody species in the understory and developing midstory of RH and RHF. However, woody species, such as red maple, sassafras, and yellow-poplar, quickly reestablished from seed during the 2 growing seasons following herbicide application. Other work has shown applications of soil-active herbicides alter plant composition and increase forage available for deer in pine systems (Blake et al. 1987, McNease and Hurst 1991, Witt et al. 1993, Chamberlain and Miller 2006). However, our data suggested an understory application of triclopyr is not effective in decreasing undesirable woody species composition or increasing NCC for deer in upland hardwoods.

Forage quality is another important consideration when evaluating NCC. We observed variable forage quality in 2007 and 2008, which was a result of accelerated plant maturation in 2007 when east Tennessee experienced the worst drought on record (National Oceanic and Atmospheric Administration 2008). Normal rainfall followed in 2008. Although we collected plant samples at the same time each year, drought-induced stress can cause plants to mature faster (Carter and Sheaffer 1983, Peterson et al. 1992). Plant maturity has a greater effect on nutritive value than any other factor (Ball et al. 2002). As plants mature, cell walls become more lignified, resulting in an overall decrease in digestibility and CP content. NCC was influenced by forage quality between 2007 and 2008 at the 14% CP constraint. Most selected plant species were below the 14% constraint in 2007 but above it in 2008. Although forage availability was similar across years within treatments,

Table 7. Percent composition of total forage available for white-tailed deer following silvicultural treatments at Chuck Swan State Forest and Wildlife Management Area, Tennessee, USA, July–September 2008.

		Herbaceous[a]		Trees[b]		Shrubs[c]		Other[d]	
Treatment	Total biomass (kg/ha)	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Control	129	23	18	74	57	10	8	22	17
Fire only	375	53	14	278	74	30	8	15	4
Shelterwood	334	50	15	227	68	23	7	33	10
Shelterwood and fire	722	65	9	570	79	43	6	51	7
Retention cut and fire	940	113	12	686	73	56	6	85	9
Retention cut with herbicide	326	46	14	222	68	36	11	23	7
Retention cut with herbicide and fire	329	66	20	214	65	20	6	30	9

[a] *Desmodium* spp., pokeweed, *Carex* spp., *Eupatorium* spp., Soloman's seal, *Lespedeza* spp., <5% other.
[b] Yellow-poplar, oaks, maples, sourwood, sassafras, blackgum, <5% other.
[c] Blueberry, Carolina buckthorn (*Frangula caroliniana*), sumac, strawberrybush, <5% other.
[d] *Smilax* spp., Virginia creeper, *Rubus* spp., *Vitis* spp., wild yam, Japanese honeysuckle, <5% other.

we estimated a proportionally low NCC in 2007 because of lower forage quality. We observed a similar trend in the 4.6 soybeans, which were planted at the same time both years. During the first and second sampling periods (Jul and Aug), average CP was 23% in 2007 but 32% in 2008. During the third sampling season (Sep), average CP was 10% in 2007 and 24% in 2008. The difference in CP between years was a result of accelerated maturation of the soybeans, which had already begun to turn yellow by the third sampling period in 2007.

In 2007, our data suggested considerable use of all food plot plantings by deer in August and cowpeas and lablab in September. However, the vining growth habit of lablab and cowpeas around the cages may have led to increased biomass collected within the exclusion cages. Thus, we planted 3 varieties of soybeans in 2008. Regardless, forage availability in all warm-season plantings exceeded that in all forest treatments during both years of the study, with the exception of RF, which was similar to early maturing soybeans in 2008. Given the use we recorded in the food plots and the tonnage of forage produced, it is clear that high-quality forage food plots could be used to buffer deer browsing pressure in areas where deer density is excessive and while efforts to restore forest understory structure and composition and reduce deer density are underway. We stress that food plots are not a substitute for sound deer population and habitat management, and we do not advocate food plots to artificially sustain excessive deer densities (see Hehman and Fulbright 1997, Fulbright and Ortega-S 2006). On our study site, excessive deer density was not a problem as deer density was low enough that we did not detect a difference between caged and uncaged plots within forested treatments.

Shelterwood regeneration harvests are economical and appropriate if the stand is ready to regenerate with advance regeneration present and if the trees intended for removal are merchantable. Costs associated with retention cutting may be sizable initially, but cost per kilogram decreased considerably over time, and rivaled that of warm-season forage food plots after only 2 years. Warm-season food plots provided thousands of kilograms of high-quality forage per hectare and the cost per kilogram for each of the plantings was low in comparison to forest treatments. However, the cost associated with planting annual forage plots recurs each year.

MANAGEMENT IMPLICATIONS

Where increased forage availability is desirable for deer in closed-canopy upland hardwoods, we recommend canopy reduction followed by periodic low-intensity prescribed fire. Landowners should evaluate available forage, species composition, stand type, age, and quality when considering management options. If the stand is ready to regenerate, landowners may consider a regeneration harvest, such as shelterwood. Otherwise, retention cutting may be used to open the canopy and stimulate understory development and forage production. Regardless of treatment, trees should be retained based on wildlife benefit (e.g., oaks and other mast producers), as well as crown class, size, shape, and form. Vegetation response will vary among sites and will dictate fire-return interval. Our data clearly show periodic low-intensity prescribed fire can be used in Appalachian upland hardwood stands to maintain available forage. A 3- to 5-year fire return interval will maintain forage availability, soft mast production, and provide suitable fawning cover. Warm-season food plots may be used to relieve native vegetation of excessive browsing where populations exceed NCC and active measures are being taken to kill an appropriate number of female deer in an effort to reduce deer density and allow plant communities to recover.

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