Prescribed Fire Interval and Economic Tradeoffs on Forage and Nutrient Availability During Stress Periods for White-tailed Deer

by

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Abstract

Prescribed fire is an effective habitat management tool that enhances the production of quality forage for white-tailed deer (*Odocoileus virginianus*), but its effectiveness is largely dependent upon return interval. We determined the suitability of a 1- versus 2-year burn interval in pine-hardwood stands and found that annual burning improved habitat quality to a greater degree than biennial burning by increasing the production of forage able to support greater nutritional planes. While native forage can provide an important supply of resources, nutritional availability may also be enhanced through food plots and supplemental feed. However, nutritional demands of deer, and forage quality and abundance fluctuate throughout the year. Therefore, we conducted a cost-benefit analysis to determine how to cost-effectively maximize food production during nutritional stress periods for deer. Native forage and food plots cost-effectively maximized food production during June and July, but supplemental feed became increasingly important during September.

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ABSTRACT

Prescribed fire is a commonly utilized, cost-effective habitat management tool in pine stands to enhance the quantity and quality of forage available for white-tailed deer (*Odocoileus virginianus*). A 3- to 5-year burn rotation is typically recommended to increase quality forage production. However, as fire frequency increases, forb and legume biomass increases and woody browse biomass decreases. A 1- or 2-year burn rotation may be viable management options for deer managers to maximize food quality and quantity in pine habitats, but there is still a lack of information regarding preferred forage and nutritional carrying capacity (NCC) response to prescribed fire at these intervals. We measured the production and nutritional quality of forage within mature pine-hardwood stands maintained on either a 1- or 2-year burn interval during 3 nutritionally stressful periods for deer (peak of antler development, third trimester of gestation, and peak of lactation) on a 259-hectare white-tailed deer enclosure located in east-central Alabama during 2014 and 2015. We then compared forage class biomass production, NCC estimates, and digestible protein production between burn treatments. Total biomass did not differ between treatments during any stress period. However, legume biomass production was greater in 1-year burn plots and vine biomass production was greater in 2-year burn plots. Annual burning improved habitat quality in pine-hardwood stands to a greater degree than biennial burning by increasing the production of forage able to support greater nutritional planes. Treating pine-hardwood stands annually with prescribed fire is an effective option for managers to maximize food quality and quantity, specifically by increasing protein

availability in these stands during nutritional stress periods for deer, but other factors such as cost and decreased cover availability should also be considered.

INTRODUCTION

Wildlife management requires a multi-faceted approach to promote abundant, healthy wildlife populations and a major component of wildlife management that has received significant emphasis is habitat management. Properly managed habitat can provide wildlife species with a variety of food sources to meet their nutritional demands, and vegetative cover for escape, protection, bedding, and/or nesting. While habitat management is important for all wildlife species, a considerable focus has been placed on managing habitat for white-tailed deer (*Odocoileus virginianus*). One of the main goals of habitat management for white-tailed deer is to provide adequate nutrition because the nutritional quality of habitats that deer utilize is related to their overall productivity (Moen 1978, Parker et al. 2009, Hewitt 2011). High-quality diets have been shown to reduce gestation length and increase fawning rates in female deer and increase body weights and antler measurements in male deer (Verme 1965, Harmel et al. 1988). Therefore, providing a sufficient quantity of nutritional forage, whether naturally, supplementally, or through habitat manipulation techniques should be an integral component of any deer management plan.

Approximately 22 million hectares of forest across the Southeast are composed of loblolly *(Pinus taeda)* –shortleaf *(Pinus echinata)* pine-hardwood stands (Thill 1984, Dickson and Sheffield 2001). Vegetation in pine-hardwood stands is a sustainable resource that can provide an abundance of nutritional forage at a relatively low cost (Halls 1970, Blair and Enghardt 1976, Edwards et al. 2004). However, these stands typically have a dense canopy cover and thick woody growth in the mid- and understory if left unmanaged, which leads to reduced vegetative production, forage availability, and nutritional carrying capacity (NCC) for deer (Halls and Alcaniz 1968, Blair and Brunett 1977, Sparks et al. 1998, Dickson and Wigley 2001, Edwards et al. 2004). Therefore, habitat manipulation techniques are commonly implemented in pine-hardwood stands to mitigate factors that lead to decreased forage productivity and enhance the abundance and quality of forage available for deer. Many forest management techniques exist to improve forage quality, including thinning, clear cutting, roller-chopping, mowing, and the use of herbicides (Kammermeyer and Thackston 1995, Jacobson et al. 2011), but prescribed burning is one of the most commonly used techniques. Prescribed fire in pine-hardwood stands can help create an open understory suitable for nutritious herbaceous forage growth by reducing forest floor litter abundance and the competition and prevalence of undesired browse species such as sweetgum (*Liquidambar styraciflua*) in the mid-story that shade out desirable herbaceous understories (Dale et al. 1989, Masters et al. 1993, Edwards et al. 2004).

Prescribed fire significantly increases herbaceous forage production, species richness and diversity, and decreases woody vegetation (Lay 1956, Lewis and Harshbarger 1976, Sparks et al. 1998). However, the effectiveness of prescribed burning is largely dependent upon the return interval of fire, because frequent fire implemented over a long period of time is needed to sustain open pine forests (Waldrop et al. 1992). A burn rotation of 3- to 5-years is the most common management recommendation to maintain quality forage abundance (Edwards et al. 2004, Iglay et al. 2010). However, as fire frequency increases, forb and legume biomass increases and woody browse biomass decreases (Lay 1956, Buckner and Landers 1979, Waldrop et al. 1992, Masters et al. 1996), suggesting that 1- or 2-year burn rotations may be viable management options for increasing quality forage production. Buckner and Landers (1979) reported that legume abundance in a Georgia longleaf pine stand during the first growing season after a prescribed burn was approximately 4 times greater than in the same stands following 3 years of fire suppression. However, Masters et al. (1996) did not find any differences in total, browse, forb, or legume forage classes among pine-hardwood stands that were located in Oklahoma and treated with midstory removal during the first, second, or third growing season following prescribed fire. Whereas previous studies have determined the effects of different burn intervals on biomass production of different forage classes, there is a scarcity of information regarding preferred forage and NCC response to prescribed fire at 1- and 2-year intervals, which may be better indicators of habitat quality compared to forage class estimates (Hobbs and Swift 1985).

Although providing adequate nutritional resources for deer on a year-round basis is important, nutritional demands and forage quality and abundance fluctuate throughout the year, creating nutritional stress periods during which meeting nutritional demands becomes more difficult (Short 1975, Thill and Morris Jr 1983, Asleson et al. 1997, Hewitt 2011). In the Southeast, these periods occur during the summer and early fall when forage quality is declining, females are entering into the final trimester of gestation and then beginning lactation, and males are in crucial stages of antler development (Blair and Halls 1967, Asleson et al. 1997, Hewitt 2011). Protein and energy are both important nutrients to support antler growth, gestation, and lactation, but protein is generally more limited in terrestrial ecosystems and is required to a greater degree than energy for these processes (White 1993, Asleson et al. 1996, Barboza and Parker 2008, Lashley et al. 2011). Crude protein requirements for antler growth and lactation are over 1.5 and 2.5 times that of maintenance requirements, respectively (Holter et al. 1979, Verme and Ullrey 1984, Asleson et al. 1996). Therefore, it is important to determine the effects of prescribed burning on forage quality and quantity during each nutritional stress period to help deer meet their nutritional demands by maximizing high-quality forage production.

Considering the importance of providing adequate nutrition for quality deer production and the significance of prescribed fire as a habitat management tool, our goal was to examine the effects of prescribed fire on production of quality forage for deer. Extensive research has been conducted to determine the effects of prescribed fire. However, there is still a lack of information regarding preferred deer forage and NCC response when prescribed fire is used at a 1- or 2-year burn interval, which has facilitated the need for a better understanding of the effectiveness of these intervals in pine-hardwood stands. Our specific objective was to determine whether a 1- or 2-year burn interval was more suitable to increase NCC and the production of preferred deer forages during stress periods for deer in pine-hardwood habitats in the Southeast. Determining the optimal burn rotation to maximize quality forage production with prescribed fire would allow managers to better provide resources during key nutritional stress periods.

METHODS

Study Area

Three Notch Wildlife Research Foundation (Three Notch) was located in Bullock County, approximately 10 km east of Union Springs, Alabama, USA, and encompassed 258.2 ha that had been enclosed by a 3-m high deer-proof fence since 1997. Deer had access to food plots and supplemental feed on a year round basis. Approximately 6.5 ha and 3.5 ha of food plots were planted year round in alfalfa (*Medicago sativa*) and Ladino clover (*Trifolium repens*), respectively, and 1 ha of winter rye (*Secale cereale*) was planted during the cool season. An extensive irrigation system supplemented natural precipitation on all alfalfa and clover plots. High-protein supplemental feed (20% protein; Purina Antlermax, St. Louis, MO) was provided ad libitum at 12 permanent feeding troughs throughout the year. Three Notch received an average annual rainfall total of approximately 1.4 m and temperatures varied from an average annual high of 24.2° C and average annual low of 10.4 ° C (National Climatic Data Center 2010). Topography of the area was primarily flat with a few gently sloping hills and an elevation of 165 m above sea level. Predominant soils on the property included gently and strongly-to-moderately sloping, moderate to well-drained, loamy sand soils (Soil Survey Staff and National Resource Conservation Service 2013).

Forested habitat on the property ranged from upland areas of mature, open pine-hardwood stands to dense hardwood stands along creek drainages. There were approximately 95 ha of pine-hardwood stands, 21.5 ha of pine stands, and 75 ha of mature hardwoods that made up approximately 40%, 10%, and 30% of the total habitat within the study area, respectively. Mean basal area of the pine-hardwood stands was 19.08 m^2/ha and mean tree density was 240 trees/ha. Common pine species on the property were loblolly and shortleaf, and common hardwood species included white oak (*Quercus alba*), water oak (*Quercus nigra*), hickory (*Carya* spp.), sweetgum, and yellow poplar (*Liriodendron tulipifera*). Approximately 100 – 120 ha of mature pine/ pine-hardwood habitat were treated with prescribed fire each year in late February to mid-March to improve natural vegetation availability for deer and aid in detection of shed antlers. Prevalent understory species included sweetgum, wax myrtle (*Myrica cerifera*), butterfly pea (*Centrosema virginianum*), pigeonwings (*Clitoria mariana*), greenbrier (*Smilax* spp.), yellow jessamine (*Gelsemium sempervirens*), Japanese honeysuckle (*Lonicera japonica*), and blackberry (*Rubus* spp.). The headwaters of the Pea River and an approximately 20-ha pond provided year-round water sources for the deer.

Hunting on the property was restricted to archery by the landowner and family members, and was limited to the harvest of mature bucks (5 years or older) and does of any age class. Extremely selective harvest, low hunting pressure limited to archery, and ample nutritious food sources facilitated a high population density within the enclosure. A mark-recapture camera survey (Jacobson et al. 1997) in 2007 indicated estimates of at least 1 deer per 1.7 ha, 3 times that normally found in the region, with a (M:F) sex ratio of 2.64:1 (Mccoy et al. 2011).

Stand Characteristics

To ensure the pine-hardwood stands were similar for comparison, we measured the canopy cover, basal area, and tree density of each stand. Using a moosehorn densiometer, canopy cover was measured at 15 points, 3 meters apart, in each cardinal direction from a random starting point within the stand (Garrison 1949, Cook et al. 1995). To calculate basal area (m^2/ha), the diameter at breast height (DBH) of all trees >10.16 cm within a 0.04-ha plot were measured with a diameter tape (Forestry Suppliers, Jackson, MS), repeated for a total of 5 plots, and then averaged across the five plots. The mean number of trees within the five plots for each stand was also calculated. We used an analysis of variance and Tukey's HSD post hoc test to test for basal area and tree density differences among stands.

Vegetation Sampling

Each year on Three Notch, we identified 8 mature upland pine-hardwood stands ranging in size from 0.38 – 1.14 ha to be used for vegetation sampling. Four stands were treated with head fires in late February to mid-March the year of sampling, and 4 were not treated to represent 1– and 2–year burn rotations. New stands were established for the second year of data collection and prescribed burning treatments were repeated. Before each year of data collection, seven 1.52-m × 1.52-m × 1.37-m exclosures were constructed in each of the pine-hardwood stands to measure biomass production. Exclosure locations within each stand were randomly generated in ArcMap 10.1 (Environmental Systems Research Institute, Inc., Redlands, CA). All exclosures were constructed at the beginning of April before vegetative green-up during the second year of data collection. Exclosure construction was intended to occur during the same period for the first year of data collection, but due to time constraints, exclosures were not constructed until the third week of May. Due to the large number of required exclosures, they were built large enough to enable 3 separate, primary-growth samples per year. To avoid stand edge bias, exclosures were >15-20 m from stand edges (Mueller-Dombois and Ellenberg 1974, Masters et al. 1993).

Sampling occurred for 7-10 days at the beginning of June, July, and September in conjunction with peak antler growth, gestation, and lactation, respectively, for the region. Rapid antler growth for males in this region occurs during June and July (Jacobson and Griffin 1983, Demarais and Strickland 2011). While breeding in most parts of the country occurs in November, peak breeding across the Southeast is often as late as the end of January (Gray et al. 2002, Diefenbach and Shea 2011). With an approximately 200-day gestation length (Ditchkoff

2011) and the greatest demands of gestation occurring during the third trimester (Pekins et al. 1998, Hewitt 2011), the greatest nutritional demands for gestation are during June and July at our study area. Does bred in late January give birth to fawns in August, and because peak milk production is approximately 10 – 37 days after birth (National Resource Council 2007, Hewitt 2011), the greatest nutritional demands for lactation are early September.

We composed a list of 25 preferred species that deer commonly consume based on the literature (Miller and Miller 2005) and relative abundance of each plant on Three Notch. The list was limited to 25 species due to logistical and financial constraints associated with sampling and testing of samples. During each sampling period, all 7 exclosures in each stand were sampled using the destructive harvest method with 0.25-m^2 quadrats. Quadrats were placed at the corners of each exclosure approximately 15 cm from the edge. Within each quadrat, all current annual woody and herbaceous vegetation was clipped 2.54 cm above the ground and up to 1.5 meters in height (Bonham 1989, Masters et al. 1993), and vegetation was separated individually into brown paper bags for the 25 preferred species. All remaining vegetation was grouped into a grass, forb, or browse category. We assumed the nutrient content of forages was the same across the entire property regardless of habitat or burn rotation (Stransky and Halls 1976, Wood 1988, Edwards et al. 2004).

Sample Processing

At the end of each sampling day, samples were placed in a Shel Lab forced-air drying oven (Sheldon Manufacturing, Inc., Cornelius, OR) at 50° C for 48 hours (Tilley and Terry 1963, Goering and Van Soest 1970). Samples were then weighed with a Fischer Scientific Model S – 300D scale (Fischer Scientific, Pittsburgh, PA) to obtain a dry matter biomass weight. Samples for each of the 25 preferred forages and 3 forage categories were saved until 10-15 grams of each were obtained for nutritional analysis and then discarded thereafter. Additional biomass was collected randomly from the property if sampling failed to produce the required quantities of 10-15 grams dry weight needed for nutritional analysis. A few species were added to the list after the June sampling period during the first year of data collection and therefore were not collected for the June nutritional analysis, but were collected for each of the remaining periods each year**.**

Nutritional Analysis

We measured *in vitro* dry matter digestibility (IVDMD) in duplicate for all samples (Tilley and Terry 1963, Goering and Van Soest 1970, Gilliland 2011). Approximately 8-10 grams of each sample was ground in a Thomas Wiley mini-mill (Thomas Scientific, Swedesboro, NJ) through a 20-mesh sieve. We pre-rinsed F57 filter bags (ANKOM Technology, Madedon, NY) in acetone for 3-5 minutes and allowed them to completely air-dry. Then, approximately 0.25 g of each sample was weighed into individual bags and heat-sealed closed. The morning of incubation, ruminal fluid was obtained from the Auburn University Veterinary Clinic's rumen-fistulated dairy cow (*Bos taurus*), and a buffer solution (In vitro True Digestibility Using the Daisy Incubator, 08/2005) was prepared. Each incubation jar was filled with 400 ml of ruminal fluid, 1600 ml of buffer solution, 24 samples, and 1 blank bag. Species were grouped into functional types/ botanical families with consideration of the presence of tannins and secondary metabolites. Duplicates were placed in the same jar, and 0.5 g/Liter of urea was added if any jar contained samples below 7% CP. Jars were then placed into a Daisy II digestion incubator (ANKOM Technology, Macedon, NY) for 48 hours at 39°C. After incubation, samples were washed under cold tap water and frozen until neutral detergent fiber extraction using an ANKOM Fiber Analyzer (ANKOM Technology, Macedon, NY). Once complete, samples were dried overnight at 100°C and reweighed to determine IVDMD.

Crude protein analysis was conducted by the Auburn University School of Forestry and Wildlife Science's Elemental Analysis Laboratory using a 2400 Series Perkin Elmer elemental analyzer (PerkinElmer, Waltham, MA). In preparation for nutritional analysis, 2-3 grams of each sample was ground in a Thomas Wiley mini-mill to pass through a 40-mesh sieve. Approximately 1.5 mg of each sample was weighed into tin foil encapsulating cups for analysis in duplicate. The elemental analyzer determined the nitrogen content of each sample by the Dumas method (Sweeney 1989, Simonne et al. 1997, Horneck and Miller 1998), whereby samples were combusted at approximately 925°C in a pure oxygen environment into simple gases including nitrogen, and then separated by chromatography (PerkinElmer 2010). Crude protein was then calculated by multiplying the nitrogen content of each sample by 6.25 (Robbins 1993).

Nutritional Constraints Models

Hobbs and Swift (1985) nutritional constraints models were used to calculate the mean biomass production for deer to attain nutritional planes of 10-18% CP and 62-78% IVDMD at a 1 and 2% interval, respectively, on a kg/ha basis. We chose 10-18% CP because this range covers the recommended CP levels to support antler growth, gestation, and lactation (Verme and Ullrey 1984, Harmel et al. 1988, Asleson et al. 1996), and also represents a greater nutritional plane for trophy management (17% and 18% CP). We chose 62-78% IVDMD because it represented the range of digestibility most of our forage sample were between. These models provide a quantifiable method to determine habitat quality and are valuable for comparing different habitats or habitat treatment effects by incorporating forage quality, quantity, and diet selection (Hobbs and Swift 1985, McCall et al. 1997). An abundance of vegetation may be produced for consumption, but if it is primarily of low quality, only a limited number of animals will be supported at greater diet qualities (Hobbs and Swift 1985). Therefore, the quantity and quality of each forage must be accounted for individually rather than as a mean value (Hobbs et al. 1982, Hobbs and Swift 1985). American beautyberry (*Callicarpa american*a) leaves have been documented as preferred forage for deer (Miller and Miller 2005), but since we sampled all current annual vegetation, most of the biomass weight was from current annual stems and branches, which deer generally do not consume. Therefore, we only included the beautyberry biomass in the forage class estimates. Grass biomass was not included in the NCC estimates as well because deer do not regularly consume grass aside from new shoots in early spring (Harlow and Hooper 1971, Miller and Miller 2005, Hewitt 2011).

Statistical Analysis

We calculated the mean production of 7 forage classes for each treatment (browse, grass, forb, vine, legume, preferred species, and total biomass). We also calculated mean digestible protein production based on Edwards et al. (2004), by summing the products of each species' biomass, CP, and IVDMD percentage. All biomass was estimated on a kg/ha, dry matter basis.

We used a mixed-effects, general linear model to compare means between 1-year (n = 8) and 2-year burn rotations (n = 8) for each forage class during each stress period (n = 3), with burn rotation and year as fixed effects and stand as a random effect. To compare NCC biomass production at each diet level interval and digestible protein production, we used a general linear model with burn rotation and year as fixed effects. To ensure normality, data were square-root and log transformed to determine if either transformation improved the fit by reducing Akaike's Information Criterion score of the model (AIC_c – which corrects for small sample size) (Anderson and Burnham 2002, Jones et al. 2009). Log transformation was used in all analyses because it improved AIC_c the greatest in all cases, but actual means are presented for interpretation purposes. Statistical tests were performed in R (R version 3.1.1, www.r-project.org, accessed 31 Aug 2014) and differences were considered significant at $\alpha \leq 0.05$.

RESULTS

All stands had similar basal areas, but 2 stands from 2014 that received a 2-year burn treatment had significantly greater tree densities from some of the other stands. However, because stands selected for each treatment were determined randomly, we decided to keep these 2 stands for analysis because pine-hardwood forests can be highly variable (Hurst et al. 1979), and these stands captured the natural variation represented in this forest type.

Mean total biomass production did not differ between the 1- and 2-year stands during June ($P = 0.524$), July ($P = 0.410$), or September ($P = 0.927$) (Table 1.1). Mean biomass production of grass, forb, browse, or preferred species also did not differ during any stress period. However, legume biomass production in 1-year stands was nearly 4 times greater in June ($P = 0.012$), 2 times greater in July ($P = 0.023$), and 3 times greater in September ($P = 0.038$) than in 2-year burn plots. The opposite trend was seen for vine biomass production which was at least 2.5 times greater in June ($P = 0.042$) and September ($P = 0.034$) in 2-year burn stands than in 1-year burn stands.

Crude protein values of the 25 preferred species used to calculate the NCC estimates ranged from 3.8% – 18.6% (Table 1.2). Neither burn treatment was able to produce any biomass to support a diet quality of 18% CP in July, nor a diet quality of 17% or 18% CP in September (Table 1.3). Biomass at 14% (P = 0.031) and 15% CP (P = 0.022) was at least 3 times greater in 1-year burn stands than 2-year burn stands during June, and similar results were found in July. However, differences in biomass production at CP diet qualities ≥14% between burn treatments were not found in September but were found at each CP diet quality ≤13%.

In vitro dry matter digestibility values used to calculate NCC estimates ranged from 46.1% - 88.9% (Table 1.4). Differences in NCC estimates of biomass production at each *IVDMD* diet interval were only detected in July at 78% digestibility (P = 0.048) between burn treatments, where biomass production was over 9 times greater in 2-year burn plots than 1-year burn plots (Table 1.5). Digestible protein production did not differ between burn treatments during June (P = 0.974), July (P = 0.237), or September (P = 0.217) (Table 1.6).

DISCUSSION

Annual burning improved habitat quality in pine-hardwood stands to a greater degree than biennial burning during June and July by increasing the production of forage able to support quality antler growth and gestation (14% and 15% CP; Verme and Ullrey 1984, Asleson et al. 1996). These improvements in habitat quality were detected despite forage class results indicating that total biomass did not differ between burn treatments. However, although differences were not detected, 2-year burn treatments tended to have a greater abundance of browse, and the primary browse species at our study area were generally of lower quality compared with herbaceous vegetation. Therefore, an abundance of vegetation was produced in stands treated with a 2-year burn rotation, but a greater percentage of the forage was of lower quality and unable to support higher nutritional planes compared with 1-year burn stands. Masters et al. (1996) found that low-preference woody growth increased approximately 30% in the second growing season following prescribed fire, but differences were not significant. White et al. (1990) reported that loblolly pine stands in South Carolina treated with an annual burn rotation effectively reduced woody biomass in the understory, which allowed for a diversity of herbaceous vegetation growth. Annual burning at our study site was more effective at reducing hardwood biomass in the understory than a biennial burn treatment, which allowed for more nutritious, shade-intolerant herbaceous vegetation to flourish.

Differences in legume and vine biomass production between burn treatments also contributed to greater habitat quality in 1-year burn stands. Legumes and vines are both important and nutritious forage sources for deer (Miller and Miller 2005), but legume production was greater in 1-year burn stands and vine production was greater in 2-year burn stands. Additionally, the nutritional quality of legumes is typically much greater than vines (Mixon et al. 2009, Iglay et al. 2010), which limited the amount of vine biomass that could be utilized to support deer on greater nutritional planes. Buckner and Landers (1979) reported that legume density was over 2 times greater in annually burned longleaf (*Pinus palustris*) pine stands in South Carolina than in stands during the second growing season after prescribed fire. Waldrop et al. (1992) also found that vine abundance was considerably reduced in South Carolina loblolly pine stands treated with prescribed fire annually. Therefore, increased production of higher quality legumes in pine-hardwood stands maintained on a 1-year burn interval increased the amount of biomass able to support antler growth and gestation. Mixon et al. (2009) similarly reported that increased forb production in mid-rotation loblolly pine stands treated with prescribed fire and herbicides contributed a greater amount of biomass to NCC estimates of 14% CP than lower quality vines, even though vine production was high. These differences also help explain why habitat improvements were found in 1-year burn stands, despite the inability to detect differences in the preferred species forage class between treatments.

Overall declines in forage quality resulted in a substantial decrease in forage production able to support greater diet qualities during September, regardless of treatment. Declines in forage quality throughout the growing season have been commonly reported (Short 1975, Stransky and Halls 1976, Jones et al. 2009). However, while differences were not detected between burn treatments, biomass production to support minimum CP recommendations for lactation (14%; Verme and Ullrey 1984) tended to be over 3 times greater in 1-year burn stands than 2-year burn stands. Although forage quality declined, the CP content of certain legumes at our study site were still high enough to contribute to a nutritional plane of 14% CP, and legume production was nearly 3 times greater in 1-year burn stands during September than 2-year burn stands. Considering that endogenous resources are often utilized by females to meet the high demands of lactation (Oftedal 1985, Hewitt 2011), the beginning of September is a critical period in some regions for managers to provide adequate nutritional resources to help females meet these demands. September is also an important time to provide for the high demands of fawn growth in other parts of the Southeast where breeding occurs earlier. While an annual burn rotation was important for increasing habitat quality during June and July to support antler growth and gestation, it became increasingly important during September to help support the high demands of lactation.

The pine-hardwood habitat at our study area had been treated annually with prescribed fire for over 15 years, resulting in an abundance of herbaceous vegetation growth by reducing mid- and understory growth of undesired browse species such as sweetgum and litter on the forest floor. After 40 years of annual burning in loblolly pine stands located in South Carolina, Waldrop et al. (1992) likewise reported an understory dominated by a variety of forb, grass, and legume species. However, prescribed fire will be far less productive in mature pine stands where management has been non-existent or used sparingly (Waldrop et al. 1992, Edwards et al. 2004). Pine stands in the absence of management are typically characterized by increasingly dense hardwood and woody shrub growth in the mid- and understory (Martin et al. 1975, Waldrop et al. 1992, Sparks et al. 1998), which negatively impacts herbaceous vegetation production. Waldrop et al. (1987) found that hardwood species in the understory exceeding 10 -15 cm diameter at breast height could not be reduced with prescribed fire alone, even if implemented annually. Additional management actions such as thinning and herbicide use, in addition to fire, might be necessary in poorly managed stands initially to reduce browse and shrub species in the mid- and understory, but can then be more easily maintained by fire alone (Hodgkins 1958, Edwards et al. 2004).

Our study area had been enclosed by a high fence and sustained a high density of deer for over 15 years, so it is possible that forage production may not have been reflective of similar pine habitat in free-ranging conditions where deer densities are typically much less. High-density deer populations can cause over browsing, eventual depletion of natural forage, and negative plant community changes (Waller and Alverson 1997, Côté et al. 2004, Mudrak et al. 2009, Thiemann et al. 2009). However, estimates of forage production at our study area were similar to values reported from other studies in free-ranging habitat. Iglay et al. (2010) reported NCC estimates at 14% CP during July in Mississippi mid-rotation pine plantations maintained on a 3-year burn interval that were slightly less than NCC estimates at our study area. Mixon et al. (2009) similarly reported NCC estimates at 14% CP that were slightly less compared to our study area in mid-rotation pines located in the Upper Coastal Plain of Mississippi and were treated with prescribe fire and herbicide. Although differences would be expected between studies due to regional variation, stand conditions, and past management history (Waldrop et al. 1992, Jones et al. 2008, Mixon et al. 2009), our results indicate that forage production at our study area was similar to that of other areas. The high availability of alternative food sources (e.g., food plots and supplemental feed) at our study area may explain the apparent lack of over browsing of forages within pine-hardwood stands.

Whereas annual burning increased production of quality forage, it has been shown to also have negative effects on other stand characteristics or wildlife species. Lashley et al. (2015*b*) found that lactating deer were more likely to utilize longleaf pine stands treated with prescribed fire as the fire return interval in those stands increased, likely due to increased cover abundance as the fire return interval increased. Lactating females prefer dense cover to decrease fawn predation risk (Kie and Bowyer 1999, Lashley et al. 2015*b*), but prescribed fire is generally utilized to open the understory, and thus eliminates many species which provide adequate cover for fawns. A decrease in cover may also negatively affect other species such as certain songbirds (Dickson and Wigley 2001). Annual burn rotations may also negatively impact soft mast production. Lashley et al. (2015*a*) found that fruit production was non-existent or significantly reduced until the 3rd year after a growing season burn in longleaf pine stands. Van Lear and Harlow (2002) also reported that soft mast production was greatest 2-4 years after burning, which could negatively impact species that are dependent upon these fruits if a more frequent fire interval is prescribed. Repeated implementation of prescribed burning that does not vary in fire return interval, season, or fire weather conditions can also create homogenous habitats, thus reducing overall biodiversity on a landscape scale (Sparks et al. 1998, Lashley et al. 2014). Additionally, whereas pine species are generally resistant to the effects of fire, prescribed fire may have a negative effect on pine growth. Boyer (1987) reported that in 14-year old longleaf pine stands located in Alabama, pine volume growth was reduced over 20% in stands biennially burned compared with non-burned stands, and other studies have also reported negative pine growth due to crown scorch (Cain 1996, McInnis et al. 2004).

Treating pine-hardwood stands annually with prescribed fire is an effective option for managers to maximize protein availability in these stands during nutritional stress periods for deer. However, managers should also consider other factors such as increased cost to burn annually and the availability of suitable cover when determining burn intervals for their property. If deer densities are relatively low and food plots or supplemental feed are also available, only a portion of the total pine-hardwood habitat of a property may need to be maintained on an annual burn rotation, and the remainder could be maintained on a longer burn interval for cover and soft mast production (Lashley et al. 2015*a*). Management plans for each property will be unique depending on overall management goals.

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Table 1.1 – Forage class biomass production (kg/ha) in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Forage class	$\bar{x}$[a]	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
Grass	450.0	51.0	410.9	63.3	0.594	652.0	78.3	620.8	99.5	0.861	744.8	84.7	555.9	87.1	0.240
Forb	125.1	24.4	98.7	19.5	0.452	256.9	58.6	160.4	35.9	0.155	268.7	38.8	171.1	29.7	0.427
Browse	415.2	66.3	948.0	140.4	0.107	947.6	159.5	1299.4	178.7	0.127	923.0	215.7	1204.5	223.1	0.151
Legume	171.3	35.7	45.1	9.4	0.012	243.9	36.4	142.9	44.2	0.023	298.5	50.7	109.1	20.3	0.038
Vine	41.8	16.3	113.4	33.9	0.042	46.4	11.9	133.7	29.3	0.059	38.4	10.4	123.2	34.1	0.034
Preferred[b]	211.6	38.1	158.2	33.9	0.649	290.1	37.5	276.5	55.4	0.824	340.8	53.7	232.1	39.5	0.480
Total	1201.9	103.2	1615.9	146.1	0.524	2146.8	201.8	2357.3	206.2	0.410	2277.3	234.7	2163.8	223.3	0.927

[a] Actual means presented. Analyses were conducted using log-transformed data.

[b] Composed of 25 forage species known to be preferred by deer and abundant at the study area.

Table 1.2 – Crude protein (%) of forages within pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	Crude Protein %					
	2014			2015		
Species	June	July	Sept.	June	July	Sept.
Legume						
Atlantic pigeonwings (*Clitoria mariana*)	14.9	17.3	13.3	17.9	17.4	13.8
Butterfly pea (Centrosema virginianum)	15.1	14.0	13.2	17.7	15.7	15.9
Chinese lespedeza (*Lespedeza cuneata*)	12.9	7.9	11.5	15.8	10.6	10.5
Creeping lespedeza (*Lespedeza repens*)	14.2	11.1	11.6	11.9	9.9	12.4
Fuzzy bean (*Strophostyles umbellata*)	18.5	15.8	16.3	13.9	14.0	13.9
Hairy small-leaf ticktrefoil (*Desmodium ciliare*)	12.9	8.4	8.1	13.7	11.3	11.0
Hoary pea (*Tephorsia spicata*)	16.8	15.7	9.3	17.7	13.7	9.9
Milk pea (*Galactia volubilis*)	15.4	16.5	13.6	16.3	11.7	13.0
Nuttall's ticktrefoil (*Desmodium nuttallii*)	12.3	9.8	11.4	13.6	11.8	11.1
Partridge pea (*Chamaecrista nictitans*)	18.6	15.5	14.6	18.0	17.5	13.9
Pencil flower (*Stylosanthes biflora*)	17.8	12.1	16.4	18.0	16.3	9.4
Pinebarren ticktrefoil (*Desmodium strictum*)	13.7	14.0	9.4	14.9	10.4	12.8
Rabbit bells (*Crotalaria rotundifolia*)	14.5	12.9	13.4	14.0	12.8	11.8
Slender lespedeza (*Lespedeza virginica*)	11.4	8.5	8.2	11.2	10.1	10.3

Table 1.2 – Continued

	Crude Protein %					
	2014			2015		
Species	June	July	Sept.	June	July	Sept.
Smooth ticktrefoil (*Desmodium laevigatum*)	---	11.2	10.8	12.9	11.4	11.9
Vine						
Blackberry (*Rubus* spp.)	7.6	5.0	4.6	8.7	7.4	6.8
Grape (*Vitis* spp.)	11.3	7.5	6.9	10.2	8.5	5.9
Greenbrier (*Smilax* spp.)	10.7	10.3	10.8	12.8	11.2	7.3
Japanese honeysuckle (*Lonicera japonica*)	8.1	7.3	9.9	9.4	9.6	9.5
Partridgeberry (*Mitchella repens*)	7.6	8.7	9.1	8.7	9.1	9.7
Poison ivy (*Toxicodendron radicans*)	10.8	9.9	10.4	14.2	13.0	11.0
Trumpet creeper (*Campis radicans*)	12.1	11.0	7.0	10.8	9.4	11.0
Virginia creeper (*Parthenocissus quinqefolia*)	10.7	8.6	9.3	13.5	11.3	11.2
Yellow jessamine (*Gelsemium sempervirens*)	9.7	3.8	7.7	9.0	6.4	6.8
Browse						
Chinese privet (*Ligustrum sinense*)	13.1	11.1	12.2	14.9	13.4	13.4
Other browse[a]	9.4	7.1	6.6	10.2	8.4	8.0
Forb[b]	10.6	7.1	5.7	9.9	7.4	6.2
Grass[c]	8.1	5.6	6.2	7.5	9.8	5.4

[a] All remaining browse species that were sampled but not individually separated.

[b] All remaining forb species that were sampled but not individually separated.

[c] All grass species sampled were grouped into a single category.

Table 1.3 – Estimates of nutritional carrying capacity (kg/ha) based on crude protein production in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Crude protein	$\bar{x}$[a]	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
18%	11.0	6.1	4.2	2.9	0.243	0.0	0.0	0.0	0.0	---	0.0	0.0	0.0	0.0	---
17%	89.5	55.9	15.2	6.0	0.089	102.8	57.8	19.4	8.5	0.349	0.0	0.0	0.0	0.0	---
16%	115.3	64.6	21.8	9.0	0.064	147.7	71.7	32.9	10.7	0.240	8.5	5.8	7.2	4.3	0.737
15%	172.2	74.1	33.4	13.9	0.022	195.7	81.1	43.7	12.5	0.018	39.2	13.3	17.3	7.7	0.077
14%	234.6	92.2	53.6	17.0	0.031	239.2	94.5	70.3	14.0	0.038	142.5	49.0	45.0	17.0	0.057
13%	285.8	91.8	83.1	20.8	0.047	295.8	110.5	98.8	21.6	0.051	250.8	65.9	93.7	19.6	0.026
12%	358.2	95.2	135.9	32.8	0.085	354.5	124.4	128.8	29.4	0.056	332.3	85.6	129.3	25.2	0.023
11%	430.4	94.6	284.9	81.2	0.410	421.2	124.0	174.3	41.0	0.057	428.7	111.7	168.8	32.9	0.027

Table 1.3 – Continued

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Crude Protein	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
10%	505.7	97.1	553.8	145.4	0.826	520.1	127.5	268.4	67.8	0.080	547.6	129.6	238.1	47.7	0.035

[a] Actual means presented. Analyses were conducted using log-transformed data.

Table 1.4 – *In vitro* dry matter digestibility (%) of forages in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	In vitro dry matter digestibility (%)					
	2014			2015		
Species	June	July	Sept.	June	July	Sept.
Legume						
Atlantic pigeonwings (*Clitoria mariana*)	70.3	68.3	62.5	62.2	54.6	56.9
Butterfly pea (Centrosema virginianum)	64.6	64.6	64.6	62.8	59.6	71.1
Chinese lespedeza (*Lespedeza cuneata*)	58.0	60.4	58.8	51.0	50.7	53.4
Creeping lespedeza (*Lespedeza repens*)	---	69.8	60.7	60.1	58.7	59.9
Fuzzy bean (*Strophostyles umbellata*)	79.5	72.3	72.4	71.5	70.1	75.5
Hairy small-leaf ticktrefoil (*Desmodium ciliare*)	62.8	58.7	52.8	52.1	49.7	53.7
Hoary pea (*Tephorsia spicata*)	62.9	59.4	54.0	62.9	52.3	60.0
Milk pea (*Galactia volubilis*)	---	73.6	66.9	68.4	67.0	68.9
Nuttall's ticktrefoil (*Desmodium nuttallii*)	---	68.5	57.3	55.2	46.1	54.2
Partridge pea (*Chamaecrista nictitans*)	77.8	78.9	68.4	74.0	65.0	73.5
Pencil flower (*Stylosanthes biflora*)	78.6	76.2	74.3	75.7	72.3	80.1
Pinebarren ticktrefoil (*Desmodium strictum*)	67.4	65.2	55.9	56.3	54.0	54.6
Rabbit bells (*Crotalaria rotundifolia*)	66.6	75.7	77.0	71.3	72.4	77.2
Slender lespedeza (*Lespedeza virginica*)	67.6	66.9	59.6	57.7	50.7	61.6

Table 1.4 – Continued

	In vitro dry matter digestibility (%)					
	2014			2015		
Species	June	July	Sept.	June	July	Sept.
Smooth ticktrefoil (*Desmodium laevigatum*)	---	64.4	65.7	53.8	48.3	63.2
Vine						
Blackberry (*Rubus* spp.)	73.1	69.4	72.2	74.8	67.3	76.7
Grape (*Vitis* spp.)	82.9	82.0	78.9	68.7	62.9	74.0
Greenbrier (*Smilax* spp.)	67.8	64.7	55.2	64.1	57.9	65.5
Japanese honeysuckle (*Lonicera japonica*)	81.2	71.8	73.1	72.8	72.1	72.8
Partridgeberry (*Mitchella repens*)	83.1	84.2	81.4	80.7	81.3	86.5
Poison ivy (*Toxicodendron radicans*)	82.5	85.8	83.2	74.4	77.8	83.8
Trumpet creeper (*Campis radicans*)	79.9	71.2	70.9	68.1	69.7	75.1
Virginia creeper (*Parthenocissus quinqefolia*)	88.9	87.3	88.5	78.6	79.0	84.4
Yellow jessamine (*Gelsemium sempervirens*)	76.3	79.6	64.9	72.6	67.1	68.6
Browse						
Chinese privet (*Ligustrum sinense*)	70.1	76.4	62.6	68.1	62.2	66.0
Other browse[a]	76.5	68.2	63.2	61.3	60.7	60.9
Forb[b]	76.4	74.9	68.6	67.6	56.2	63.9

Table 1.4 – Continued

	In vitro dry matter digestibility (%)					
	2014			2015		
Species	June	July	Sept.	June	July	Sept.
Grass[c]	71.1	61.8	56.1	67.7	56.9	62.2

[a] All remaining browse species that were sampled but not individually separated.

[b] All remaining forb species that were sampled but not individually separated.

[c] All grass species sampled were grouped into a single category.

Table 1.5 – Estimates of nutritional carrying capacity (kg/ha) based on *in vitro* dry matter digestibility production in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Digestibility	$\bar{x}$[a]	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
78%	15.5	11.0	121.0	88.3	0.072	12.3	8.8	108.6	77.4	0.048	10.7	7.0	23.5	13.1	0.494
76%	96.6	47.4	205.2	125.8	0.367	35.0	24.6	142.9	98.0	0.084	53.2	23.7	90.3	21.9	0.153
74%	155.0	65.0	244.6	119.8	0.449	186.8	90.4	195.1	131.8	0.899	118.5	48.1	131.5	30.7	0.368
72%	193.1	66.3	264.3	117.5	0.735	291.3	136.3	291.8	194.9	0.198	165.4	58.3	183.9	37.3	0.228
70%	226.6	59.8	304.8	116.1	0.754	429.5	189.7	380.6	231.4	0.327	241.5	78.0	280.1	59.5	0.270
68%	288.3	52.2	347.6	114.2	0.832	461.0	181.9	427.1	237.7	0.441	430.5	93.9	377.2	78.9	0.845
66%	350.6	56.9	391.1	114.6	0.887	496.0	173.9	463.2	231.4	0.560	651.4	127.1	529.2	119.5	0.621
64%	470.5	87.5	461.5	116.6	0.967	556.0	162.8	517.7	224.2	0.587	831.9	134.6	635.7	115.8	0.503

Table 1.5 – Continued

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Digestibility	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
62%	499.1	95.7	559.0	144.3	0.777	697.6	141.9	650.6	210.0	0.620	923.8	144.2	648.7	117.0	0.361

[a] Actual means presented. Analyses were conducted using log-transformed data.

Table 1.6 – Digestible protein production (kg/ha) in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	1-Year		2-Year		
Month	$\bar{x}$[a]	SE	$\bar{x}$	SE	P
June	39.2	7.5	39.2	9.8	0.974
July	55.1	7.8	41.7	10.7	0.237
Sept.	51.2	8	33	5.2	0.217

[a] Actual means presented. Analyses were conducted using log-transformed data.

Chapter 2: Economic Optimization of Forage and Nutrient Availability During Stress Periods for Deer

ABSTRACT

Providing a sufficient quantity of nutritional forage should be an integral component of white-tailed deer (*Odocoileus virginianus*) management plans that aim to maximize deer condition and quality. Deer managers generally attempt to meet the nutritional needs of their herd through some combination of habitat management, food plot production, and/or supplemental feed provisioning. However, nutritional demands of deer, and forage quality and abundance fluctuate throughout the year, creating nutritional stress periods and a dilemma for managers regarding how to maximize the nutritional plane of their herd while minimizing cost. We measured crude protein availability from mature pine habitat managed with prescribed fire and Ladino clover food plots during 3 nutritionally stressful periods for deer on a 259-hectare white-tailed deer enclosure located in east-central Alabama. We then used a cost-benefit analysis to determine how to cost-effectively maximize food production by comparing management options which varied by the percentage of total area planted in food plots (0 - 5%), percentage of pine stands treated with prescribed fire (0 - 100%), and the addition of supplemental feed. Native forage in pine stands treated with prescribed fire and food plots cost-effectively maximized food production during June and July without the addition of supplemental feed. However, supplemental feed became increasingly important during September to compensate for the decreased availability of high-quality native forage. Deer managers should understand how the relative importance of each nutritional input varies

seasonally in order to maximize the nutritional availability of their land for deer in a cost-effective and efficient manner.

INTRODUCTION

Improving the nutritional quality of habitats for white-tailed deer (*Odocoileus virginianus*) is a major focus for deer managers because high-quality diets can significantly improve deer condition and quality (Moen 1978, Johnson et al. 1987, Hewitt 2011). The three primary ways aside from population reduction that managers can enhance quantity and quality of nutritional resources are by: utilizing habitat management techniques to enhance the quality and abundance of naturally occurring vegetation (hereafter native vegetation/forage), planting food plots, and providing supplemental feed. Native vegetation is an important, sustainable resource for deer, but food plots and supplemental feed can provide additional high-quality resources to supplement native forage during periods when the quality and/or quantity of native vegetation is poor or limited (Waer et al. 1994, Hehman and Fulbright 1997, Bartoskewitz et al. 2003, Stephens et al. 2005). Therefore, it is commonly recommended that deer managers use some combination of these 3 nutritional inputs to provide deer with a variety of resources to meet their nutritional demands (Koerth and Kroll 1998, Yarrow and Yarrow 1999).

In the southeastern United States there are approximately 86.5 million hectares of forestland that makes up slightly over 50% of available habitat for white-tailed deer (Thill 1984, Dickson and Sheffield 2001). Of the available forested lands, approximately 20% comprise pine/pine-hardwood woodlands (Thill 1984, Dickson and Sheffield 2001), and native vegetation in pine habitats has been reported to provide an abundance of highly nutritious forage when managed properly (Halls 1970, Blair and Enghardt 1976, Edwards et al. 2004). There are a variety of habitat management techniques that are commonly implemented to improve habitat quality and enhance forage productivity for white-tailed deer, but prescribed burning is frequently recommended (Waldrop et al. 1987, Strickland 2012). Prescribed fire increases herbaceous forage production, species richness and diversity, and decreases low-quality woody vegetation (Lewis and Harshbarger 1976, Masters et al. 1993, Sparks et al. 1998), all important factors in improving nutritional availability for white-tailed deer.

Food plots and supplemental feed are nutritional supplements that are commonly provided to enhance deer productivity beyond what would normally be achieved through habitat management alone. These supplements are typically greater in nutritional value than native vegetation (Keegan et al. 1989, Waer et al. 1994, Bartoskewitz et al. 2003, Stephens et al. 2005), and have been shown to improve body size, fawn production, antler size, and carrying capacity (Ozoga and Verme 1982, Johnson et al. 1987, Keegan et al. 1989, Kammermeyer and Thackston 1995, Hehman and Fulbright 1997, Bartoskewitz et al. 2003). Despite the increased nutritional resources that food plot forages and supplemental feed can provide, deer continue to consume native vegetation even when provided with these additional resources (Ozoga and Verme 1982, Johnson et al. 1987, Bartoskewitz et al. 2003), indicating that the management of native forage is important even when nutrition is supplemented. Additionally, food plots and supplemental feed are more costly than native habitat management from a nutritional perspective (Kammermeyer et al. 1993, Kammermeyer and Thackston 1995, McBryde 1995). These mitigating factors suggest that native habitat management combined with supplemental feed and food plot provisioning should provide a variety of nutritious food sources.

Nutritional demands of deer and forage quality and abundance naturally fluctuate throughout the year, creating stress periods during which deer have difficulty meeting their nutritional needs. These periods occur in the Southeast during the summer and early fall when males are in the rapid growth stage of antler development, females are trying to meet the high demands of both gestation and lactation, and the nutritional quality of native forage is decreasing (Short 1975, Asleson et al. 1997, Hewitt 2011). Whereas energy is important to support productive processes such as lactation and antler growth, protein is commonly more limiting and may also place a greater constraint on these processes when limited (White 1993, Asleson et al. 1996, Barboza and Parker 2008, Lashley et al. 2011). Crude protein requirements for maintenance are approximately 6% CP, but CP requirement are over 1.5 times greater to support antler growth and over 2.5 times greater for gestation and lactation (Holter et al. 1979, Verme and Ullrey 1984, Asleson et al. 1996). Therefore, ensuring nutritional demands are being met during these stress periods is extremely important.

Deer managers are continuously challenged with meeting the nutritional needs of their herd through some combination of habitat management, food plot production, and/or supplemental feed provisioning, while trying to keep costs to a minimum. Meeting nutritional demands while also reducing costs becomes even more complex considering that the relative nutritional value of native forage and food plots varies throughout the year, and nutritional needs of deer vary. Considering the complexity of the nutritional environment for white-tailed deer, our objectives were to: (1) determine the relative nutritional value of native forage treated with prescribed fire, food plots, and supplemental feed for deer, (2) assess how the nutritional value of native and food plot forages changed during the growing season, and (3) determine how to cost-effectively maximize food production during 3 key nutritional stress periods.

METHODS

Study Area

The study area was located at Three Notch Wildlife Research Foundation (Three Notch) inside a 258.2-ha high-fence enclosure in Bullock County, approximately 10 km east of Union Springs, Alabama, USA. A 3-m high deer-proof fence had enclosed the study area since 1997, and year-round access to food plots and supplemental feed was available to deer. Food plots on the property consisted of approximately 6.5 ha and 3.5 ha of alfalfa (*Medicago sativa*) and Ladino clover (*Trifolium repens*), respectively, and 1 ha of winter rye (*Secale cereale*) was planted during the winter. An extensive irrigation system supplemented natural precipitation on all alfalfa and clover plots. A total of 12 permanent feeding troughs equally distributed across the study area provided a high-protein supplemental feed (20% protein; Purina Antlermax, St. Louis, MO) ad libitum throughout the year. Average annual rainfall at Three Notch was approximately 1.4 m, and temperatures varied from an average annual high of 24.2° C and average annual low of 10.4° C (National Climatic Data Center 2010). Three Notch was 165 m above sea level, and topography of the area was primarily flat with a few gently sloping hills. Predominant soils on the property included gently and strongly-to-moderately sloping, moderate to well-drained, loamy sand soils (Soil Survey Staff and National Resource Conservation Service 2013).

Upland areas of mature, open pine-hardwood and dense hardwood stands along creek drainages were the primary forested habitat on the study area. There were approximately 95 ha of pine-hardwood stands, 21.5 ha of pine stands, and 75 ha of mature hardwoods; which made up approximately 40%, 10%, and 30% of the total habitat within the study area, respectively. Mean pine-hardwood stand basal area was 19.08 m^2/ha and mean tree density was approximately 240 trees/ha. Loblolly (*Pinus taeda*) and shortleaf (*Pinus echinata*) pine were the common pine species, and common hardwood species included white oak (*Quercus alba*), water oak (*Quercus nigra*), hickory (*Carya* spp.), sweetgum (*Liquidambar styraciflua*), and yellow poplar (*Liriodendron tulipifera*). To enhance native vegetation quality and quantity and aid in detection of shed antlers, approximately 100 – 120 ha of mature pine/pine-hardwood habitat were treated with prescribed fire each year in late February to mid-March. Prevalent understory species included sweetgum, wax myrtle (*Myrica cerifera*), butterfly pea (*Centrosema virginianum*), pigeonwings (*Clitoria mariana*), greenbrier (*Smilax* spp.), yellow jessamine (*Gelsemium sempervirens*), Japanese honeysuckle (*Lonicera japonica*), and blackberry (*Rubus* spp.). Year-round water sources for deer included the headwaters of the Pea River and an approximately 20-ha pond.

Hunting on the property was restricted to archery by the landowner and family members, and was limited to the harvest of mature bucks (5 years or older) and does of any age class. There was a high population density within the exclosure due to extremely selective harvest, low hunting pressure limited to archery, and ample nutritious food sources. A mark-recapture camera survey (Jacobson et al. 1997) in 2007 indicated estimates of at least 1 deer per 1.7 ha, 3 times that normally found in the region, with a (M:F) sex ratio of 2.64:1 (Mccoy et al. 2011).

Vegetation Sampling

For native vegetation sampling, we identified 8 mature, upland pine-hardwood stands ranging in size from 0.38 - 1.14 ha in 2014 and 2015. Four stands were treated with head fires in late February to mid-March the year of sampling, and 4 were not treated to represent 1– and 2–year burn rotations. We also identified 3 mature hardwood stands and 2 pre-existing Ladino clover stands ranging in size from 0.14 – 1.03 ha**.** New stands were established for the second year of data collection, and prescribed burning treatments were repeated within the pine-hardwood stands. A total of seven 1.52-m × 1.52-m × 1.37-m exclosures were constructed in each of the 11 forested stands and three 0.31-m × 0.31-m × 1.37-m exclosures were constructed in each food plot stand to measure total forage production each year. Exclosures were constructed at the beginning of April during the second year of data collection. Exclosure construction was intended to occur during the same period for the first year of data collection, but due to time constraints, exclosures in pine-hardwood stands were not constructed until the third week of May. During 2014, clover exclosures were not constructed until after the first sampling period in June. Therefore, Ladino clover production in June was based on 2015 data only. Forested exclosures were built large enough to enable 3 separate, primary-growth samples per year due to the large number of exclosures needed. Food plot exclosures were moved to a new random location after each sampling period and were built smaller than forested exclosures to allow for quick removal when the food plots needed to be mowed or sprayed. Exclosure locations within each stand were randomly generated in ArcMap 10.1 (Environmental Systems Research Institute, Inc., Redlands, CA).

Sampling occurred for 7-10 days at the beginning of June, July, and September in conjunction with peak antler growth, gestation, and lactation, respectively, for the region.

Bucks enter into a period of rapid antler growth during June and July when high-quality resources are needed for quality antler production (Jacobson and Griffin 1983, Demarais and Strickland 2011). Peak breeding across the Southeast is often as late as the end of January (William N. Gray et al. 2002, Diefenbach and Shea 2011), which is when it peaked at the study site. The greatest nutritional demands for gestation occurred during June and July because the average gestation length for deer is 200 days and the greatest demands occur during the third trimester (Pekins et al. 1998, Ditchkoff 2011, Hewitt 2011). Does bred in late January give birth to fawns in August, and peak milk production is approximately 10 – 37 days after birth (National Resource Council 2007, Hewitt 2011). Therefore, the greatest nutritional demands for lactation are the beginning of September. A list of 25 native forage species preferred by deer was composed based on the literature (Miller and Miller 2005) and relative abundance of each plant at Three Notch. A total of 25 species was chosen due to logistical and financial constraints.

All exclosures within stands were sampled using the destructive harvest method with 0.25-m^2 quadrats, and all current annual woody and herbaceous vegetation was clipped 2.54 cm above the ground and up to 1.5 meters in height (Bonham 1989, Masters et al. 1993). For forested stands, each of the 25 preferred species were individually separated and placed into brown paper bags, and all remaining vegetation was grouped into a grass, forb, or browse category. Ladino clover stands were sampled the same way as native forage, but only clover forage was collected. To avoid stand edge bias, sampling did not occur within 15-20 m from any stand edge (Mueller-Dombois and Ellenberg 1974, Masters et al. 1993). If sampling did not produce the required quantity of 10-15 grams dry weight biomass of each species needed for nutritional analysis, additional biomass was collected randomly from the property. We assumed the nutrient content of forages were the same across the entire property regardless of habitat or burn rotation (Stransky and Halls 1976, Wood 1988, Edwards et al. 2004).

Sample Processing

After sampling each day, samples were placed in a Shel Lab forced-air drying oven (Sheldon Manufacturing, Inc., Cornelius, OR) at 50° C for 48 hours (Tilley and Terry 1963, Goering and Van Soest 1970). Samples were then weighed with a Fischer Scientific Model S – 300D scale (Fischer Scientific, Pittsburgh, PA) to obtain a dry matter biomass weight. Samples for each of the 25 preferred forages, 3 forage categories, and Ladino clover were saved until 10-15 grams of each were obtained for nutritional analysis and then discarded thereafter. After the June sampling period during the first year of data collection, a few species were added to the list and were not included in the June nutritional analysis for the first year. However, they were collected for each of the remaining periods each year**.**

Nutritional Analysis

Auburn University School of Forestry and Wildlife Science's Elemental Analysis Laboratory conducted the CP analysis using a 2400 Series Perkin Elmer elemental analyzer (PerkinElmer, Waltham, MA). Using a Thomas Wiley mini-mill, 2-3 grams of each sample were ground to pass through a 40-mesh sieve. Approximately 1.5 mg of each sample were weighed into tin foil encapsulating cups for analysis in duplicate. The nitrogen content of samples was determined by combusting each sample at approximately 925°C in a pure oxygen environment into simple gases including nitrogen, and then separating those gases by chromatography (Sweeney 1989, Simonne et al. 1997, Horneck and Miller 1998, PerkinElmer 2010). Crude protein was then calculated by multiplying the nitrogen content of each sample by 6.25 (Robbins 1993).

Cost-Benefit Analysis

We used a cost-benefit analysis in order to determine the relative nutritional value of native forage in pine-hardwood stands treated with prescribed fire, food plots, and supplemental feed and how to cost-effectively maximize food production during each nutritional stress period. Ladino clover was used as the representative for food plots and Purina Antlermax 20% CP was used for supplemental feed because that is what the landowner at our study site had planted and provided during the duration of the study. We assumed a theoretical 259-ha property, and based on the distribution of habitat types at the study area, we assumed pine-hardwood stands made up a total of 121 ha. Pine-hardwood stands were assumed to be maintained on a 2-year burn interval. We then considered 0-100% of the total 121 ha of pine-hardwood stands to be treated with a 1-year burn interval, at 20% increments, for a total of 6 options because we found that high-quality biomass production was greater in stands maintained on a 1-year compared to 2-year burn interval. Because it is generally recommended to landowners that 1-5% of their total property be planted in food plots for white-tailed deer management (Kammermeyer and Thackston 1995, Harper 2006), we considered 0-5% of the total property area planted in Ladino clover at 1% increments for a total of 6 food plot options. Additionally, we determined the average amount of supplemental feed that was placed out on a 2-week basis between June and September at the study area, which we considered as a “high” option (3100 kg) for supplemental feed provisioning. We reduced that amount by 50% for a “low” option (1550 kg), and also considered the addition of no supplemental feed, for a total of 3 supplemental feed options. We then determined all possible combinations of treatments with the 3 nutritional inputs for a total of 105 combinations (we did not include 0% burn, 0% food plot, and 0 supplemental feed as an option, nor did we consider any option of supplemental feed by itself).

Nutritional constraints models (Hobbs and Swift 1985) were used to calculate the mean biomass on a kg/ha basis available for deer to attain nutritional planes of 14%, 16%, and 18% CP within the pine-hardwood stands treated with either a 1- or 2-year burn interval during each nutritional stress period. An abundance of vegetation may be available for consumption, but if it is primarily of low quality, only a limited number of deer will be supported at a high nutritional plane (Hobbs and Swift 1985). Therefore, the quantity and quality of each forage must be accounted for individually rather than as a mean value (Hobbs et al. 1982, Hobbs and Swift 1985). Ladino clover forage and supplemental feed exceeded 18% CP during each stress period, so nutritional constraint models were not needed because all of the feed and forage could be utilized to meet each of the 3 nutritional planes. We chose these diet qualities because 14% and 16% are the upper and lower recommended CP levels to support lactation, which is also sufficient for quality antler production and gestation (Verme and Ullrey 1984, Harmel et al. 1988, Asleson et al. 1996). We also wanted to consider 18% CP to simulate an even more intensive management option similar to a trophy management plan. Mature hardwood stands were not included as a nutritional input because they were unable to produce any biomass to support a 16% or 18% CP diet quality, and less than 2 kg/ha of biomass to support a 14% CP diet quality during any of the 3 nutritional stress periods.

The cost for prescribed burning was assumed to be \$74.13/ha (Strickland 2012), and the cost to establish Ladino clover food plots was assumed to be \$805.56/ha, which included the price of seed, lime, fertilizer, herbicide, labor, fuel, and equipment costs. Prices of seed, lime, fertilizer, and herbicides were based on local co-op prices near the study site in January, 2016. Costs associated with labor, fuel, and equipment included the costs of 2 herbicide applications, 1 fertilizer treatment, spreading lime, disking fields, planting seed, and mowing twice per year (Harper 2008). The costs for each were determined based on a 2015 Iowa farm custom rate survey (Plastina and Johanns 2015). Supplemental feed costs were \$500 per 907 kg (1 ton).

The total food production on a kg/ha basis and associated cost of each management option was then determined. For native forage in pine-hardwood stands, we multiplied mean biomass production (kg/ha) for a 1-year burn interval at each CP increment by each of the 6 respective treatment areas (0 - 100% of 121 ha; i.e. 20% of 121 ha = 24.3 ha X kg/ha). We repeated the same process for native forage from pine-hardwood stands maintained on a 2-year burn interval, but it was dependent upon the amount of area treated with a 1-year burn interval, such that if 20% was treated with a 1-year burn interval, then the remaining contribution of native forage was calculated based on 80% being maintained on a 2-year burn interval. The Ladino clover input was calculated the same as the native forage input for each of the 6 food plot options (0-5%). Costs for prescribed burning and food plots were determined the same way total food production was calculated, but with prices for each input rather than biomass (i.e. 20% prescribed burning: 20% of 121 ha = 24.3 ha X \$74.13/ha = \$1801.36). Supplemental feed costs were determined by the total amount of feed provided over the 4-month period of interest (June - September), which was approximately 24,675 kg for the high feed option and 12,337.5 kg for the low feed option. The respective amounts of forage or feed from each nutritional input and associated costs were then added together to calculate the total food production on a property-wide basis and cost for each management combination. We then ranked the management options in order of greatest total food production during each stress period, took the top ten management options, and ranked them in order of lowest cost in terms of unit cost.

RESULTS

In June, native forage production in pine-hardwood stands maintained on a 1-year burn interval to support CP diet qualities of 14%, 16% and 18% was 234.6 kg/ha, 115.3 kg/ha, and 11.0 kg/ha, respectively (Table 2.1). Ladino clover forage production was 2,156 kg/ha at each diet quality. Forage production was very similar in July, except that native forage production at 18% CP was 0 kg/ha. In September, native forage production was reduced by at least 50% at 14% and 16% CP, and was again 0 kg/ha at 18% CP. Production of Ladino clover forage was also reduced by nearly 75% in September due to a *Rhizoctonia* sp. fungal outbreak in 3 of the 4 research plots in both 2014 and 2015, resulting in only 575.4 kg/ha produced.

At 14% CP, there was an approximately 15% difference in food production among the top 10 management plans during each nutritional stress period compared to an approximately 40% difference in total cost (Table 2.2). Food production in June and July ranged from 194.0 kg/ha to 229.5 kg/ha, and costs were between \$0.34 and \$0.58 per kg of feed produced. For September, food production was reduced and ranged from 108.0 kg/ha to 127.5 kg/ha and costs increased to \$0.65 to \$1.04 per kg produced. Every management plan during each stress period at 14% CP included 60%, 80%, or 100% of the total pine-hardwood stands maintained on a 1-year burn interval and 3%, 4%, or 5% or the total property planted in food plots. Supplemental feed was absent in the top 3 most cost-effective management options followed by the low option of supplemental feed in the next 3 options in both June and July, but was only absent in the top option in September.

Trends at 16% CP in June and July were similar to 14% CP but less food was available due to an increased nutritional plane. Food production during June and July ranged from 147.1 kg/ha to 183.5 kg/ha and costs were between \$0.42 and \$0.79 per kg produced (Table 2.3). However, there was a reduction in the percentage of prescribed burning in the top management plans at 16% CP during September, and overall food production was also reduced to between 58.5 kg/ha and 64.7 kg/ha. Food plots were still an important forage source during September, with 5% in all 10 management plans, but supplemental feed options also became more important to maximize food production and were included in all 10 management plans. Total costs increased in September to \$1.37 to \$1.97 per kg due to the addition of supplemental feed and reduction of native forage production. The top management plans at 18% CP during all 3 nutritional stress periods followed the same trends as 16% CP in September, except that less food was available again due to an increased nutritional plane (Table 2.4).

DISCUSSION

Native forage in pine-hardwood stands treated with prescribed fire and food plots cost-effectively maximized food production at 14% and 16% CP in June and July. Both of these options provided deer with an abundance of forage to meet their nutritional demands for quality production without the addition of supplemental feed. Prescribed fire is an effective management option to increase the abundance of quality native forage (Masters et al. 1996, Sparks et al. 1998, Haywood et al. 2001). Haywood et al. (2001) found that biennial burns in Louisiana longleaf pine (*Pinus palustris*) stands maintained on a long-term burning regime produced over 90 times more herbaceous vegetation compared with unburned stands. Sparks et al. (1998) similarly reported that species richness, species diversity, and forb and legume production increased in stands treated with fire in restored pine-grassland communities in Arkansas. An abundance of high-quality native forage was also produced due to the large area that could be burned at a low cost. In addition to native forage, food plots produced over 2000 kg/ha of clover forage exceeding 20% CP, and were also more cost-effective than supplemental feed at maximizing food production. McBryde (1995) also found that in most cases, food plots are more economical than supplemental feed. Although management options that included supplemental feed increased total feed output, it was considerably more expensive with a much lower return value compared with prescribed fire and food plots during June and July.

In contrast to our results from June and July, declines in native forage quality during September resulted in a substantial decrease in native forage able to support greater nutritional planes. As a result, there was a greater dependence on food plots during September to compensate for the decreased availability of high-quality native forage. It has been well documented that food plots provide an important source of forage for deer when high quality native forage is limited (Waer et al. 1992, Hehman and Fulbright 1997, Stephens et al. 2005). Native forage production was abundant during September, but the nutritional quality was primarily too low to contribute to high nutritional planes. While a few native forage species exceeded 14% CP in September, the average CP concentration of native species was 10.2%, compared with nearly 22% CP for Ladino clover forage. Native forage quality has been commonly reported to decrease throughout the growing season (Short 1975, Jones et al. 2008), but other studies have also shown that clover forage can equal or exceed 20% CP during September (Waer et al. 1992, Stephens et al. 2005).

Supplemental feed also became an important, cost-effective option during September to maximize food production. In addition to food plots, supplemental feed helped compensate for the decreased availability of quality native forage. Ozoga and Verme (1982) reported that deer in an enclosure located in Michigan increased utilization of supplemental feed throughout the summer as native forage quality declined. Supplemental feed also became increasingly important in order to compensate for a reduction in clover production due to a *Rhizoctonia* sp. fungal outbreak at our study area. Based on other studies, clover production would be expected to be similar to production in June and July if the fungal outbreak hadn't occurred (Waer et al. 1992, Kammermeyer et al. 1993). An advantage to supplemental feed is that it can provide a high-quality source of feed on a consistent basis, regardless of season or environmental conditions, whereas food plot quality can vary (McBryde 1995, Hehman and Fulbright 1997). Unlike supplemental feed, food plots have the potential for crop failure due to drought, insects, or disease (Koerth and Kroll 1998).

September was a critical time period in which to provide nutritional resources for lactating females at our study area, but it may not be as important in other parts of the Southeast where breeding occurs earlier. Peak breeding typically occurs between November and December across many other parts of the Southeast, compared with the end January at our study area (William N. Gray et al. 2002, Diefenbach and Shea 2011). As a result, most females in areas where breeding occurs earlier are past the peak of lactation. However, it is still an important time period to provide high-quality nutritional resources for adequate fawn growth. Crude protein requirements for fawn growth range from approximately 13 - 25% CP, and after weaning, fawns may grow up to 210 g/day (French et al. 1956, Ullrey et al. 1967, Smith et al. 1975, Hewitt 2011). Ullrey et al. (1967) found that the body weight of weaned fawns was strongly associated with the level of protein in their diet. Kirkpatrick et al. (1975) similarly found that female fawns on a high CP diet (18.2%) had greater body weights than fawns on a low CP diet (9.6%).

Whereas Ladino clover was selected for our study, there are a wide variety of food plot forages that can be utilized to provide high-quality forage for deer. Numerous food plot forages, including cowpeas (*Vigna unguiculata*), lablab (*Lablab purpureus*), and alyceclover (*Alysicarpus vaginalis*) have all been reported to have similar output and nutritional quality as the Ladino clover reported in our study (Beals et al. 1993, McDonald and Miller 1995, Edwards et al. 2004). Additionally, rather than planting a single species, it is often recommended to plant a variety of food plot forages, including both annual and perennial forages, because monthly forage production, costs to establish and maintain food plots, and responses to varying rainfall, soil conditions, and browsing pressure vary by species (Stephens et al. 2005, Kammermeyer et al. 2006, Harper 2008). A combination of food plot forages will help ensure a variety of nutritious forage is available for deer during nutritional stress periods.

During each stress period, 4-5% of the total land planted in food plots were part of the top 10 management plans to maximize food production, but this may not be practical or required for many deer managers. Johnson et al. (1987) found that as little as 1% of the total area planted in food plots increased body weights and diet quality of free-ranging yearling bucks in Louisiana. Approximately 1% of the total land area planted in food plots may be sufficient, especially if deer densities are relatively low and habitat management techniques are being used to enhance native forage production. Other land-use practices may also limit the percentage of area planted in food plots, such as timber or agricultural production. If so, supplemental feed may become increasingly important, especially if a high density of deer needs to be supported. Additionally, financial limitations may restrict the area that can be converted to food plots or the quantity of supplemental feed that can be provided.

Providing a sufficient quantity of nutritional resources should be an integral component of any management plan that aims to maximize deer condition and quality. Land managers have numerous choices when attempting to meet the nutritional demands of their deer herd, including habitat management options such as prescribed fire to enhance the quality and quantity of native forage. They may also provide additional high-quality resources by planting food plots and providing supplemental feed. However, the relative importance of each nutritional input varies seasonally, which is important for managers to understand when determining how to maximize food production during nutritional stress periods. The degree to which managers invest in each nutritional input will be dependent upon their property layout, financial resources, management goals, and deer density, such that each property will require a unique management plan.

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Table 2.1 – Estimates of nutritional carrying capacity (kg/ha) based on crude protein production in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval and Ladino clover food plots during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	Crude Protein Diet Quality					
	14%		16%		18%	
Nutritional Input	x̄	SE	x̄	SE	x̄	SE
June						
Pine-hardwood (1-yr Burn)	234.6	92.2	115.3	64.6	11.0	6.1
Pine-hardwood (2-yr burn)	53.6	17.0	21.8	9.0	4.2	2.9
Ladino clover	2156.1	107.4	2156.1	107.4	2156.1	107.4
July						
Pine-hardwood (1-yr Burn)	239.2	94.5	147.7	71.7	0.0	0.0
Pine-hardwood (2-yr burn)	70.3	14.0	32.9	10.7	0.0	0.0
Ladino clover	2051.8	219.0	2051.8	219.0	2051.8	219.0
September						
Pine-hardwood (1-yr Burn)	142.5	49.0	8.5	5.8	0.0	0.0
Pine-hardwood (2-yr burn)	45.0	17.0	7.2	4.3	0.0	0.0
Ladino clover	575.4	199.4	575.4	199.4	575.4	199.4

Table 2.2 – Top 10 management plans ranked in order of most cost-effective at 14% crude protein during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

Rank	% Burn	% Food plot	Feed	Total cost	Food production (kg/ha)	Unit cost ($/kg)
June						
1	80%	5%	0	$17,632.00	200.4	$0.34
2	100%	4%	0	$17,345.60	196.0	$0.34
3	100%	5%	0	$19,432.00	217.5	$0.34
4	100%	5%	1	$26,232.00	223.5	$0.45
5	80%	5%	1	$24,432.00	206.4	$0.46
6	100%	4%	1	$24,145.60	202.0	$0.46
7	100%	5%	2	$33,032.00	229.5	$0.56
8	80%	5%	2	$31,232.00	212.4	$0.57
9	100%	4%	2	$30,945.60	208.0	$0.57
10	60%	5%	2	$29,432.00	195.5	$0.58
July						
1	80%	5%	0	$17,632.00	198.6	$0.34
2	100%	4%	0	$17,345.60	194.0	$0.35
3	100%	5%	0	$19,432.00	214.4	$0.35
4	100%	5%	1	$26,232.00	220.4	$0.46
5	80%	5%	1	$24,432.00	204.6	$0.46

Table 2.2 – Continued

Rank	% Burn	% Food plot	Feed	Total cost	Food production (kg/ha)	Unit cost ($/kg)
6	100%	4%	1	$24,145.60	200.0	$0.47
7	100%	5%	2	$33,032.00	226.4	$0.56
8	80%	5%	2	$31,232.00	210.6	$0.57
9	100%	4%	2	$30,945.60	206.0	$0.58
10	60%	5%	2	$29,432.00	194.7	$0.58
September						
1	100%	5%	0	$19,432.00	115.5	$0.65
2	100%	5%	1	$26,232.00	121.5	$0.83
3	100%	4%	1	$24,145.60	111.7	$0.83
4	80%	5%	1	$24,432.00	112.4	$0.84
5	100%	5%	2	$33,032.00	127.5	$1.00
6	100%	4%	2	$30,945.60	117.7	$1.02
7	80%	5%	2	$31,232.00	118.4	$1.02
8	100%	3%	2	$28,859.20	108.0	$1.03
9	80%	4%	2	$29,145.60	108.6	$1.04
10	60%	5%	2	$29,432.00	109.2	$1.04

Table 2.3 – Top 10 management plans ranked in order of most cost-effective at 16% crude protein during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

Rank	% Burn	% Food plot	Feed	Total cost	Food production (kg/ha)	Unit cost ($/kg)
June						
1	80%	5%	0	$17,632.00	152.7	$0.45
2	100%	5%	0	$19,432.00	161.5	$0.46
3	60%	5%	1	$22,632.00	150.0	$0.58
4	80%	5%	1	$24,432.00	158.7	$0.59
5	100%	5%	1	$26,232.00	167.5	$0.60
6	40%	5%	2	$27,632.00	147.1	$0.73
7	60%	5%	2	$29,432.00	156.0	$0.73
8	80%	5%	2	$31,232.00	164.7	$0.73
9	100%	5%	2	$33,032.00	173.5	$0.74
10	100%	4%	2	$30,945.60	152.0	$0.79
July						
1	80%	5%	0	$17,632.00	160.7	$0.42
2	100%	5%	0	$19,432.00	171.5	$0.44
3	60%	5%	1	$22,632.00	156.0	$0.56
4	80%	5%	1	$24,432.00	166.7	$0.57
5	100%	5%	1	$26,232.00	177.5	$0.57

Table 2.3 – Continued

Rank	% Burn	% Food plot	Feed	Total cost	Food production (kg/ha)	Unit cost ($/kg)
6	100%	4%	1	$24,145.60	157.1	$0.59
7	100%	5%	2	$33,032.00	183.5	$0.70
8	80%	5%	2	$31,232.00	172.7	$0.70
9	60%	5%	2	$29,432.00	162.0	$0.70
10	100%	4%	2	$30,945.60	163.1	$0.73
September						
1	40%	5%	1	$20,832.00	58.5	$1.37
2	0%	5%	2	$24,032.00	64.1	$1.45
3	60%	5%	1	$22,632.00	58.5	$1.49
4	20%	5%	2	$25,832.00	64.2	$1.55
5	80%	5%	1	$24,432.00	58.6	$1.61
6	40%	5%	2	$27,632.00	64.5	$1.65
7	100%	5%	1	$26,232.00	58.7	$1.73
8	60%	5%	2	$29,432.00	64.5	$1.76
9	80%	5%	2	$31,232.00	64.6	$1.87
10	100%	5%	2	$33,032.00	64.7	$1.97

Table 2.4 – Top 10 management plans ranked in order of most cost-effective at 18% crude protein during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

Rank	% Burn	% Food plot	Feed	Total cost	Food production (kg/ha)	Unit cost ($/kg)
June						
1	40%	5%	1	$20,832.00	116.7	$0.69
2	60%	5%	1	$22,632.00	117.3	$0.74
3	0%	5%	2	$24,032.00	121.4	$0.76
4	80%	5%	1	$24,432.00	117.9	$0.80
5	20%	5%	2	$25,832.00	122.0	$0.82
6	100%	5%	1	$26,232.00	118.6	$0.85
7	40%	5%	2	$27,632.00	122.7	$0.87
8	60%	5%	2	$29,432.00	123.3	$0.92
9	80%	5%	2	$31,232.00	123.9	$0.97
10	100%	5%	2	$33,032.00	124.6	$1.02
July						
1	0%	5%	1	$17,232.00	108.2	$0.61
2	20%	5%	1	$19,032.00	108.2	$0.68
3	40%	5%	1	$20,832.00	108.2	$0.74
4	60%	5%	1	$22,632.00	108.2	$0.81
5	0%	5%	2	$24,032.00	114.2	$0.81

Table 2.4 – Continued

Rank	% Burn	% Food plot	Feed	Total cost	Food production (kg/ha)	Unit cost ($/kg)
6	20%	5%	2	$25,832.00	114.2	$0.87
7	40%	5%	2	$27,632.00	114.2	$0.93
8	60%	5%	2	$29,432.00	114.2	$1.00
9	80%	5%	2	$31,232.00	114.2	$1.06
10	100%	5%	2	$33,032.00	114.2	$1.12
September						
1	0%	5%	1	$17,232.00	54.7	$1.22
2	20%	5%	1	$19,032.00	54.7	$1.34
3	40%	5%	1	$20,832.00	54.7	$1.47
4	0%	5%	2	$24,032.00	60.7	$1.53
5	60%	5%	1	$22,632.00	54.7	$1.60
6	20%	5%	2	$25,832.00	60.7	$1.64
7	40%	5%	2	$27,632.00	60.7	$1.76
8	60%	5%	2	$29,432.00	60.7	$1.87
9	80%	5%	2	$31,232.00	60.7	$1.99
10	100%	5%	2	$33,032.00	60.7	$2.10

Appendix 1 – Mean biomass production (kg/ha) of forages within pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Legume												
Atlantic pigeonwings (*Clitoria mariana*)	58.9	22.7	6.9	2.8	75.9	26.1	11.7	6.0	53.0	17.4	7.1	3.4
Butterfly pea (Centrosema virginianum)	11.0	5.2	0.5	0.3	17.7	7.6	3.3	1.5	14.7	4.9	10.7	4.6
Chinese lespedeza (*Lespedeza cuneata*)	2.2	2.2	2.8	2.8	5.5	4.4	41.6	37.4	18.8	18.8	0.1	0.0[a]
Creeping lespedeza (*Lespedeza repens*)	3.6	1.6	5.0	2.2	12.2	4.1	7.8	4.2	12.8	3.9	5.8	2.3
Fuzzy bean (*Strophostyles umbellata*)	23.6	8.6	5.7	2.2	39.4	12.5	23.5	7.8	31.4	10.7	23.9	10.3
Hairy small-leaf ticktrefoil (*Desmodium ciliare*)	34.2	24.0	11.0	5.9	41.4	19.4	36.1	16.6	54.6	24.9	19.4	8.5
Hoary pea (*Tephorsia spicata*)	5.8	3.1	1.6	1.1	3.7	1.3	2.3	1.8	9.5	3.2	1.4	1.0
Milk pea (*Galactia volubilis*)	0.2	0.2	2.6	1.3	5.2	2.5	7.1	3.1	8.1	5.2	1.8	1.2

Appendix 1 – Continued

	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
Species	x̄	SE	x̄	SE	x̄	SE	x̄	SE	x̄	SE	x̄	SE
Nuttall's ticktrefoil (*Desmodium nuttallii*)	0.0	0.0	0.0	0.0	1.4	1.4	0.7	0.7	11.8	10.6	3.1	3.1
Partridge pea (*Chamaecrista nictitans*)	4.6	1.4	0.5	0.3	13.5	5.3	4.5	2.5	49.0	13.9	9.4	5.1
Pencil flower (*Stylosanthes biflora*)	0.9	0.6	0.1	0.1	1.8	0.7	0.0	0.0	3.5	1.9	0.0	0.0
Pinebarren ticktrefoil (*Desmodium strictum*)	6.0	5.4	2.5	2.2	13.3	8.4	2.7	2.7	18.9	13.6	11.8	5.5
Rabbit bells (*Crotalaria rotundifolia*)	10.0	8.0	0.4	0.3	7.8	3.9	1.2	0.7	10.7	5.0	11.2	5.6
Slender lespedeza (*Lespedeza virginica*)	8.0	3.2	3.2	1.9	3.2	3.2	0.4	0.3	1.8	1.4	0.7	0.5
Smooth ticktrefoil (*Desmodium laevigatum*)	0.9	0.9	2.2	1.7	1.9	1.5	0.0	0.0	0.0	0.0	2.6	2.2
Vine												
Blackberry (*Rubus* spp.)	32.3	15.7	46.8	12.8	23.8	8.4	52.3	13.6	24.4	9.1	41.8	11.6

Appendix 1 – Continued

Species	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
	x̄	SE	x̄	SE	x̄	SE	x̄	SE	x̄	SE	x̄	SE
Grape (*Vitis* spp.)	0.7	0.7	27.7	15.3	8.3	6.6	36.4	19.1	0.3	0.3	12.9	6.9
Greenbrier (*Smilax* spp.)	4.6	1.9	14.1	4.5	2.3	0.8	12.2	3.1	5.0	2.2	12.3	4.9
Japanese honeysuckle (*Lonicera japonica*)	0.0	0.0	2.3	1.3	0.0	0.0	1.9	1.3	0.0	0.0	2.4	1.6
Partridgeberry (*Mitchella repens*)	0.0	0.0	2.6	1.7	0.0	0.0	0.8	0.6	0.0	0.0	0.8	0.6
Poison ivy (*Toxicodendron radicans*)	0.0	0.0	0.2	0.1	0.0	0.0	2.2	2.2	0.0	0.0	0.0	0.0
Trumpet creeper (*Campis radicans*)	0.0	0.0	0.9	0.9	0.4	0.4	0.3	0.3	0.0	0.0	16.6	15.2
Virginia creeper (*Parthenocissus quinqefolia*)	0.1	0.1	1.2	0.6	0.0	0.0	0.6	0.3	0.7	0.7	1.2	0.7
Yellow jessamine (*Gelsemium sempervirens*)	3.9	2.8	17.7	15.1	11.8	5.9	26.9	12.3	8.1	4.0	35.2	16.9

Appendix 1 – Continued

	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Browse												
Chinese privet (*Ligustrum sinense*)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other browse[b]	170.0	46.3	303.7	77.0	391.9	103.3	360.7	85.4	335.4	82.2	244.9	58.4
Forb[c]	125.1	24.4	98.7	19.5	256.9	58.6	160.4	35.9	268.7	38.8	171.1	29.7
Grass[d]	450.0	51.0	410.9	63.3	652.0	78.3	620.8	99.5	744.8	84.7	555.9	87.1

[a] Standard error less than 0.05.

[b] All remaining browse species that were sampled but not individually separated.

[c] All remaining forb species that were sampled but not individually separated.

[d] All grass species sampled were grouped into a single category.

Appendix 2 – Mean biomass availability[a] (kg/ha) of forages within pine-hardwood stands burned on a 1- (n = 8) or 2-year (n = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Legume												
Atlantic pigeonwings (*Clitoria mariana*)	15.5	7.7	11.9	5.5	60.2	22.5	21.0	7.4	27.1	11.3	22.2	9.9
Butterfly pea (Centrosema virginianum)	10.6	6.7	3.4	2.0	17.7	8.2	7.0	3.4	20.8	14.4	13.8	5.6
Chinese lespedeza (*Lespedeza cuneata*)	12.5	12.2	2.4	2.3	0.4	0.4	6.7	6.7	18.3	11.4	0.2	0.2
Creeping lespedeza (*Lespedeza repens*)	15.9	5.7	17.1	7.2	36.6	11.4	8.7	5.2	26.2	9.6	13.0	6.0
Fuzzy bean (*Strophostyles umbellata*)	15.7	3.9	8.9	3.2	32.0	6.8	12.4	4.4	41.6	8.0	10.5	3.4
Hairy small-leaf ticktrefoil (*Desmodium ciliare*)	31.6	14.5	7.7	4.1	29.7	12.3	17.0	8.1	24.7	10.5	13.8	6.5
Hoary pea (*Tephorsia spicata*)	13.8	6.8	3.0	1.1	22.3	7.8	2.2	1.1	8.8	3.8	6.9	3.8
Milk pea (*Galactia volubilis*)	4.1	2.6	3.0	2.0	5.2	2.4	2.5	1.6	16.2	7.1	4.4	2.7

Appendix 2 – Continued

Species	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
	x̄	SE	x̄	SE	x̄	SE	x̄	SE	x̄	SE	x̄	SE
Nuttall's ticktrefoil (*Desmodium nuttallii*)	0.0	0.0	0.0	0.0	16.0	10.0	11.2	6.2	6.6	4.1	6.1	4.1
Partridge pea (*Chamaecrista nictitans*)	10.7	4.3	11.2	10.8	9.4	2.5	1.5	0.7	39.7	18.7	7.8	3.8
Pencil flower (*Stylosanthes biflora*)	2.1	1.1	0.0	0.0	2.2	1.0	0.0	0.0	4.6	2.8	0.0	0.0
Pinebarren ticktrefoil (*Desmodium strictum*)	2.4	1.6	2.2	1.6	0.4	0.4	3.3	2.7	6.4	3.8	3.5	3.2
Rabbit bells (*Crotalaria rotundifolia*)	0.5	0.4	0.9	0.4	19.8	11.1	1.4	0.9	9.9	6.0	1.7	1.4
Slender lespedeza (*Lespedeza virginica*)	6.5	3.2	10.2	4.3	12.7	6.0	3.6	2.5	14.7	9.0	0.0	0.0
Smooth ticktrefoil (*Desmodium laevigatum*)	11.7	7.1	6.6	4.2	9.1	8.7	11.5	9.9	2.2	1.6	0.0	0.0
Vine												
Blackberry (*Rubus* spp.)	19.5	5.9	15.8	4.7	44.9	22.4	71.6	33.1	41.0	27.4	48.7	16.7

Appendix 2 – Continued

Species	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Grape (*Vitis* spp.)	2.0	1.4	5.2	3.6	2.3	1.4	11.7	6.0	0.2	0.2	7.4	2.8
Greenbrier (*Smilax* spp.)	1.0	0.4	19.1	6.6	15.6	12.8	16.2	5.8	9.3	4.6	7.4	2.9
Japanese honeysuckle (*Lonicera japonica*)	0.3	0.3	3.5	2.0	0.0	0.0	1.4	1.1	0.0	0.0	1.8	1.2
Partridgeberry (*Mitchella repens*)	0.5	0.5	1.2	0.8	0.0	0.0	0.8	0.6	0.0	0.0	0.6	0.4
Poison ivy (*Toxicodendron radicans*)	0.0	0.0	0.2	0.2	0.0	0.0	1.5	0.7	0.0	0.0	0.1	0.0[c]
Trumpet creeper (*Campis radicans*)	0.0	0.0	2.3	1.2	0.0	0.0	2.5	1.3	0.9	0.7	1.8	1.1
Virginia creeper (*Parthenocissus quinqefolia*)	0.2	0.2	1.0	0.6	0.0	0.0	0.6	0.4	0.0[b]	0.0[c]	0.3	0.2
Yellow jessamine (*Gelsemium sempervirens*)	2.0	1.3	5.1	2.8	3.4	1.3	10.0	5.7	3.2	2.1	22.5	11.0

Appendix 2 – Continued

Species	June				July				September			
	1-Year		2-Year		1-Year		2-Year		1-Year		2-Year	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Browse												
Chinese privet (*Ligustrum sinense*)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other browse[d]	180.7	44.5	279.8	56.9	358.1	110.5	265.0	61.8	276.0	61.5	195.4	43.7
Forb[e]	128.2	25.9	123.2	32.2	128.4	24.3	170.4	45.0	203.4	32.9	144.3	33.4
Grass[f]	527.1	157.2	417.0	60.7	672.1	86.2	526.1	71.4	761.3	94.7	466.6	66.4

[a] Species biomass availability was determined by sampling 7 randomly generated points within each pine-hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by deer and were abundant at the study area. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into

brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

[b] Mean biomass less than 0.05 kg/ha.

[c] Standard error less than 0.05.

[d] All remaining browse species that were sampled but not individually separated.

[e] All remaining forb species that were sampled but not individually separated.

[f] All grass species sampled were grouped into a single category.

Appendix 3 – Forage class biomass availability[a] (kg/ha) in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Forage class	$\bar{x}$[b]	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
Grass	527.1	157.2	417.0	60.7	0.742	672.1	86.2	526.1	71.4	0.782	761.3	94.7	466.6	66.4	0.196
Forb	128.2	25.9	123.2	32.2	0.852	128.4	24.3	170.4	45.0	0.406	203.4	32.9	144.3	33.4	0.381
Browse	420.0	77.5	1019.3	153.9	0.023	860.2	167.8	910.4	125.7	0.050	926.0	177.5	1039.4	179.7	0.639
Legume	154.3	29.9	88.6	16.7	0.372	285.9	45.1	113.7	22.5	0.074	273.1	45.3	106.0	20.2	0.030
Vine	25.5	6.2	53.3	11.0	0.051	66.2	30.4	116.2	35.4	0.022	54.6	27.6	90.6	21.0	0.031
Preferred[c]	179.1	32.5	141.5	19.2	0.668	339.9	57.3	226.1	40.0	0.413	322.4	66.2	194.5	27.2	0.653
Total	1254.9	176.9	1701.1	148.0	0.075	2012.9	199.4	1836.4	139.2	0.677	2218.3	208.0	1844.8	171.2	0.518

[a] Estimates based on species biomass availability which was determined by sampling 7 randomly generated points within each pine-hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by

deer and were abundant at the study area. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

[b] Actual means presented. Analyses were conducted using log-transformed data.

[c] Composed of 25 forage species known to be preferred by deer and abundant at the study area.

Appendix 4 – Estimates of nutritional carrying capacity (kg/ha) based on crude protein availability[a] in pine-hardwood stands burned on a 1- (*n* = 8) or 2-year (*n* = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Crude protein	$\bar{x}$[b]	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
18%	8.1	3.7	2.1	1.6	0.164	0.0	0.0	0.0	0.0	---	0.0	0.0	0.0	0.0	---
17%	63.3	20.7	36.0	17.1	0.336	78.1	46.8	25.3	13.2	0.976	0.0	0.0	0.0	0.0	---
16%	87.8	28.5	50.7	22.5	0.372	116.3	64.4	34.3	15.7	0.710	23.6	10.1	3.1	1.7	0.023
15%	125.4	38.1	70.2	29.4	0.105	175.6	74.9	51.5	18.4	0.261	57.4	26.7	12.1	3.6	0.065
14%	179.5	47.5	97.1	37.3	0.090	229.7	83.3	75.2	23.2	0.139	129.0	35.8	37.4	11.7	0.028
13%	249.3	63.6	139.1	49.0	0.123	289.7	96.0	99.0	27.7	0.127	239.1	46.3	84.7	26.3	0.018
12%	364.9	85.0	198.9	58.6	0.147	332.9	93.4	131.1	32.9	0.145	306.4	52.6	120.0	29.5	0.017
11%	473.3	102.6	363.2	87.6	0.526	385.4	88.4	178.3	41.1	0.182	384.2	62.5	160.5	37.0	0.020

Appendix 4 – Continued

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Crude protein	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
10%	488.1	109.0	512.7	88.3	0.570	485.3	84.5	258.1	55.4	0.209	482.1	75.4	226.1	52.7	0.031

[a] Estimates based on species biomass availability which was determined by sampling 7 randomly generated points within each pine-hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by deer and were abundant at the study area. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

[b] Actual means presented. Analyses were conducted using log-transformed data.

Appendix 5 – Estimates of nutritional carrying capacity (kg/ha) based on *in vitro* dry matter digestibility availability[a] in pine-hardwood stands burned on a 1- (n = 8) or 2-year (n = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Digestibility	$\bar{x}$[b]	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
78%	13.7	7.4	42.8	21.4	0.063	11.9	6.5	37.1	23.6	0.501	9.6	8.4	6.7	3.2	0.700
76%	108.9	61.0	220.1	100.7	0.225	43.0	22.6	85.1	53.2	0.225	42.9	15.2	36.5	10.7	0.444
74%	157.4	64.6	256.4	101.3	0.291	101.8	47.8	156.3	74.1	0.028	84.0	29.3	67.2	14.4	0.340
72%	194.3	69.3	273.7	97.1	0.422	170.7	76.1	238.9	113.4	0.474	160.5	46.4	122.1	14.3	0.981
70%	237.4	65.8	304.6	90.5	0.494	279.8	103.0	379.4	156.4	0.946	266.8	83.8	189.0	23.4	0.826
68%	292.8	67.7	364.1	78.3	0.420	373.9	134.8	425.0	162.2	0.863	377.8	100.8	270.9	34.5	0.686
66%	358.7	79.9	417.0	74.0	0.489	398.3	130.9	437.8	158.2	0.880	515.3	116.0	377.8	50.3	0.608
64%	452.9	105.6	487.4	75.5	0.577	448.5	121.6	464.7	150.2	0.878	694.2	114.5	493.9	69.3	0.389

Appendix 5 – Continued

	June					July					September				
	1-Year		2-Year			1-Year		2-Year			1-Year		2-Year		
Digestibility	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P	$\bar{x}$	SE	$\bar{x}$	SE	P
62%	487.0	109.5	540.9	75.0	0.539	581.7	108.0	536.4	133.5	0.814	807.7	138.3	534.2	84.1	0.295

[a] Estimates based on species biomass availability which was determined by sampling 7 randomly generated points within each pine-hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by deer and were abundant at the study area. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

[b] Actual means presented. Analyses were conducted using log-transformed data.

Appendix 6 – Digestible protein availability[a] (kg/ha) in pine-hardwood stands burned on a 1- (n = 8) or 2-year (n = 8) interval during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	1-Year		2-Year		
Month	$\bar{x}$[b]	SE	$\bar{x}$	SE	P
June	36.6	7.8	39.5	5.4	0.434
July	49.9	7.3	34.9	5.6	0.544
September	45.2	6.6	27.1	4.5	0.122

[a] Estimates based on species biomass availability which was determined by sampling 7 randomly generated points within each pine-hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by deer and were abundant at the study area. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

[b] Actual means presented. Analyses were conducted using log-transformed data.

Appendix 7 – Mean biomass production (kg/ha) of forages in mature hardwood stands (*n* = 6) during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June		July		September	
Species	x̄	SE	x̄	SE	x̄	SE
Legume						
Atlantic pigeonwings (*Clitoria mariana*)	0.2	0.2	0.2	0.1	1.2	0.7
Butterfly pea (Centrosema virginianum)	0.0	0.0	0.0	0.0	0.1	0.1
Chinese lespedeza (*Lespedeza cuneata*)	0.0	0.0	0.5	0.5	0.0	0.0
Creeping lespedeza (*Lespedeza repens*)	0.0	0.0	0.0	0.0	0.0	0.0
Fuzzy bean (*Strophostyles umbellata*)	0.0	0.0	0.2	0.2	0.1	0.1
Hairy small-leaf ticktrefoil (*Desmodium ciliare*)	0.0	0.0	0.0	0.0	0.0	0.0
Hoary pea (*Tephorsia spicata*)	0.0	0.0	0.0	0.0	0.0	0.0
Milk pea (*Galactia volubilis*)	0.0	0.0	0.0[a]	0.0[b]	0.0	0.0
Nuttall's ticktrefoil (*Desmodium nuttallii*)	0.0	0.0	0.0	0.0	0.0	0.0
Partridge pea (*Chamaecrista nictitans*)	0.0	0.0	0.1	0.1	0.0	0.0
Pencil flower (*Stylosanthes biflora*)	0.0	0.0	0.0	0.0	0.0	0.0
Pinebarren ticktrefoil (*Desmodium strictum*)	0.0	0.0	0.1	0.1	0.0	0.0
Rabbit bells (*Crotalaria rotundifolia*)	0.0	0.0	0.0	0.0	0.0	0.0
Slender lespedeza (*Lespedeza virginica*)	0.0	0.0	0.0	0.0	0.0	0.0
Smooth ticktrefoil (*Desmodium laevigatum*)	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 7 – Continued

Species	June		July		September	
	x̄	SE	x̄	SE	x̄	SE
Vine						
Blackberry (*Rubus* spp.)	0.4	0.3	0.1	0.1	0.0	0.0
Grape (*Vitis* spp.)	0.0[a]	0.0[b]	0.2	0.2	0.8	0.6
Greenbrier (*Smilax* spp.)	7.4	2.9	2.3	0.9	9.7	4.7
Japanese honeysuckle (*Lonicera japonica*)	5.9	3.2	3.2	1.5	2.4	1.1
Partridgeberry (*Mitchella repens*)	1.2	1.0	3.1	2.3	3.7	1.8
Poison ivy (*Toxicodendron radicans*)	0.2	0.1	0.8	0.4	0.6	0.3
Trumpet creeper (*Campis radicans*)	0.0	0.0	0.1	0.1	0.0	0.0
Virginia creeper (*Parthenocissus quinqefolia*)	1.5	0.5	1.7	0.6	3.5	1.4
Yellow jessamine (*Gelsemium sempervirens*)	0.2	0.2	1.3	0.9	1.3	0.8
Browse						
Chinese privet (*Ligustrum sinense*)	0.9	0.7	4.1	2.2	5.1	4.4
Other browse	11.0	2.3	26.7	12.9	25.1	10.3
Forb	5.1	3.4	2.6	0.9	4.7	2.3
Grass	88.7	21.2	104.9	25.5	131.8	30.3

[a] Mean biomass less than 0.05 kg/ha.

[b] Standard error less than 0.05.

[c] All remaining browse species that were sampled but not individually separated.

[d] All remaining forb species that were sampled but not individually separated.

[e] All grass species sampled were grouped into a single category.

Appendix 8 – Mean biomass availability[a] (kg/ha) of forages in mature hardwood stands (n = 6) during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June		July		September	
Species	x̄	SE	x̄	SE	x̄	SE
Legume						
Atlantic pigeonwings (*Clitoria mariana*)	0.5	0.4	1.5	1.0	0.3	0.3
Butterfly pea (Centrosema virginianum)	0.0	0.0	0.0	0.0	0.0	0.0
Chinese lespedeza (*Lespedeza cuneata*)	0.0	0.0	0.0	0.0	0.0	0.0
Creeping lespedeza (*Lespedeza repens*)	0.0	0.0	0.0	0.0	0.0	0.0
Fuzzy bean (*Strophostyles umbellata*)	0.4	0.3	0.0	0.0	0.0	0.0
Hairy small-leaf ticktrefoil (*Desmodium ciliare*)	0.0	0.0	0.0	0.0	0.0	0.0
Hoary pea (*Tephorsia spicata*)	0.0	0.0	0.0	0.0	0.0	0.0
Milk pea (*Galactia volubilis*)	0.0	0.0	0.0	0.0	0.0	0.0
Nuttall's ticktrefoil (*Desmodium nuttallii*)	0.0	0.0	0.0	0.0	0.0	0.0
Partridge pea (*Chamaecrista nictitans*)	0.0	0.0	0.0	0.0	0.0	0.0
Pencil flower (*Stylosanthes biflora*)	0.0	0.0	0.0	0.0	0.0	0.0
Pinebarren ticktrefoil (*Desmodium strictum*)	0.0	0.0	0.0	0.0	0.0	0.0
Rabbit bells (*Crotalaria rotundifolia*)	0.0	0.0	0.0	0.0	0.0	0.0
Slender lespedeza (*Lespedeza virginica*)	0.3	0.3	0.0	0.0	0.0	0.0
Smooth ticktrefoil (*Desmodium laevigatum*)	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 8 – Continued

Species	June		July		September	
	x̄	SE	x̄	SE	x̄	SE
Vine						
Blackberry (*Rubus* spp.)	0.0	0.0	7.6	7.4	0.6	0.6
Grape (*Vitis* spp.)	0.3	0.3	0.5	0.3	4.3	3.0
Greenbrier (*Smilax* spp.)	9.0	3.2	14.0	6.1	3.6	1.5
Japanese honeysuckle (*Lonicera japonica*)	14.2	9.2	2.3	1.6	0.3	0.1
Partridgeberry (*Mitchella repens*)	0.9	0.5	1.3	0.7	2.1	1.0
Poison ivy (*Toxicodendron radicans*)	0.4	0.3	0.8	0.6	0.2	0.1
Trumpet creeper (*Campis radicans*)	0.0	0.0	0.0	0.0	0.0	0.0
Virginia creeper (*Parthenocissus quinqefolia*)	1.9	0.6	3.0	1.0	0.4	0.2
Yellow jessamine (*Gelsemium sempervirens*)	1.0	0.7	1.8	1.1	3.2	2.2
Browse						
Chinese privet (*Ligustrum sinense*)	1.8	1.5	0.0	0.0	0.0	0.0
Other browse[b]	10.8	2.8	12.2	4.3	6.4	1.8
Forb[c]	1.6	0.6	3.2	1.2	0.9	0.4
Grass[d]	153.5	43.7	145.8	30.5	137.6	41.6

[a] Species biomass availability was determined by sampling 7 randomly generated points within each mature hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by deer and were abundant at the study area.

Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

[b] All remaining browse species that were sampled but not individually separated.

[c] All remaining forb species that were sampled but not individually separated.

[d] All grass species sampled were grouped into a single category.

Appendix 9 – Estimates of nutritional carrying capacity (kg/ha) based on crude protein production and availability[a] in mature hardwood stands (*n* = 6) during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

	June		July		September	
Crude protein	x̄	SE	x̄	SE	x̄	SE
Production						
18%	0.0	0.0	0.0	0.0	0.0	0.0
17%	0.0	0.0	0.2	0.2	0.0	0.0
16%	0.0	0.0	0.3	0.2	0.1	0.1
15%	0.0	0.0	0.8	0.5	0.2	0.1
14%	1.6	1.3	1.0	0.6	0.5	0.3
13%	5.9	3.1	3.9	2.3	3.0	1.3
12%	9.1	4.6	7.4	3.9	9.9	5.6
11%	16.4	8.6	13.2	5.6	18.4	7.4
10%	27.8	8.9	21.0	8.7	33.9	11.0
Availability						
18%	0.0	0.0	0.0	0.0	0.0	0.0
17%	0.4	0.4	1.7	1.2	0.0	0.0
16%	0.6	0.6	2.2	1.5	0.0	0.0
15%	0.9	0.9	2.9	2.0	0.0	0.0
14%	1.9	1.6	4.0	2.7	0.0	0.0

Appendix 9 – Continued

	June		July		September	
Crude protein	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
13%	6.3	2.6	6.3	4.2	0.5	0.5
12%	9.9	4.0	9.4	6.0	0.6	0.6
11%	17.2	6.0	13.6	8.0	1.1	0.8
10%	29.7	5.7	34.1	11.7	4.1	1.2

[a] Estimates based on species biomass availability which was determined by sampling 7 randomly generated points within each mature hardwood stand during 3 nutritional stress periods. We composed a list of 25 forage species that were known to be preferred by deer and were abundant at the study area. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all vegetation within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height. Vegetation was separated individually into brown paper bags for the 25 preferred forage species and all remaining vegetation was grouped into a grass, forb, or browse category.

Appendix 10 – Mean biomass production and availability[a] (kg/ha), crude protein (%), and *in vitro* dry matter digestibility (%) of Alfalfa and Ladino clover during 3 periods in 2014 and 2015 at Three Notch Wildlife Research Foundation in east-central Alabama, USA.

		Biomass					
		Production		Availability		Nutritional Content	
Year	Species	$\bar{x}$	SE	$\bar{x}$	SE	CP %	*IVDMD*
2014	Alfalfa						
	June	---[b]	---	1367.2	118.3	22.92	70.44
	July	1502.5	180.6	1257.1	256.6	20.66	76.33
	September	3175.2	300.7	2127.9	199.3	18.71	69.78
	Clover						
	June	---[c]	---	2823.5	201.5	21.16	87.76
	July	2642.3	171.0	2335.9	133.0	17.85	89.4
	September	976.9	305.7	1095.3	327.1	19.81	86.92
2015	Alfalfa						
	June	---[b]	---	2142.1	139.9	24.99	76.70
	July	2297.5	263.5	2148.1	394.7	18.03	75.08
	September	749.9	264.3	565.9	105.7	22.10	74.29
	Clover						
	June	2156.1	107.4	1893.1	217.2	21.68	85.15
	July	1461.4	205.8	1650.6	101.7	23.03	85.02

Appendix 10 – Continued

		Biomass					
		Production		Availability		Nutritional Content	
Year	Species	$\bar{x}$	SE	$\bar{x}$	SE	CP %	*IVDMD*
	September	173.9	130.6	203.3	124.0	23.56	93.25

[a] Food plot biomass availability was determined by sampling 3 randomly generated points within each food plot during 3 nutritional stress periods. Each random point was sampled with a 0.25 m^2 quadrat using the destructive harvest method and all food plot forage within each quadrat was clipped 2.54 cm above the ground and up to 1.5 m in height.

[b] Did not measure Alfalfa production in June 2014 or 2015.

[c] Did not measure clover production in June 2014.