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Forage availability and nutritional carrying capacity for cervids following prescribed fire and herbicide applications in young mixed-hardwood forest stands in the Cumberland Mountains, Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Jordan Scott Nanney entitled "Forage availability and nutritional carrying capacity for cervids following prescribed fire and herbicide applications in young mixed-hardwood forest stands in the Cumberland Mountains, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Craig A. Harper, Major Professor

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DEDICATION

I dedicate this thesis to my parents, Sharon and Norman Nanney, who have encouraged, supported, and loved me unconditionally throughout my life. I also dedicate this thesis to my great-uncle David Byers and my grandfather John Wayne Jolley who instilled in me a passion for the outdoors and fueled my desire to pursue a career in wildlife management.

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ABSTRACT

I evaluated the influence of timber harvest combined with prescribed fire and/or herbicide in young mixed-hardwood forest on forage availability and nutritional carrying capacity (NCC) for elk (*Cervus elaphus*) and white-tailed deer (*Odocoileus virginianus*) at the North Cumberland Wildlife Management Area (WMA), July-August, 2013-15. I combined land cover data, forest management data, field management data, and forage availability data to model summer elk forage availability across the WMA.

I compared forage availability, NCC (animal days/ha) using 12 and 14% crude protein (CP) nutritional constraints, and vegetation composition among 6 young forest treatments, reclaimed surface mines (MINE), and closed-canopy mature forest (MATFOR). Forage availability (kg/ha) in MATFOR and MINE was less than forage availability in all young forest treatments. Less forage was available in young forest stands that were treated with both fire and herbicide than forage availability in other young forest treatments. NCC estimates at the 12 and 14% CP constraint were greater in all young forest treatments and MINE than in MATFOR. Herbaceous species coverage in MINE and young forest treated with a combination of fire and herbicide was greater than all other young forest treatments and MATFOR, which did not differ. Woody species coverage was greater in MATFOR and untreated young forest than in all other young forest treatments and MINE. Woody species coverage was reduced most in young forest stands treated with both fire and herbicide and in MINE.

Closed-canopy forest produced less summer elk forage (147 kg/ha) than all other land cover types across the WMA, but accounted for the largest percentage of land cover within 6 generated summer elk use-area buffers (69-94%) and across the WMA (80%). Young forest produced the most summer elk forage (1,116 kg/ha, 4,879,152 kg total) and outperformed the impact of wildlife openings (742 kg/ha, 215,024 kg total).

My results indicate periodic prescribed fire will maintain increased forage availability and NCC for elk and deer in young mixed-hardwood forest stands across the eastern United States and converting closed-canopy forest to young forest through timber harvest is the most efficient method for increasing summer elk forage availability on the North Cumberland WMA.

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INTRODUCTION

State wildlife agencies in Arkansas, Kentucky, Michigan, Missouri, North Carolina, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin are working to restore elk (*Cervus elaphus*) populations in select areas in the eastern United States (Rocky Mountain Elk Foundation 2016). Elk are an important species not only ecologically because of their role as herbivores, but also economically and socially as they provide recreational opportunities for hunters, photographers, artists, and other wildlife enthusiasts (USFWS 2011). Successful restoration of elk in the eastern United States hinges on the successful restoration and maintenance of elk habitat, which also could enhance habitat for white-tailed deer (*Odocoileus virginianus;* hereafter deer) and other wildlife species.

The Tennessee Wildlife Resources Agency released 201 elk across the North Cumberland Wildlife Management Area (WMA) from 2000–2008 as part of the Tennessee Elk Restoration Project. The North Cumberland WMA is central to the Tennessee Elk Restoration Zone and serves as the focus of elk management in Tennessee. A population viability analysis on Tennessee's reintroduced elk herd predicted that the population would not be sustainable unless survival rates were increased (Kindall et al. 2011).

Forage availability during spring and summer is a critical component of elk habitat and likely has the largest influence on the number of elk that breed and successfully reproduce in all portions of their range (Cook et al. 1998, Cook 2003). As such, management of forage availability may be an important strategy for increasing elk population viability in Tennessee. Closed-canopy mature forests currently dominate much of the landscape across the southern Appalachians and limit available sunlight to stimulate and support understory vegetation (Anderson and Katz 1993, Webster et al. 2005, Rossell et al. 2005, Shaw et al. 2010, McCord et al. 2014), which limits food and cover resources for many wildlife species, including elk and deer (Beck and Harlow 1981, de Calesta 1994, Johnson et al. 1995, Lashley et al. 2011, McCord et al. 2014). The prominence of closed-canopy forest in and around the Cumberland Mountains of Tennessee threatens the success of elk restoration and techniques to increase nutritional carrying capacity must be evaluated to enable population expansion.

As a result, attention has been focused on understanding the availability of elk forage across the WMA and evaluating techniques to increase forage availability to sustain Tennessee's elk herd and enable population growth. The University of Tennessee in cooperation with the Tennessee Wildlife Resources Agency and the Rocky Mountain Elk Foundation initiated a study to investigate elk habitat management techniques that may increase elk forage availability to promote increased elk herd health and vigor in Tennessee.

The overall goal of the project was to evaluate the influence of timber harvest combined with prescribed fire and/or herbicide application in young mixed-hardwood forest stands on vegetation composition, forage availability, and nutritional carrying capacity (NCC) for elk and deer across the North Cumberland WMA, then use that information to develop a spatially-explicit summer elk forage model.

I collected data, along with multiple technicians, to measure vegetation composition, forage availability, and NCC across the North Cumberland WMA from July-August 2013-2015. I used those data along with 16 years of site-specific forest management data, and site-specific field management data, combined with land cover data we retrieved from the 2011 National Land Cover Database (Homer et al. 2015), to model summer elk forage availability across the North Cumberland WMA. I then identified six elk use-areas across the study area to help demonstrate the applicability of the model. My identified elk use-areas should not be confused with measured elk home ranges or identified core areas. Elk use-areas were simply locations across the North Cumberland WMA where TWRA had consistently documented the presence of elk during summer through trail-camera surveys and visual observation. The model was designed to provide elk managers and biologists a resource to help guide future elk habitat management decisions on the WMA. To demonstrate the applicability of our model, we conducted spatial analysis of summer forage availability to address the following specific management questions:

1) What is the mean summer elk forage availability across the North Cumberland Wildlife Management Area and within elk use-area buffers?

2) How well are summer elk forage resources distributed across the North Cumberland Wildlife Management Area?

3) Which elk habitat management technique has the largest impact on summer elk forage availability: harvesting timber or maintaining wildlife openings?

I developed 2 chapters. In Chapter 1, I evaluated the influence of timber harvest combined with prescribed fire and/or herbicide application in young mixed-hardwood forest stands on vegetation composition, forage availability, and NCC for elk and deer. In Chapter 2, I described the development of a spatially-explicit summer elk forage model and I applied the model to answer the previously mentioned management questions addressing elk habitat across the North Cumberland WMA.

CHAPTER I. FORAGE AVAILABILITY FOR CERVIDS FOLLOWING DISTURBANCE IN HARDWOOD FORESTS

ABSTRACT Closed-canopy forests dominate the landscape across much of the eastern United States and often lack a well-developed understory, which limits nutrition available for cervids. We evaluated the influence of timber harvest combined with prescribed fire and/or herbicide treatment in young mixed-hardwood forests on forage availability and nutritional carrying capacity (NCC) for elk (*Cervus elaphus*) and white-tailed deer (*Odocoileus virginianus*) at the North Cumberland WMA, July-August, 2013-15. We compared forage availability, NCC (animal days/ha) using 12 and 14% crude protein (CP) nutritional constraints, and vegetation composition in untreated mature forest stands (MATFOR), reclaimed surface mines (MINE), and 6 harvest treatments (timber harvest alone (HARV), early growing-season fire (EBURN), late growing-season fire (LBURN), herbicide alone (HERB), herbicide and early growing-season fire (EBHERB), and herbicide and late growing-season fire (LBHERB)). Forage availability (kg/ha) in MATFOR and MINE was less than in all harvest treatments. More forage was available in HARV, EBURN, LBURN, and HERB than in EBHERB and LBHERB. NCC estimates at the 12% CP constraint were greater in all harvest treatments and MINE than in MATFOR. NCC estimates at the 12% CP constraint were greater in prescribed fire only treatments than in MINE. NCC estimates at the 14% CP constraint were less in MATFOR than all timber harvest treatments and MINE, which were not different. Herbaceous species coverage in LBHERB, EBHERB, and MINE was greater than in HARV, EBURN, LBURN, HERB, and MATFOR, which were not different. Woody species coverage was greater in MATFOR and HARV than in all other harvest treatments and MINE. Woody species coverage in LBHERB, EBHERB and MINE, was less than in HERB, EBURN, and LBURN. Our data indicate using periodic prescribed fire as well as following an herbicide application with prescribed fire are effective

techniques to maintain increased forage availability and NCC for elk and deer in young mixed-hardwood forest stands across the eastern United States.

KEY WORDS cervid, deer, elk, forage availability, herbicide, nutritional carrying capacity, prescribed fire, young forest.

Several state wildlife agencies in the eastern United States, including those in Arkansas, Kentucky, Missouri, North Carolina, Pennsylvania, Tennessee, Virginia, and West Virginia, are working to restore elk (*Cervus elaphus*) populations in select areas (Rocky Mountain Elk Foundation 2016). Elk are an important species not only ecologically, but also economically and socially as they provide recreational opportunities for hunters, photographers, artists, and other wildlife enthusiasts (USFWS 2011). Successful restoration of elk in the eastern United States hinges on the successful restoration and maintenance of elk habitat, which could also enhance habitat for white-tailed deer (*Odocoileus virginianus;* hereafter deer). Closed-canopy mature forests currently dominate the landscape across much of the eastern United States and limit available sunlight to stimulate and support understory vegetation (Anderson and Katz 1993, Webster et al. 2005, Rossell et al. 2005, Shaw et al. 2010, McCord et al. 2014). Closed-canopy forests limit food and cover resources for many wildlife species, including elk and deer that benefit from a well-developed forest understory (Beck and Harlow 1981, de Calesta 1994, Johnson et al. 1995, Lashley et al. 2011, McCord et al. 2014). The prominence of closed-canopy forest in the eastern United States threatens the success of elk restoration and techniques to increase nutritional carrying capacity should be evaluated as populations expand.

Young forest stands (stand initiation stage) provide greater forage availability for elk and deer than stands that have experienced canopy closure (stem exclusion stage and beyond) (Ford et al. 1993, Strong and Gates 2006). Young forests provide large amounts of highly nutritious, digestible, and selected forage species for elk and deer (Irwin and Peek 1983, Edge et al. 1988, Ford et al. 1993, Johnson et al. 1995). Nutritional demands of elk and deer are greatest during summer to support lactation and juvenile growth (Oftedal 1985, Cook et al. 1996, Hewitt 2011). Inadequate summer forage availability results in poor nutrition, which may negatively impact pregnancy rates, age at first breeding, fetal survival, birth weight, juvenile growth, juvenile survival, and adult survival of elk (Cook et al. 1996, Cook 2002, Cook et al. 2004, Hewitt 2011). Nutritional requirements and foraging preferences of elk and deer are similar (Cook 2002, Beck and Peek 2005, Hewitt 2011), but their foraging strategies are different. Elk have greater digestive capabilities and a wider range of foraging options in comparison to deer because elk are intermediate feeders, whereas deer are concentrate selectors (Cook 2002, Hewitt 2011), which is the most limited of the morphophysiological feeding types (Hofmann 1988). Large proportions of young forest stands are characterized by forbs and woody species, which are the most selected groups of forages by elk and deer during summer (Waller and Alverson 1997, Beck and Peek 2005, Schnieder et al. 2006, Lupardus et al. 2011). Increasing disturbance to set-back succession in mixed-hardwood forest stands is essential to provide high-quality forage plants, increase forage availability, and increase nutritional carrying capacity (NCC) for elk and deer.

Disturbance techniques, such as canopy reduction, prescribed fire, and herbicide applications, may increase forage availability and improve forage quality for elk and deer. Canopy reduction methods, such as clearcutting, shelterwood harvest, improvement cuts, and thinning operations, allow increased sunlight to the forest floor, which stimulates additional browse and herbaceous forage (Collins and Urness 1983, Beck and Harlow 1981, Ford et al. 1993, Strong and Gates 2006, Lashley et al. 2011). Characteristics of closed-canopy forests in the eastern United States often make it necessary to couple canopy disturbance with prescribed fire to achieve increased forage for cervids (Masters et al. 1992, Sachro et al. 2005, Van Dyke and Darragh 2007, Shaw et al. 2010, Lashley et al. 2011). The use of herbicides to manipulate vegetation composition and control undesirable plant species can increase the availability of more nutritious vegetation and has implications for increasing forage availability for elk and deer (Hurst and Warren 1986, Rice et al. 1997, Edwards et al. 2004, Chamberlain and Miller 2006).

Combining timber harvest, prescribed fire, and herbicide techniques to set-back succession and to improve and maintain forage availability and NCC for elk and deer in the eastern United States may be an efficient approach when working to restore elk habitat in areas where closed-canopy forests dominate the landscape and limits the success of elk restoration. Our objectives were to evaluate the influence of timber harvest combined with prescribed fire and/or herbicide application in young mixed-hardwood forest stands on vegetation composition, forage availability, and NCC for elk and deer. We hypothesized NCC for elk and deer would be most effectively increased and maintained in timber harvest treatments that involved repeated prescribed fire and that treatments involving herbicide application would reduce woody species composition.

STUDY AREA

We conducted our research at 3 study sites across the North Cumberland Wildlife Management Area (WMA), located in Anderson, Campbell, and Scott counties, Tennessee, USA (Figure 1.1). Elevation (600-1,000 m), weather, and geographical characteristics were similar across all sites. In addition to the naturally mountainous terrain, a history of strip, bench, and deep coal mining in the area resulted in benches and valleys distributed throughout the study area. Shale and siltstone influences have resulted in acidic, loamy, and well-drained soils (Conner 2002). Mean daily temperatures ranged from 1° C to 24° C and mean annual precipitation was 137 cm (National Oceanic and Atmospheric Administration 2016). The North Cumberland WMA is approximately 60,750 ha and is centrally located within Tennessee's 272,000 ha elk restoration zone. The dominant vegetation type across the study area was mixed-hardwood forest (87%) with interspersed openings characterized as reclaimed surface mines or wildlife openings (12%) and a small cropland component (1%) (Tennessee Wildlife Resources Agency 2000). Mature forest across the study area primarily consisted of *Quercus* spp., *Carya* spp., *Acer* spp., and *Liriodendron tulipifera* with lesser amounts of *Fagus grandifolia* and *Pinus* spp. interspersed. Reclaimed surface mines were dominated by tall fescue (*Schedonorus arundinaceus*) and sericea lespedeza (*Lespedeza cuneata*) with scattered autumn olive (*Eleagnus umbellata*) and black locust (*Robinia psuedoacacia*). Most wildlife openings were mowed annually and dominated by perennial cool-season grasses (tall fescue, orchardgrass (*Dactylis glomerata*), and timothy (*Phleum pretense*)) with native forb species and perennial clovers present to a lesser extent.

METHODS

Study Design

We selected 18 young forest stands across the North Cumberland WMA, all harvested in 2010. Subsequently, we contracted a professional crew to treat 9 stands (3 at each site) with a foliar herbicide application consisting of a tank mixture of glyphosate (5%), imazapyr (1%), metsulfuron-methyl (0.15%), Optima® surfactant (0.10%), and Bullseye® spray pattern indicator (0.10%) in the summer of 2012. We used Accord® XRT II (glyphosate, 50.2%) and DuPont® Lineage Clearstand (imazapyr, 63.2% and metsulfuron-methyl, 9.5%) as mixing agents to achieve the appropriate tank mix ratio. We treated 4 stands with late-growing season fire (2 that overlapped with herbicide treatments) in the fall of 2012 and 2014 and we treated 8 stands with early-growing season fire (4 that overlapped with herbicide treatments) in the spring of 2013 and 2015. We assigned random data collection points in each young forest stand, mature forest stand, and mine site (190 total) using ArcGIS. We collected data to estimate vegetation composition, browse selectivity, forage availability, and NCC at each predetermined point during July-August, 2013-15.

Vegetative Composition

We used the point-intercept transect method to collect vegetative composition data (Canfield 1941). We established a 40-m line transect centered on each random point determined by ArcGIS. We recorded each plant species that intercepted each transect at 2-m intervals.

Forage Sampling

We randomly placed 2 1-m^2 forage collection frames along each transect. We collected leaf biomass and young twig ends ($\leq$1 growing-season) from woody plants and herbaceous plants (excluding large stems) that were $\leq$2 meters vertical height within the collection frame (Lashley et al. 2014). We collected forages according to genus in forage collection bags and labeled each sample.

Forage Analysis

We dried all forage samples to constant mass in an air-flow dryer at 50^{o}C. We weighed dried forage samples using a digital scale and recorded weight in grams. We packaged and submitted forage samples from each genus within each treatment for nutritional analysis using wet chemistry methods at the Agriculture Service Laboratory at Clemson University. Using wet chemistry is especially important when measuring nutritional content of naturally occurring forages because the secondary method, NIRS (Near Infrared Reflectance Spectroscopy), is based on reference evaluations of nutrients from calibrated forages analyzed by wet chemistry. The majority of forage species considered in this study have not had reference evaluations to develop calibrations for the NIRS method.

Browse Selectivity

We obtained browse selectivity data by recording evidence of browsing along the point-intercept transect. We documented browse intensity by comparing the number of stems eaten to the total number of stems available on each plant (Shaw et al. 2010). We used the browse intensity data to develop a selectivity index to rank selected forages (Chesson 1983).

Nutritional Carrying Capacity

We estimated NCC using a mixed-diet approach incorporating nutritional constraints as outlined in Hobbs and Swift (1985). We selected nutritional constraints based on crude protein requirements for antler growth (12%) and peak lactation (14%) for elk and deer (Cook 2002, Hewitt 2011). We also used the average lactation intake rates of a cow elk weighing 236 kg (7.7 kg (dry mass)/day) and a white-tailed deer doe weighing 50 kg (2.3 kg (dry mass)/day) to complete the NCC model (Cook 2002, Hewitt 2011).

DATA ANALYSIS

Our experimental design was a Completely Randomized Design with replication, sampling, and repeated measures. We conducted mixed-model ANOVAs using SAS 9.4 (SAS Institute, Cary, NC) to compare means of forage availability, NCC, and vegetation composition among treatment stands and sampled vegetation types. We used the Tukey's Procedure to compare means at $\alpha = 0.05$. Unique subject numbers were given to each data collection point because the same points were revisited in each year of the study. Fixed effects were treatment, year, and treatment*year. Random effects were replication within treatment and subject within replication. We developed orthogonal contrasts to gain greater insight to our data and explain differences between treatments when treatment*year interactions were present.

We used the Chesson Index to determine browse species selection (Chesson 1983). Each plant species received an index value based on the number of stems of plant species that are browsed compared to the proportion of each species available. An Index cut-off was determined to rank species selection.

RESULTS

Forage Availability

There was a treatment*year interaction within forage availability estimates (Table 1.1). Using orthogonal contrasts ($\alpha = 0.05$), we determined forage availability in MATFOR and MINE did not differ ($P = 0.1244$) and was less than all young forest treatments ($F = 101.70$, $P < 0.0001$ and $F = 48.94$, $P < 0.0001$ respectively) (Figure 1.2). Forage availability in harvested stands that were not treated with fire, HARV and HERB, were similar ($P = 0.4912$) to stands that were burned. Forage availability decreased when herbicide was combined with prescribed fire in comparison to treatments involving prescribed fire alone ($F = 8.83$, $P = 0.0107$) and herbicide alone ($P = 0.0484$) (Figure 1.3), but did not differ when compared to harvest only ($P = 0.1916$). Seasonality of fire did not result in differences among forage availability estimates ($P = 0.3611$). Forage availability declined 5 years post-harvest in HARV to levels that were approaching MINE and MATFOR.

Species Selection at North Cumberland WMA

We detected 297 plant species using the point-intercept transect method during our study. Out of those 297 species, we identified 28 species as moderately or highly selected forages using a selection cut-off value of $\alpha = 0.010$ determined through our selectivity index calculations

(Chesson 1978) (Table 1.2). Almost half of the selected forage species were forbs (13 species), whereas 5 bramble and vine species were selected, 5 shrub species were selected, and 5 tree species were selected. Although we detected 21 gramminoid species, no grasses were selected by elk or deer.

Nutritional Carrying Capacity: 12% Crude Protein Constraint

There was a treatment*year interaction ($P < 0 .0001$) when NCC was evaluated at the 12% crude protein constraint (Table 1.3). Orthogonal contrasts identified differences ($\alpha = 0.05$) in NCC between treatments at the 12% crude protein constraint. Nutritional carrying capacity was greater in HARV (40 elk days/ha, 132 deer days/ha, $F = 17.73$, $P = 0.0007$), HERB (43 elk days/ha, 143 deer days/ha, $F = 21.67$, $P = 0.0003$), EBURN (52 elk days/ha, 171 deer days/ha, $F = 34.81$, $P < 0.0001$), LBURN (46 elk days/ha, 153 deer days/ha, $F = 22.13$, $P = 0.0005$), EBHERB (37 elk days/ha, 122 deer days/ha, $F = 16.04$, $P = 0.0015$), and LBHERB (35 elk days/ha, 116 deer days/ha, $F = 10.54$, $P = 0.0058$) in comparison to MATFOR (8 elk days/ha, 27 deer days/ha) (Figure 1.4). Nutritional carrying capacity in MINE (31 elk days/ha, 102 deer days/ha, $F = 10.26$, $P = 0.0073$) was similar to HARV ($P = 0.2739$), HERB ($P = 0.1436$), and combined herbicide and fire treatments ($P = 0.4690$), but NCC was less in MINE than in fire only treatments ($F = 6.79$, 0.0218). Following timber harvest with herbicide ($P = 0.7048$), prescribed fire ($P = 0.2453$), or a combination of herbicide and prescribed fire ($P = 0.6033$) did not increase or decrease NCC at the 12% crude protein constraint. Seasonality of fire had no impact on NCC ($P = 0.5290$).

Nutritional Carrying Capacity: 14% Crude Protein Constraint

There was a treatment effect ($F = 5.93$, $P = 0.0013$) when NCC was estimated at the 14% crude protein nutritional constraint (Table 1.4). Nutritional carrying capacity in MATFOR was less than all timber harvest treatments and MINE (Table 1.4). Nutritional carrying capacity was greater in EBURN and LBURN than HARV and HERB. No differences were detected between MINE, EBHERB, LBHERB, and all other harvest treatments.

Vegetation Composition

Woody species coverage.—There was a treatment*year interaction ($P < 0.0001$) for woody species (shrubs, trees, and woody vines) coverage (Table 1.5). Orthogonal contrasts (α = 0.05) indicated woody composition in HARV (47%) was greater than HERB (32%, $F = 5.61$, $P = 0.0288$), prescribed fire only treatments (29%, $F = 9.76$, $P = 0.0060$), treatments involving herbicide and prescribed fire (15%, $F = 30.31$, $P < 0.0001$), and MINE (15%, $F = 25.67$, $P < 0.0001$), but similar to MATFOR ($P = 0.8959$) (Figure 1.5). Woody composition did not differ in stands that were treated with herbicide only versus stands that were treated with prescribed fire alone ($P = 0.6587$), but combining herbicide with prescribed fire decreased woody composition more than using herbicide alone ($F = 8.08$, $P = 0.0110$) or prescribed fire ($F = 7.91$, $P = 0.0127$) (Figure 1.5). Woody composition was greater in herbicide only ($F = 6.89$, $P = 0.0181$) and prescribed fire only treatments ($F = 6.37$, $P = 0.0235$) than in mine sites. No differences in woody composition were detected between MINE and treatments that combined herbicide and prescribed fire ($P = 0.9826$) (Figure 1.5). Woody species coverage was similar between early growing-season and late growing-season prescribed fire treatments ($P = 0.6746$).

Herbaceous species coverage.—There was a treatment*year interaction ($F = 13.82$, $P < 0.0001$) for herbaceous species (forbs, grasses, sedges, rushes, ferns) coverage (Table 1.6). Orthogonal contrasts (α = 0.05) detected differences in herbaceous composition between mature forest, mine sites, and young forest treatments (Figure 1.6). Herbaceous species coverage was less in mature forest stands (20%) than in harvest treatments ($F = 14.86$, $P = 0.0040$) and MINE

(69%, *F* = 20.90, *P* = 0.0004). MINE had similar proportions of herbaceous coverage to treatments involving herbicide and prescribed fire (67%, *P* = 0.8684), but greater than HARV (27% *F* = 13.31, *P* = 0.0023), HERB (43% *F* = 5.00 *P* = 0.0566), and prescribed fire only treatments (38%, *F* = 8.71, *P* = 0.0100). Herbaceous composition was lower in timber harvest treatments that did not include prescribed fire (*F* = 5.85, *P* = 0.0279) than treatments that did include prescribed fire. Herbaceous coverage increased when herbicide was combined with prescribed fire, as opposed to HERB (*F* = 5.29, *P* = 0.0354) and prescribed fire only treatments (*F* = 9.96, *P* = 0.0064). There was no difference in herbaceous species coverage between early growing-season and late growing-season prescribed fire treatments (*P* = 0.8005).

Bramble species coverage.—There was a treatment*year interaction (*F* = 8.90, P < 0.0001) for bramble species (*Rubus* spp., *Smilax* spp., and *Rosa* spp.) coverage (Table 1.7). Orthogonal contrasts (α = 0.05) indicated mature forest (7%, *F* = 53.10, P < 0.0001) and mine sites (6%, *F* = 40.49, P < 0.0001) had less bramble coverage than young forest treatments (Figure 1.7). Bramble coverage in treatments that included an herbicide application was 20% less than treatments without herbicide application (*F* = 23.72, *P* = 0.0002). Bramble coverage was reduced by 23% in treatments that incorporated fire with herbicide as opposed to using fire alone (*F* = 19.63, P = 0.0006). Bramble coverage in HERB was similar to combined herbicide and fire treatments (P = 0.2447). Stands that were not treated with prescribed fire had similar bramble coverage compared to stands that were burned (P = 0.4426). Bramble coverage was similar among treatments involving early growing-season and late growing-season prescribed fire (P = 0.4407).

DISCUSSION

All timber harvest treatments increased forage availability and NCC in comparison to mature forest at North Cumberland WMA; however, repeated disturbance was necessary to maintain increased forage availability and NCC following timber harvest. Combining herbicide and prescribed fire effectively maintained increased forage availability and NCC for elk and deer and encouraged the transformation of young forest stands to early successional plant communities, which is critical to improve habitat for elk and deer in primarily forested regions. We did not detect differences in vegetation composition, forage availability, or NCC between early growing-season and late growing-season prescribed fire treatments; however, we collected data after only two burns and differences may emerge following continued applications of the prescribed fire treatments.

Forage availability in timber harvest treatments increased up to tenfold in comparison to mature forest stands. Studies in similar regions of the southern Appalachians also reported increases in forage availability and NCC for deer following canopy disturbance (Beck and Harlow 1981, Ford et al. 1993, Lashley et al. 2011). Researchers in western forest systems have reported similar increases in summer forage availability and NCC for elk following timber harvest (Hett et al. 1978, Collins and Urness 1983, Strong and Gates 2006). However, forage availability and NCC benefits realized from timber harvest are short lived in the eastern United States because of rapid rates of forest regeneration and canopy closure.

Forage availability decreased 5 years following complete canopy removal without additional disturbance at North Cumberland WMA. Previous research has reported forage availability in young hardwood forest stands decreases to levels similar to mature forest stands 6-

8 years after canopy removal as hardwood regeneration advances to a point of canopy closure and reduces available sunlight to the understory (Lashley et al. 2011, McCord et al. 2014). Prescribed fire is an effective and cost efficient method of disturbance to increase the quality and quantity of forage for elk and deer when adequate sunlight is available (Masters et al. 1992, Sachro et al. 2005, Van Dyke and Darragh 2007, Shaw et al. 2010, Lashley et al. 2011). Our data suggest a 5-year fire-return interval would maintain increased forage availability and NCC following timber harvest.

Increasing the presence of early successional plant communities has major implications for improving forage availability and NCC for elk and deer in areas where closed-canopy forests dominate the landscape. Forbs remain the most selected, most easily digested, and most nutritious summer forages for both elk and deer, though elk are more digestively adaptive (Cook 2002, Hewitt 2011). Recent diet studies in Kentucky and Tennessee have detected high proportions of forbs in elk diets (Schneider et al. 2006, Lupardus et al. 2011). Using an herbicide application specifically designed to target woody sprouts reduced woody composition at North Cumberland WMA. The reduction in woody composition followed with prescribed fire encouraged greater herbaceous coverage in comparison to all other treatments and maintained increased NCC for elk and deer. Additionally, a reduction in bramble composition occurred in stands that were treated with herbicide, which further reduced competition with herbaceous species. Using a combination of triclopyr herbicide and prescribed fire following retention cuts and shelterwood harvests did not increase forage availability or NCC for deer or reduce woody species in comparison to using fire alone in east Tennessee (Lashley et al. 2011). The lack of woody control resulted from the establishment of hardwood seedlings that were not affected by the broadcast application of triclopyr, which has no residual soil activity and is safe for use under hardwoods (Dow Agro-Sciences 2005). Our treatments involved complete overstory removal, so we were not concerned about overstory tree mortality and could incorporate imazapyr into our herbicide application, which is not recommended for use when managing hardwood stands because of soil activity (BASF 2007). Our data suggest a growing-season application of 5% glyphosate, 1% imazapyr, and 0.15% metsulfuron-methyl in recently harvested mixed hardwood stands followed by periodic growing-season prescribed fire is effective in decreasing woody and bramble composition, increasing herbaceous composition, and encouraging growth of high-quality forages for elk and deer.

Prescribed fire is an irreplaceable tool in the restoration and maintenance of early successional plant communities, especially in rugged terrain where mechanical treatment is problematic or not possible. However, vegetation response to prescribed fire in hardwood-dominated regions of the central and eastern United States is not well-understood (Harper et al. 2016). Research has indicated burning during the dormant-season or the early growing-season only topkills young woody plants (Glitzenstein et al. 2012, McCord et al. 2014). Woody stem densities commonly increase following dormant-season prescribed fire and have been reported to remain the same or increase following early growing-season prescribed fire (Sparks et al. 1999, Drewa et al. 2002, Robertson and Hmielowski 2014). Fewer studies have evaluated the effects of late growing-season fire on young woody plants in hardwood regions. Applications of prescribed fire in June and August in the Ozark Mountains decreased hardwood sprouts in comparison to April burning (Lewis et al. 1964). In west Tennessee, late growing-season fire reduced woody encroachment and maintained an herbaceous-dominated plant community much more effectively than dormant-season fire (Gruchy et al. 2009). We did not detect differences in vegetation composition, forage availability, or NCC in response to seasonality of prescribed fire, but both prescribed fire treatments effectively decreased woody composition in comparison to timber harvest alone. Differences in woody composition related to seasonality of prescribed fire may be detected following additional prescribed fire treatments. Future research devoted to better understanding the relationships between vegetation composition and seasonality of fire would provide valuable information to managers and biologists who are working to restore and maintain early successional plant communities in hardwood-dominated regions of the eastern United States.

MANAGEMENT IMPLICATIONS

Full canopy removal followed by repeated prescribed fire or an initial herbicide application followed with repeated prescribed fire will improve and maintain forage availability and NCC for elk and deer in forested landscapes in the eastern United States. Recurring prescribed fire will be required to maintain increased forage availability and NCC. Fire-return intervals should be determined by vegetation response and may vary year to year and across sites. However, it is clear from our data and other research that a fire-return interval within 5 – 8 years will be necessary to maintain increased forage availability in mixed hardwood systems of the eastern United States. If the objective is to convert mixed-hardwood forest stands to early successional plant communities to maximize forage quality for elk and deer, we recommend a targeted herbicide application in recently harvested stands (2 – 3 years post-harvest) to reduce coppice growth and young woody plants followed by periodic prescribed fire. The combination of this herbicide application with periodic prescribed fire will reduce woody competition with herbaceous plants and accelerate the transition of young mixed-hardwood forest stands to early successional plant communities, which will be required to restore and maintain elk habitat on many sites in the eastern United States.

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APPENDIX

Table 1.1. Total forage available (kg/ha (SE)) in timber harvest treatments, mature forest stands, and reclaimed mine sites at North Cumberland Wildlife Management Area, TN, USA, July-August 2013-15.

	Year[a]					
Treatment[b]	2013		2014		2015	
MATFOR	141 (17)	G	124 (20)	G	176 (44)	FG
HARV	1,160 (106)	ABC	1,411 (115)	ABC	778 (73)	CD
HERB	1,158(136)	BC	1,056 (104)	BC	1,446 (124)	AB
EBURN	972 (118)	BCD	1,316 (98)	ABC	1,261 (110)	ABC
LBURN	1,168 (86)	BC	1,479 (86)	A	1,423 (91)	AB
EB_HERB	753 (101)	D	937 (85)	BC	1,050 (120)	BC
LB_HERB	761 (61)	BCD	1,031 (91)	BC	1,071(101)	ABC
MINE	363 (73)	E	348 (50)	EF	378 (68)	E

[a]Treatment*Year effect significant ($F_{7,13}$ = 19.83, P < 0.0001). Means with the same letter are not different (α = 0.05)

[b]HARV, HERB, MINE (N = 3); EBURN, EB_HERB, MATFOR (N = 4); LBURN, LB_HERB (N = 2)

Table 1.2. Selected forages (Index Value[a]; Crude Protein %) as determined by selection transects at North Cumberland Wildlife Management Area, TN, USA, July-August 2013-15.

Common Name	Species	(IV)	(CP%)
wild lettuce	*Lactuca spp.*	0.071	17.56
common greenbrier	*Smilax rotundifolia*	0.054	11.56
wood nettle	*Laportea canadensis*	0.047	12.35
jewelweed	*Impatiens spp.*	0.044	27.38
oldfield aster	*Symphyotrichum pilosum*	0.039	14.87
white wood aster	*Eurybia divaricata*	0.039	16.25
American pokeweed	*Phytolacca americana*	0.036	28.13
cankerweed	*Prenanthes spp.*	0.035	14.12
buffalo nut	*Pyrularia pubera*	0.034	19.38
Queen Anne's lace	*Daucus carota*	0.027	17.06
striped maple	*Acer pennsylvanicum*	0.026	12.81
common ragweed	*Ambrosia artemisiifolia*	0.024	21.12
maple-leaf viburnum	*Viburnum acerifolium*	0.021	8.75
giant ragweed	*Ambrosia trifida*	0.020	17.81
joe-pye weed	*Eupatorium purpureum*	0.019	18.13
cat greenbrier	*Smilax glauca*	0.019	12.38
wild hydrangea	*Hydrangea arborescens*	0.019	14.18
woodland sunflower	*Helianthes divaricatus*	0.018	16.68
lowbush blueberry	*Vaccinium angustifolium*	0.017	9.61
blackgum	*Nyssa sylvatica*	0.017	12.68
Canada goldenrod	*Solidago canadensis*	0.015	16.31
blackberry	*Rubus argutus*	0.013	11.88
black raspberry	*Rubus occidentalis*	0.013	12.56
smooth sumac	*Rhus glabra*	0.012	11.88
black birch	*Betula nigra*	0.011	12.31
grape	*Vitis spp.*	0.011	14.93
sourwood	*Oxydendrum arboreum*	0.011	13.38
red maple	*Acer rubrum*	0.011	11.31

[a] Index Value cut-off was 0.010

Table 1.3. Nutritional carrying capacity for elk and deer (animal days/ha (SE)) at a 12% crude protein constraint at North Cumberland WMA, TN, USA, July-August 2013-15.

	Year[a]					
	2013		2014		2015	
Treatment[b]	Elk		Elk		Elk	
MATFOR	7 (2)	E	8 (2)	E	9 (3)	E
HARV	46 (8)	BC	39 (10)	BCD	35 (8)	CD
HERB	23 (3)	DE	39 (8)	BCD	68 (10)	A
EBURN	45 (5)	BC	61 (9)	AB	49 (6)	BC
LBURN	31 (4)	CD	42 (6)	BC	64 (9)	AB
EB_HERB	30 (3)	CD	29 (4)	CD	52 (10)	B
LB_HERB	34 (3)	CD	25 (3)	CD	47 (6)	BC
MINE	31 (6)	CD	27 (5)	CD	35 (9)	CD
Treatment[b]	Deer		Deer		Deer	
MATFOR	23 (5)	E	26 (7)	E	31 (10)	E
HARV	150 (27)	BC	130 (34)	BCD	116 (25)	CD
HERB	75 (11)	DE	129 (25)	BCD	224 (33)	A
EBURN	149 (18)	BC	202 (28)	AB	163 (20)	BC
LBURN	102 (12)	CD	139 (19)	BC	212 (28)	AB
EB_HERB	100 (11)	CD	95 (12)	CD	171 (33)	B
LB_HERB	111 (10)	CD	82 (11)	CD	155 (20)	BC
MINE	102 (20)	CD	89 (16)	CD	114 (30)	CD

[a]Treatment*Year effect significant ($F_{14,324} = 4.68$, $P < 0.0001$). Means with the same letter are not different ($\alpha = 0.05$)

[b]HARV, HERB, MINE (N = 3); EBURN, EB_HERB, MATFOR (N = 4); LBURN, LB_HERB (N = 2)

Table 1.4. Nutritional carrying capacity for elk and deer (animal days/ha (SE)) at a 14% crude protein constraint at North Cumberland WMA, TN, USA, July-August 2013-15.

Treatment[a]	Elk[b]		Deer[b]	
MATFOR	7 (3)	C	22 (10)	C
HARV	18 (4)	B	60 (13)	B
HERB	20 (4)	B	64 (13)	B
EBURN	32 (4)	A	105 (13)	A
LBURN	31 (4)	A	104 (15)	A
EB_HERB	30 (4)	AB	97 (12)	AB
LB_HERB	28 (5)	AB	91 (16)	AB
MINE	26 (4)	AB	85 (12)	AB

[a]HARV, HERB, MINE (N = 3); EBURN, EB_HERB, MATFOR (N = 4); LBURN, LB_HERB (N = 2)

[b]Treatment effect significant ($F_{7,17} = 5.93$, $P = 0.0013$). Means with the same letter are not different ($\alpha = 0.05$). NCC was analyzed for elk and deer separately, thus letter codes are species specific.

Table 1.5. Percentage coverage of woody species by year and treatment at North Cumberland WMA, TN, USA, July-August 2013-15.

	Year[a]					
Treatment[b]	2013		2014		2015	
MATFOR	51 (5)	A	48 (5)	A	37 (5)	B
HARV	54 (5)	A	38 (5)	B	57 (5)	A
HERB	39 (5)	B	30 (5)	BCD	35 (5)	BC
EBURN	32 (5)	BC	35 (5)	BC	25 (5)	DE
LBURN	37 (5)	B	32 (5)	BCD	26 (5)	CDE
EB_HERB	31 (5)	BCD	20 (5)	EFG	15 (5)	FGH
LB_HERB	17 (6)	EFGH	15 (6)	FGH	9 (6)	H
MINE	17 (5)	EFGH	20 (5)	EFGH	13 (5)	GH

[a]Treatment*Year effect significant ($F_{14,325} = 4.16$, $P < 0.0001$). Means with the same letter are not different ($\alpha = 0.05$)

[b]HARV, HERB, MINE (N = 3); EBURN, EB_HERB, MATFOR (N = 4); LBURN, LB_HERB (N = 2)

Table 1.6. Percentage coverage of herbaceous species by year and treatment at North Cumberland WMA, TN, USA, July-August 2013-15.

	Year[a]					
Treatment[b]	2013		2014		2015	
MATFOR	21 (8)	GH	23 (8)	GH	15 (8)	GH
HARV	51 (9)	CD	21 (9)	G	6 (9)	H
HERB	61 (9)	ABC	43 (9)	DEF	24 (9)	GH
EBURN	75 (9)	AB	30 (9)	EFG	22 (9)	GH
LBURN	50 (10)	CDE	25 (10)	FGH	29 (10)	FG
EB_HERB	73 (10)	AB	62 (10)	ABCD	56 (10)	ABCD
LB_HERB	77 (10)	A	61 (10)	BCD	73 (10)	ABC
MINE	69 (9)	ABC	70 (9)	ABC	68 (9)	ABC

[a]Treatment*Year effect significant ($F_{14,325} = 13.82$, $P < 0.0001$). Means with the same letter are not different ($\alpha = 0.05$)

[b]HARV, HERB, MINE (N = 3); EBURN, EB_HERB, MATFOR (N = 4); LBURN, LB_HERB (N = 2)

Table 1.7. Percentage coverage of bramble species by year and treatment at North Cumberland WMA, TN, USA, July-August 2013-15.

	Year[a]					
Treatment[b]	2013		2014		2015	
MATFOR	9 (5)	HI	7 (4)	IJ	3 (3)	J
HARV	71 (7)	A	40 (6)	BCD	34 (4)	CDEF
HERB	37 (6)	CDE	25 (5)	DEFG	39 (5)	BCD
EBURN	53 (7)	B	35 (5)	CDEF	47 (6)	BC
LBURN	74 (6)	A	43 (5)	BC	44 (5)	BC
EB_HERB	35 (5)	CDE	18 (5)	GHI	27 (6)	DEFG
LB_HERB	35 (6)	CDE	24 (6)	EFGH	19 (5)	FGHI
MINE	7 (5)	IJ	8 (5)	HIJ	6 (5)	IJ

[a]Treatment*Year effect significant ($F_{14,359} = 8.90$, $P < 0.0001$). Means with the same letter are not different ($\alpha = 0.05$)

[b]HARV, HERB, MINE (N = 3); EBURN, EB_HERB, MATFOR (N = 4); LBURN, LB_HERB (N = 2)

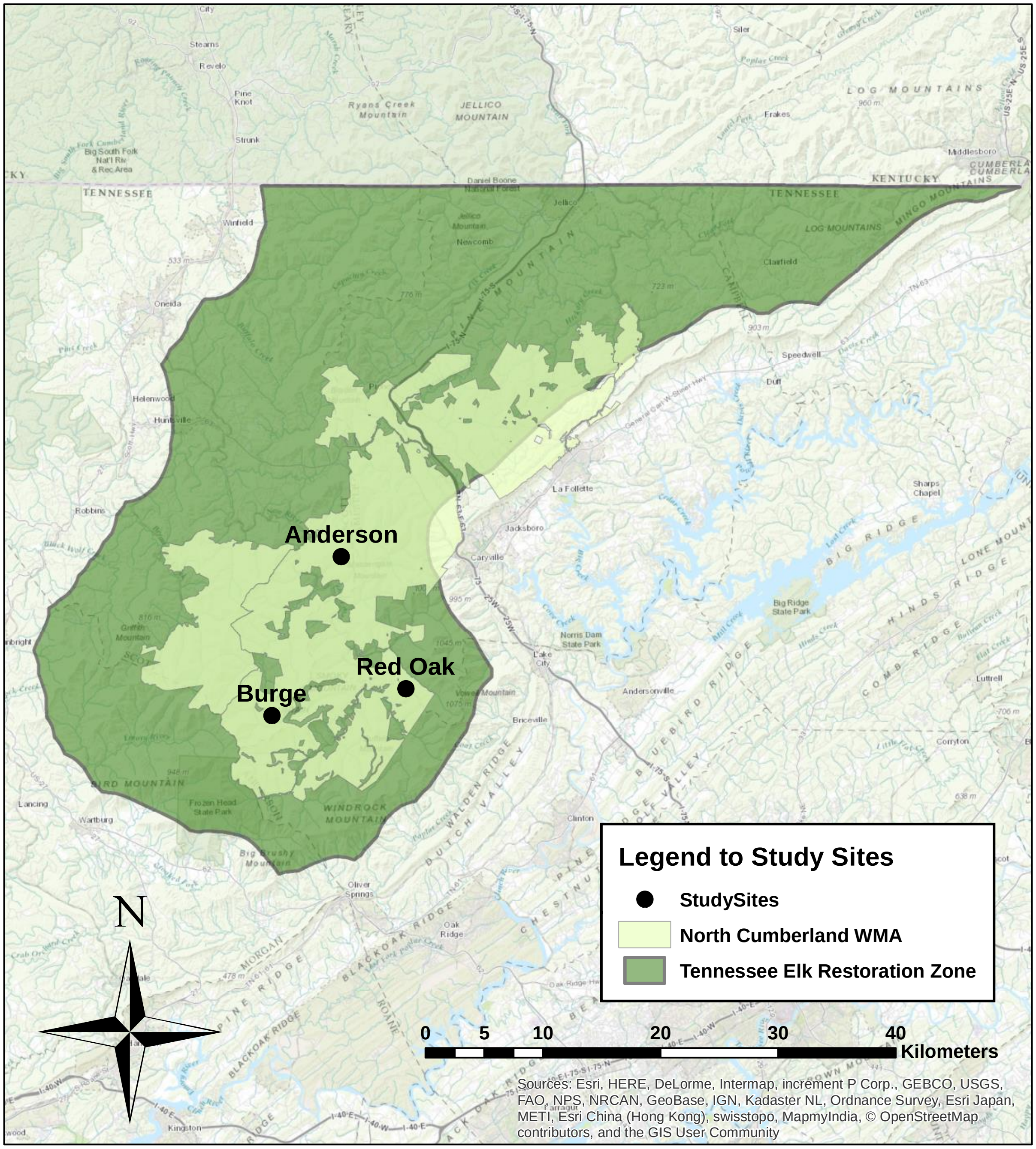

Figure 1.1. Map of the location of Anderson, Burge, and Red Oak study sites where young forest treatments were implemented.

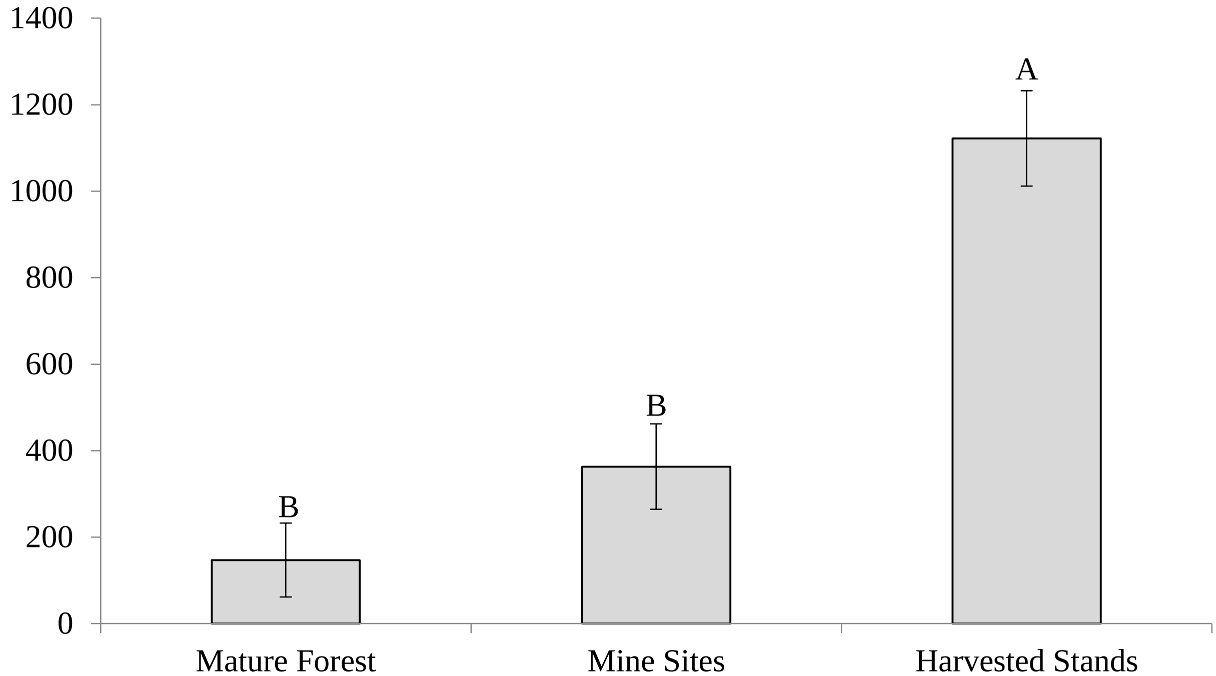

Figure 1.2. Significant (α = 0.05) contrasts of forage availability (kg/ha) for elk and deer in mature forest stands, mine sites, and harvested stands from 2013-15 at North Cumberland Wildlife Management Area, Tennessee, USA. Contrasts include: Mature Forest vs. Mine Sites (+216 kg/ha ± 131 SE, $F = 1.65$, $P = 0.1244$), Mature Forest vs. Harvested Stands (+975 kg/ha ± 97 SE, $F = 101.70$, $P < 0.0001$), and Mine Sites vs. Harvested Stands (+759 kg/ha ± 109 SE, $F = 7.00$, $P < 0.0001$). Means with the same letter are not different.

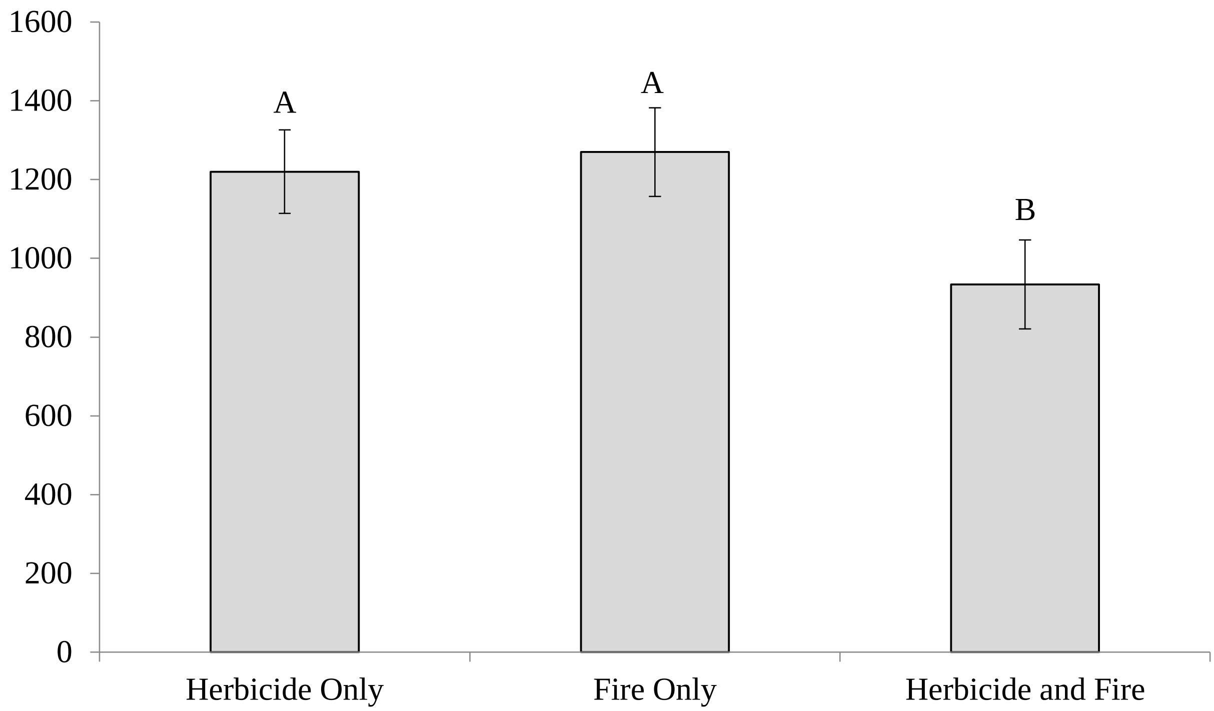

Figure 1.3. Significant (α = 0.05) contrasts of forage availability (kg/ha) for elk and deer in young forest stands treated with herbicide alone, fire alone, and a combination of herbicide and fire from 2013-15 at North Cumberland Wildlife Management Area, Tennessee, USA. Contrasts included: Herbicide Only vs. Fire Only (+50 kg/ha ± 133 SE, $F = 0.37$, $P = 0.7138$), Herbicide Only vs. Herbicide and Fire (-286 kg/ha ± 133, $F = 4.63$, $P = 0.0484$), and Herbicide and Fire vs. Fire Only (-336 kg/ha ± 113 SE, $F = 8.83$, $P = 0.0107$). Means with the same letter are not different.

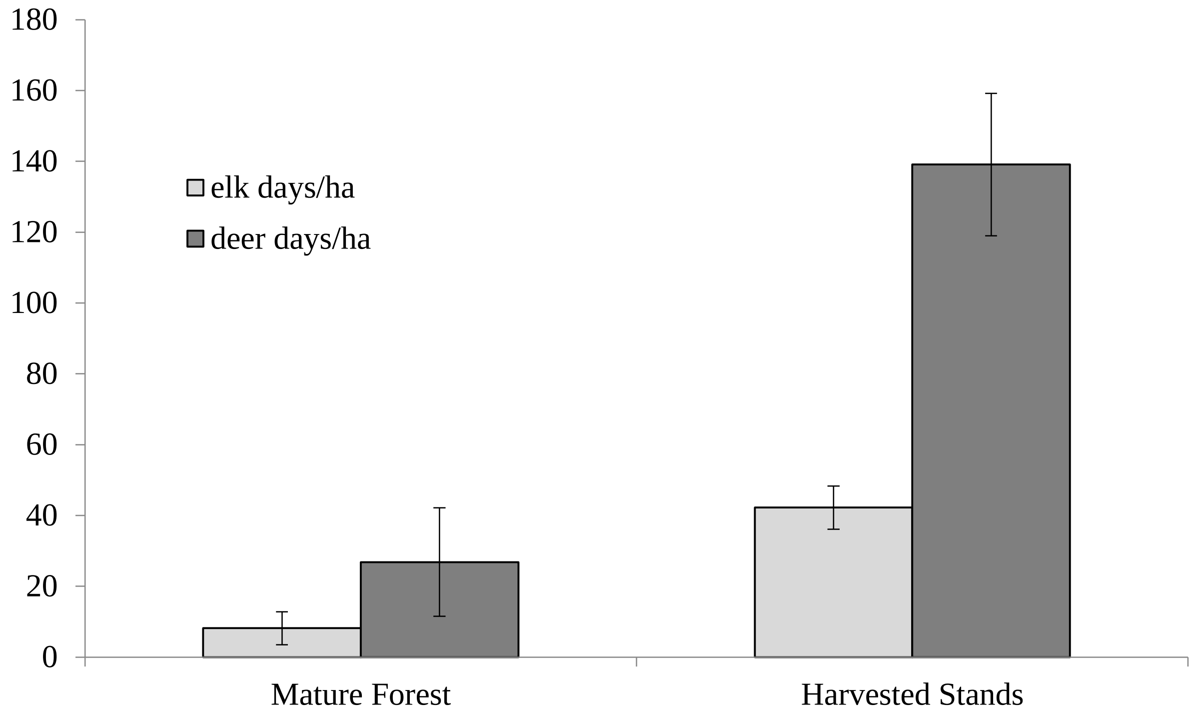

Figure 1.4. Significant ($\alpha = 0.05$) contrasts of nutritional carrying capacity at a 12% crude protein nutritional constraint for elk and deer in mature forest stands and harvested stands from 2013-15 at North Cumberland Wildlife Management Area, Tennessee, USA. Nutritional carrying capacity in harvested stands was 34 elk days/ha (±5 SE) and 112 deer days/ha (±17 SE) greater than in mature forest stands ($F = 41.65$, $P < 0.0001$).

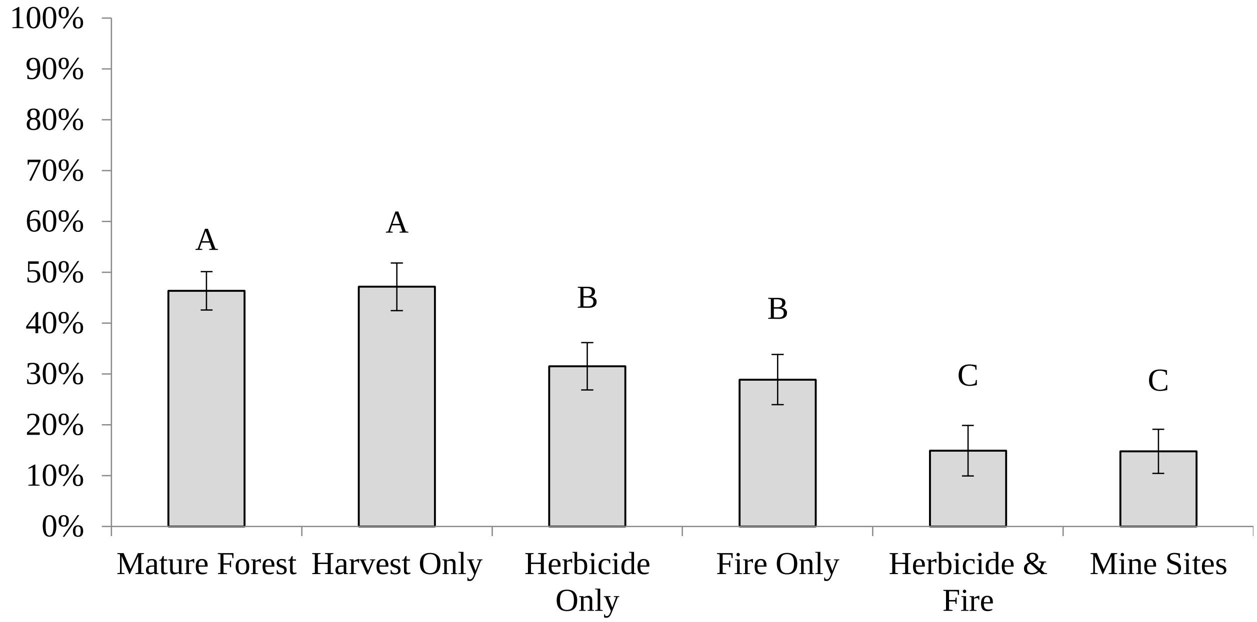

Figure 1.5. Orthogonal contrasts (α = 0.05) of woody vegetation composition between mature forest, mine sites, and young forest treatments from 2013-15 at North Cumberland Wildlife Management Area, Tennessee, USA. Contrasts include Mature Forest vs. Harvest Only (+1% ± 6% SE, F = 0.02, P = 0.8959), Mature Forest vs. Herbicide Only (-15% ± 6% SE, F = 6.13, P = 0.0244), Mature Forest vs. Fire Only (-17% ± 5% SE, F = 11.49, P = 0.0041), Mature Forest vs. Herbicide and Fire (-31% ± 5% SE, F = 37.05, P < 0.0001), Mature Forest vs. Mine Sites (-32%, 6% SE, F = 30.02, P < 0.0001), Harvest Only vs Herbicide Only (-16% ± 7% SE, F = 5.61, P = 0.0288), Harvest Only vs. Fire Only (-18% ± 6% SE, F = 9.76, P = 0.0060), Harvest Only vs. Herbicide and Fire (-32% ± 6% SE, F = 30.31, P < 0.0001), Harvest Only vs. Mine Sites (-32% ± 6% SE, F = 25.67, P < 0.0001), Herbicide Only vs. Fire Only (-3% ± 6% SE, F = 0.20, P = 0.6587), Herbicide Only vs. Herbicide and Fire (-16% ± 6% SE, F = 8.08, P = 0.0110), Herbicide Only vs. Mine Sites (-17% ± 6% SE, F = 6.89, P = 0.0181), Fire Only vs. Herbicide and Fire (-14% ± 5% SE, F = 7.91, P = 0.0127), Fire Only vs. Mine Sites (-14% ± 6% SE, F = 6.37, P = 0.0235), and Herbicide and Fire vs. Mine Sites (0% ± 6% SE, F = 0.00, P = 0.9826). Means with the same letter are not different.

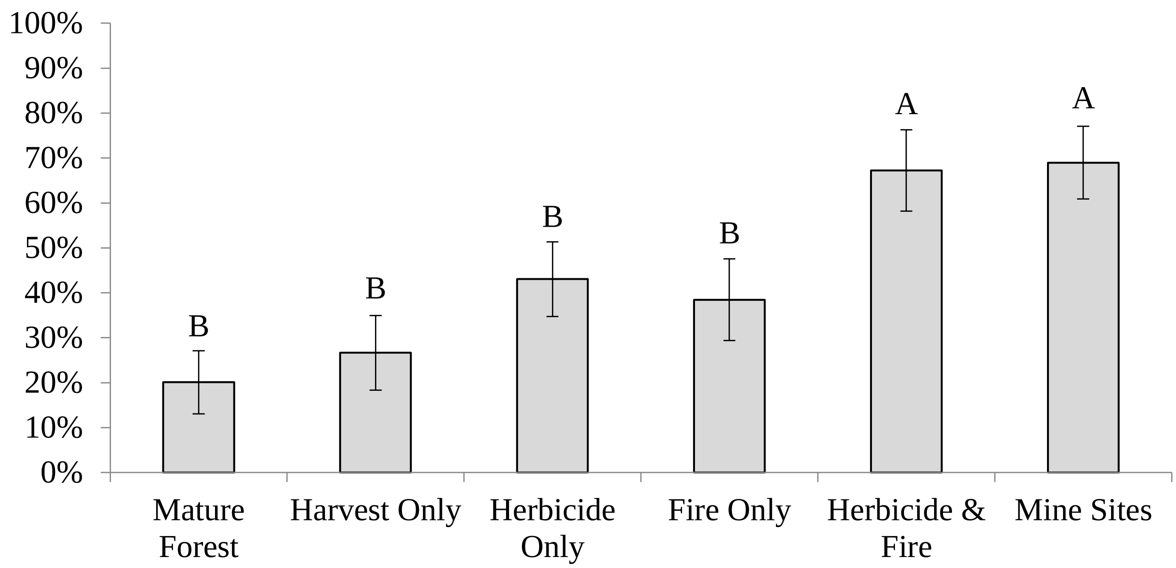

Figure 1.6. Orthogonal contrasts (α = 0.05) of herbaceous vegetation composition between mature forest, mine sites, and young forest treatments from 2013-15 at North Cumberland Wildlife Management Area, Tennessee, USA. Contrasts include Mature Forest vs. Harvest Only (+7% ± 11% SE, F = 0.37, P = 0.5529), Mature Forest vs. Herbicide Only (+23% ± 11% SE, F = 4.48, P = 0.0508), Mature Forest vs. Fire Only (+18% ± 10% SE, F = 3.74, P = 0.0725), Mature Forest vs. Herbicide and Fire (+45% ± 10% SE, F = 24.52, P = 0.0002), Mature Forest vs. Mine Sites (+49%, 11% SE, F = 20.90, P = 0.0004), Harvest Only vs Herbicide Only (+16% ± 12% SE, F = 1.95, P = 0.1817), Harvest Only vs. Fire Only (+12% ± 11% SE, F = 1.26, P = 0.2784), Harvest Only vs. Herbicide and Fire (+40% ± 11% SE, F = 14.86, P = 0.0014), Harvest Only vs. Mine Sites (+42% ± 12% SE, F = 13.31, P = 0.0023), Herbicide Only vs. Fire Only (-5% ± 11% SE, F = 0.19, P = 0.6681), Herbicide Only vs. Herbicide and Fire (+24% ± 11% SE, F = 5.29, P = 0.0354), Herbicide Only vs. Mine Sites (+26% ± 12% SE, F = 5.00, P = 0.0404), Fire Only vs. Herbicide and Fire (+28% ± 9% SE, F = 9.96, P = 0.0064), Fire Only vs. Mine Sites (+30% ± 10% SE, F = 8.71, P = 0.0100), and Herbicide and Fire vs. Mine Sites (+1% ± 10% SE, F = 0.03, P = 0.8684). Means with the same letter are not different.

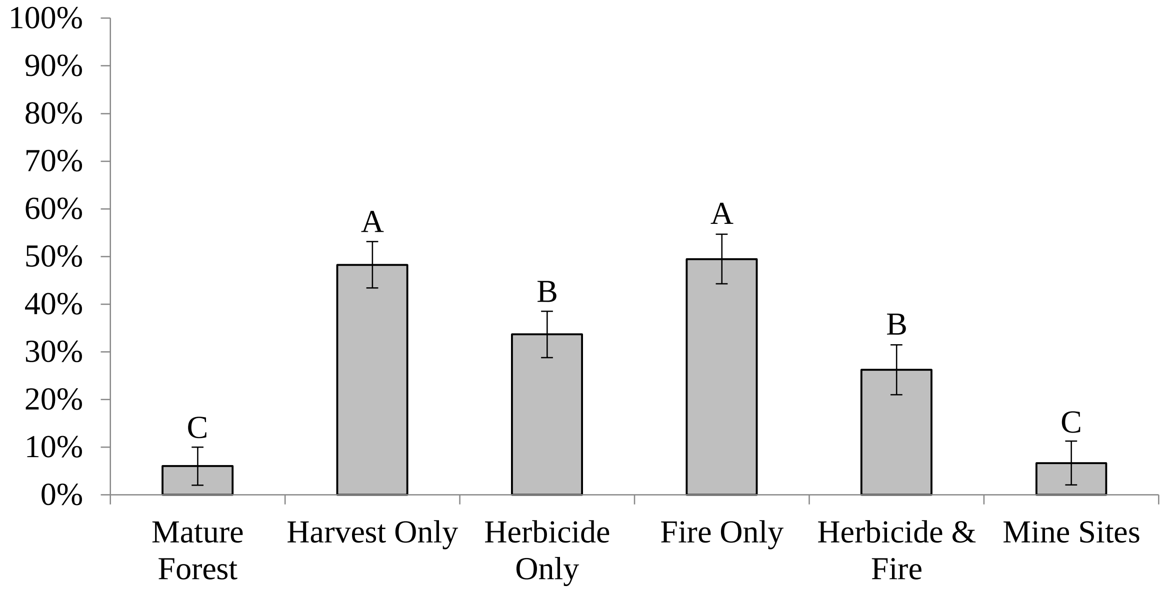

Figure 1.7. Orthogonal contrasts (α = 0.05) of bramble composition between mature forest, mine sites, and young forest treatments from 2013-15 at North Cumberland Wildlife Management Area, Tennessee, USA. Contrasts include Mature Forest vs. Harvest Only (+33% ± 6% SE, F = 44.95, P < 0.0001), Mature Forest vs. Herbicide Only (+28% ± 6% SE, F = 19.29, P = 0.0005), Mature Forest vs. Fire Only (+43% ± 5% SE, F = 63.67, P < 0.0001), Mature Forest vs. Herbicide and Fire (+20% ± 5% SE, F = 13.73, P = 0.0024), Mature Forest vs. Mine Sites (+1%, 6% SE, F = 0.01, P = 0.9196), Harvest Only vs Herbicide Only (-15% ± 6% SE, F = 4.52, P = 0.0493), Harvest Only vs. Fire Only (+1% ± 6% SE, F = 0.04, P = 0.8446), Harvest Only vs. Herbicide and Fire (-22% ± 6% SE, F = 12.91, P = 0.0025), Harvest Only vs. Mine Sites (-41% ± 7% SE, F = 38.46, P < 0.0001), Herbicide Only vs. Fire Only (+16% ± 6% SE, F = 6.73, P = 0.0201), Herbicide Only vs. Herbicide and Fire (-7% ± 6% SE, F = 1.46, P = 0.2447), Herbicide Only vs. Mine Sites (-27% ± 7% SE, F = 16.23, P = 0.0011), Fire Only vs. Herbicide and Fire (-23% ± 5% SE, F = 19.63, P = 0.0006), Fire Only vs. Mine Sites (-43% ± 6% SE, F = 52.43, P < 0.0001), and Herbicide and Fire vs. Mine Sites (-20% ± 6% SE, F = 10.94, P = 0.0053). Means with the same letter are not different

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CHAPTER II. MODELING SUMMER FORAGE AVAILABILITY FOR ELK IN THE CUMBERLAND MOUNTAINS OF TENNESSEE

ABSTRACT We developed a spatially-explicit forage model to estimate the availability of summer forage resources for elk (*Cervus elaphus*) and evaluate the distribution of those resources across the North Cumberland Wildlife Management Area (WMA) in the Cumberland Mountains of Tennessee. We combined land cover data, site-specific forest management data, site-specific field management data, and 3 years of site-specific summer elk forage availability data to model summer elk forage using the ordinary kriging interpolation method. Closed-canopy forest produced less summer elk forage (147 kg/ha) than all other land cover types across the North Cumberland WMA, but accounted for the largest percentage of land cover within 6 generated summer elk use-area buffers (69-94%) and across the WMA (80%). Young forest produced the most summer elk forage (1,116 kg/ha) and outperformed the impact of wildlife openings (742 kg/ha) within all generated summer elk use-area buffers and across the WMA. We determined that converting closed-canopy forest to young forest through timber harvest would be the most effective method for increasing summer elk forage availability. Our model indicated areas of high summer elk forage production are unevenly distributed across the North Cumberland WMA, which limits the ability of elk to benefit from concentrated summer forage resources in some areas. The widespread coverage of closed-canopy forest across the WMA provides an opportunity to strategically increase summer elk forage resources through timber harvest to create a more even distribution of highly productive summer foraging areas. Additional applications of our model should be explored to evaluate other factors, such as nutritional carrying capacity and winter forage availability, that influence elk habitat quality across the North Cumberland WMA.

KEY WORDS *Cervus elaphus*, elk, forage availability, habitat management, kriging, model, young forest, wildlife opening.

The Tennessee Wildlife Resources Agency (TWRA) began elk (*Cervus elaphus*) reintroduction efforts in December of 2000 with the release of 50 elk from Elk Island National Park in Alberta, Canada to the North Cumberland Wildlife Management Area (WMA) in the Cumberland Mountains of Tennessee. Another 151 elk were released across the North Cumberland WMA in subsequent years (2001, 2002, 2003, and 2008). The North Cumberland WMA is central to the Tennessee Elk Restoration Zone and serves as the focus of elk management in Tennessee. A population viability analysis on Tennessee's reintroduced elk herd predicted that the population would not be sustainable unless survival rates were increased (Kindall et al. 2011). Forage availability during spring and summer is a critical component of elk habitat and likely has the largest influence on the number of elk that breed and successfully reproduce in all portions of their range, even in regions with harsh winter climates where thermal cover was once perceived to be most important (Cook et al. 1998, Cook 2003). As a result, attention has been focused on understanding the availability of elk forage across the WMA and evaluating techniques to increase forage availability to sustain Tennessee's elk herd and enable population growth.

Nutritional demands of elk are greatest during summer to support lactation and juvenile growth (Oftedal 1985, Cook et al. 1996). Inadequate summer forage availability results in poor nutrition, which may negatively impact pregnancy rates, age at first breeding, fetal survival, birth weight, juvenile growth, juvenile survival, and adult survival of elk (Cook et al. 1996, Cook 2002, Cook et al. 2004). Similar to other cervids, home range sizes of elk are inversely related to forage availability during all seasons of the year (Knight 1970, Craighead et al 1973, Geist 2002, Anderson et al. 2005). Elk damage to crops on private lands surrounding the North Cumberland WMA has been a concern for TWRA since elk reintroduction began. Increasing forage for elk across the North Cumberland WMA could decrease elk home range size, concentrate elk use on the WMA, and reduce elk damage on private property in addition to improving the overall health and productivity of the population. The primary land-cover type across the North Cumberland WMA and the Cumberland Mountains in general is closed-canopy hardwood forest (Homer 2015). Closed-canopy forests limit sunlight penetration to the forest floor and prevent the establishment of a well-developed forest understory (Rossell et al. 2005, Webster et al. 2005, Shaw et al. 2010, McCord et al. 2014). As a result, closed-canopy forests limit food and cover resources for many wildlife species, including elk (Beck and Harlow 1981, de Calesta 1994, Strong and Gates 2006, Lashley et al. 2011). Young forest stands (stand initiation stage) and reclaimed surface mines provided greater forage availability for elk than closed-canopy stands across the North Cumberland WMA (See Chapter 1).

Many factors must be considered to determine how to effectively manage habitat for any wildlife species. Understanding the spatial distribution and availability of elk forage resources across areas where elk are a focal species is necessary for elk managers and biologists to make appropriate elk habitat management decisions. Determining which habitat management practices are the most feasible and can have the greatest impact on elk in Tennessee from a population benefit perspective is equally important. Modeling techniques have been developed since the 1970's to aid in decision making concerning land use and habitat conservation for many wildlife species (Berry 1986). Habitat modeling has become an increasingly valuable tool for wildlife managers and biologists who need to evaluate the effects of their habitat management practices. Existing land-use and land-cover data provide opportunities to investigate ways that land-use and land-cover impact the spatial distribution and availability of elk forage resources. Combining existing land-use and land-cover data with associated site-specific seasonal elk forage availability data can serve as inputs into the development of spatially-explicit forage models for elk. Researchers in regions of the western United States have developed habitat-based models for elk by evaluating factors influencing elk habitat, such as forage quality, forage quantity, cover resources, forest management, fire, roads, topography, and more (Rowland et al. 2000, Roloff et al. 2001, Jones et al. 2002, Benkobi et al. 2004, O'Neil and Bump 2014). However, only one habitat-based model has been published concerning elk in the southeastern United States (Telesco et al. 2007). Habitat-based models using similar approaches have been developed for mammalian and avian species in the southern Appalachians (Klaus et al. 2005, Buehler et al. 2006, Menzel et al. 2006), but our model is the first to address elk habitat in the southern Appalachians.

Our objective was to develop a spatially-explicit summer elk forage model for the North Cumberland WMA. We modeled summer elk forage availability based on 3 years of site-specific forage availability data, 16 years of site-specific forest management data, and site-specific field management data, combined with land cover data we retrieved from the 2011 National Land Cover Database (Homer et al. 2015). Our model was designed to provide elk managers and biologists a resource to help guide future elk habitat management decisions on the North Cumberland WMA. To demonstrate the applicability of our model, we conducted spatial analysis of summer forage availability to address the following specific management questions:

1) What is the mean summer elk forage availability across the North Cumberland Wildlife Management Area and within elk use-area buffers?

2) How well are summer elk forage resources distributed across the North Cumberland Wildlife Management Area?

3) Which elk habitat management technique has the largest impact on summer elk forage availability: harvesting timber or establishing wildlife openings?

STUDY AREA

Our study area was the North Cumberland WMA, which spans across portions of Anderson, Campbell, and Scott counties, Tennessee, USA. The North Cumberland WMA lies within the Cumberland Mountains with elevations ranging from 324-1,012 m. In addition to the naturally mountainous terrain, a history of strip, bench, and deep coal mining in the area resulted in about 10% of the area in reclaimed and unreclaimed mine areas. Shale and siltstone influences have resulted in acidic, loamy, and well-drained soils (Conner 2002). The North Cumberland WMA is approximately 60,775 ha and is centrally located within Tennessee's 272,000 ha elk restoration zone. The dominant vegetation type across the study area was closed-canopy mixed-hardwood forest (80%), with interspersed stands of young mixed-hardwood forest (≤ 7 years-old, 9%) and openings characterized as reclaimed surface mines, wildlife openings, herbaceous, or shrub (11%) (Homer et al. 2015, TWRA 2016). A portion of the WMA is currently under timber management through a ten-year lease (2007 – 2016) with Lyme Timber Company, which has resulted in the harvest of approximately 12,000 ha of forest. Mature forest across the study area primarily consisted of *Quercus* spp., *Carya* spp., *Acer* spp., and *Liriodendron tulipifera* with lesser amounts of *Fagus grandifolia* and *Pinus* spp. interspersed. Young mixed-hardwood forest stands composed a diverse mixture of vegetation, including forbs, gramminoids, brambles, shrubs, and young trees. Most wildlife openings were mowed annually and dominated by perennial cool-season grasses (tall fescue (*Schedonorus arundinaceus*), orchardgrass (*Dactylis glomerata*), and timothy (*Phleum pretense*)) with native forb species and perennial clovers present to a lesser extent. Coal surface mines had been reclaimed from 1980 – present and were generally dominated by tall fescue (*Schedonorus arundinaceus*) and sericea lespedeza (*Lespedeza cuneata*) with scattered autumn olive (*Eleagnus umbellata*) and black locust (*Robinia *psuedoacacia*), however a variety of native forbs and brambles (*Rubus* spp. and *Smilax* spp.) were also widely present.

METHODS

Elk Forage Availability

Site-specific forage availability data were collected in young forest stands, closed-canopy forest stands, reclaimed surface mine sites, and wildlife openings July – August 2013 – 15. We established random data collection points (190) distributed across the aforementioned major vegetation types using ArcGIS. We sampled from 2 randomly placed 1-m^2 forage collection frames along a 40-m transect at each data collection point. Two random numbers between 0 and 40 were assigned to each data collection point to corresponded with the area along the transect where the forage collection frames were placed. We collected leaf biomass and young twig ends ($\leq$ 1 growing-season) from woody plants and herbaceous plants (excluding large stems) that were $\leq$ 2 m vertical height within the collection frame. We collected forages according to genus in forage collection bags and labeled each sample. We dried all forage samples to constant mass in an air-flow dryer at 50^{o} C then weighed dried forage samples using a digital scale and recorded weight in grams (Lashley et al. 2014). Dry mass forage estimates from each 1-m^2 frame were extrapolated to calculate kg (dry mass forage) per ha.

Model Development

We retrieved land cover data from the 2011 National Land Cover Database and assigned the data to a raster file of the North Cumberland WMA at a resolution of 1-ha^2. We then added timber harvest, reclaimed surface mine, and wildlife opening cover types to the North Cumberland WMA land cover raster using GIS data we obtained from TWRA. We assigned specific forage availability values to young forest ($\leq$ 5 years-old), mature closed-canopy forest, wildlife opening, and reclaimed surface mine land cover types in the North Cumberland WMA land cover raster based on the site-specific forage availability estimates we previously obtained. We assigned forage availability values to unsampled land cover types (moderate closed-canopy young forest (6 – 7 years-old), herbaceous, and shrub) (4% of the study area) across the study area based on our opinion after 3 years of research. We assumed young closed-canopy forest (> 7 years-old) produced similar forage availability levels to mature closed-canopy forest based on research in Tennessee that reported sunlight penetration returns to levels similar to mature closed-canopy forest 6 – 8 years following timber harvest in mixed-hardwood systems (Lashley et al. 2011, McCord et al. 2014). Developed land, barren land, woody wetlands, and water cover types also were present across the study area; however, they were not considered in our forage availability model because we assumed they were unable to be managed for summer elk forage production (Table 2.1).

We used systematic grid sampling tool (Fishnet) in ArcGIS to systematically place sampling points at a 1 point per 10-ha scale across the North Cumberland WMA forage availability raster. We assigned forage availability values to each sampling point to create input point features for our forage availability model. We considered multiple interpolation techniques including inverse distance weighting (IDW), kriging, and spline to determine which was most appropriate for our model and most accurately estimated summer elk forage availability across the study area. Kriging is a flexible and statistically powerful interpolation method useful in many fields of research (Childs 2004, Yang et al. 2004). Kriging operates under the assumption that distances or directions between sampling points reflect a spatial correlation (Childs 2004). Zimmerman et al. (1999) evaluated the performance of kriging and IDW methods considering the effects of multiple data and sampling characteristics and reported that kriging methods performed considerably better. Kriging also provided the best estimations for digital elevation models in comparison to IDW and spline methods when modelling landscapes with strong spatial structure (Chaplot et al. 2006). Based on these considerations, we decided to use kriging to provide elk forage model interpolation from the underlying data points.

We identified six elk use-areas (Hatfield Knob, Massengale, Jenny Creek, Frenchman's Grave, Chestnut Ridge, and Titus Creek) (Figure 2.1) across the study area where elk activity had been concentrated during summer based on direct observations and summer trail camera data provided by TWRA. Our elk use-areas should not be confused with measured elk home ranges or identified core areas. Elk use-areas were simply locations across the North Cumberland WMA where TWRA had consistently documented the presence of elk during summer through trail-camera surveys and visual observation. We inserted point features into our model to represent an area center corresponding with each identified elk use-area. Summer home range estimates for elk in Tennessee have not been published, so we used a mean summer buffer size estimate for female elk in Alberta (5,296 ha) (Anderson et al. 2005), where the Tennessee herd originated, to create use-area buffers (4,107 m radius) around elk use-area points (Figure 2.2). We also generated two additional buffers (Low Productivity and High Productivity) that represented portions of the WMA with low and high summer forage production (Figure 2.3). We visually selected center points for the Low Productivity and High Productivity buffers based on the summer forage availability model output. We extracted values from the forage availability model and the land cover raster to calculate land-cover proportions and mean forage availability per ha within each use-area buffer to compare to total proportions on the WMA. Portions of each use-area buffer overlapped with areas outside of the study area. We removed all non-WMA portions of each use-area buffer before conducting further spatial analysis. We calculated proportions of elk forage produced in wildlife openings and young forest stands within each use-area buffer and on the WMA to determine the current impact of each management practice on summer elk forage resources.

RESULTS

Distribution of Summer Elk Forage

Distribution of summer elk forage was uneven across the study area. Our model indicated that greater forage resources were concentrated in northeast and southern portions of the WMA and were less available in central and southwestern portions (Figure 2.4). Mean summer elk forage availability (kg/ha) was noticeably greater across the North Cumberland WMA than within the Chestnut Ridge, Frenchman's Grave, Titus Creek, and Low Productivity elk use-area buffers. Mean summer elk forage availability within the Jenny Creek and Massengale elk use-area buffers was similar to mean summer elk forage availability across the WMA. The Hatfield Knob buffer and the High Productivity buffer both had greater mean summer elk forage availability in comparison to the WMA (Figure 2.5).

North Cumberland Wildlife Management Area

Mean summer elk forage availability across the North Cumberland WMA was 254 kg/ha. Closed-canopy forest accounted for 80% of the land cover across the North Cumberland WMA, but only provided 47% of available summer elk forage. Young forest (< 7 years-old) only accounted for 9% of the land cover, but produced 36% of the available summer elk forage. Reclaimed surface mines represented 6% of the land cover and provided 11% of the available summer elk forage. Wildlife openings accounted for 0.5% of the land cover across the WMA and produced 1% of the available summer elk forage. Herbaceous and shrub represented 2% of the land cover and produced 5% of the total forage.

Chestnut Ridge Buffer

Mean summer elk forage availability within the Chestnut Ridge buffer was 190 kg/ha. Closed-canopy forest represented 91% of the land cover and produced 70% of the available summer elk forage within the Chestnut Ridge buffer. Young forest (< 7 years-old) accounted for 3% of the land cover within the buffer and produced 11% of the available summer elk forage. Reclaimed surface mines represented 2% of the land cover and provided 4% of the available summer elk forage. Wildlife openings accounted for 3% of the land cover within the buffer and produced 9% of the available forage. Herbaceous and shrub represented 2% of the land cover and produced 6% of the available summer elk forage within the buffer.

Hatfield Knob Buffer

Mean summer elk forage availability in the Hatfield Knob buffer was 302 kg/ha. Closed-canopy forest represented 69% of the land cover and produced 34% of the available summer elk forage within the Hatfield Knob buffer. Young forest (≤ 7 years-old) accounted for 13% of the land cover within the buffer, but produced 43% of the available summer elk forage. Reclaimed surface mines represented 16% of the land cover and provided 19% of the available summer elk forage. Wildlife openings accounted for 1% of the land cover within the buffer and produced 2% of the available forage. Herbaceous and shrub represented 2% of the land cover and produced 3% of the available summer elk forage within the buffer.

Frenchman's Grave Buffer

Mean summer elk forage availability in the Frenchman's Grave buffer was 186 kg/ha. Closed-canopy forest represented 89% of the land cover and produced 70% of the available summer elk forage within the buffer. Young forest (≤ 7 years-old) accounted for 1% of the land cover within the buffer, but produced 9% of the available summer elk forage. Reclaimed surface mines represented 8% of the land cover and provided 15% of the available summer elk forage. Wildlife openings accounted for 1% of the land cover within the buffer and produced 3% of the available forage. Herbaceous and shrub represented 2% of the land cover and produced 4% of the available summer elk forage within the buffer.

Jenny Creek Buffer

Mean summer elk forage availability in the Jenny Creek buffer was 252 kg/ha. Closed-canopy forest represented 84% of the land cover and produced 49% of the available summer elk forage within the buffer. Young forest (≤ 7 years-old) accounted for 10% of the land cover within the buffer, but produced 41% of the available summer elk forage. Reclaimed surface mines represented 4% of the land cover and provided 5% of the available summer elk forage. Wildlife openings accounted for 1% of the land cover within the buffer and produced 3% of the available forage. Herbaceous and shrub represented 1% of the land cover and produced 2% of the available summer elk forage within the buffer.

Massengale Buffer

Mean summer elk forage availability in the Massengale buffer was 234 kg/ha. Closed-canopy forest represented 83% of the land cover and produced 52% of the available summer elk forage within the buffer. Young forest (≤ 7 years-old) accounted for 6% of the land cover within the buffer, but produced 30% of the available summer elk forage. Reclaimed surface mines represented 10% of the land cover and provided 19% of the available summer elk forage. Wildlife openings accounted for 0.5% of the land cover within the buffer and produced 2% of the available forage. Herbaceous and shrub represented 1% of the land cover and produced 2% of the available summer elk forage within the buffer.

Titus Creek Buffer

Mean summer elk forage availability in the Titus Creek buffer was 176 kg/ha. Closed-canopy forest represented 94% of the land cover and produced 78% of the available summer elk forage within the buffer. Young forest ($\leq$ 7 years-old) accounted for 1% of the land cover within the buffer, but produced 7% of the available summer elk forage. Reclaimed surface mines represented 2% of the land cover and provided 3% of the available summer elk forage. Wildlife openings accounted for 1% of the land cover within the buffer and produced 5% of the available forage. Herbaceous and shrub represented 2% of the land cover and produced 8% of the available summer elk forage within the buffer.

Low Productivity Buffer

Mean summer elk forage availability in the Low Productivity buffer was 168 kg/ha. Closed-canopy forest represented 91% of the land cover and produced 83% of the available summer elk forage within the buffer. Young forest ($\leq$ 7 years-old) accounted for 1% of the land cover within the buffer and produced 4% of the available summer elk forage. Reclaimed surface mines represented 2% of the land cover and provided 5% of the available summer elk forage. Wildlife openings accounted for 1% of the land cover within the buffer and produced 3% of the available forage. Herbaceous and shrub represented 2% of the land cover and produced 5% of the available summer elk forage within the buffer.

High Productivity Buffer

Mean summer elk forage availability in the High Productivity buffer was 398 kg/ha. Closed-canopy forest represented 65% of the land cover and produced 25% of the available summer elk forage within the buffer. Young forest ($\leq$ 7 years-old) accounted for 26% of the land cover within the buffer and produced 68% of the available summer elk forage. Reclaimed surface mines represented 6% of the land cover and provided 5% of the available summer elk forage.

Wildlife openings accounted for 0% of the land cover within the buffer. Herbaceous and shrub represented 2% of the land cover and produced 2% of the available summer elk forage within the buffer.

DISCUSSION

Closed-canopy forest provided less mean forage availability than all other considered land cover types across the North Cumberland WMA, but accounted for the largest percentage of land cover within all elk use-area buffers and across the WMA. Young forest was the most productive land cover type and produced much more forage per ha and overall than forage associated with wildlife openings. Our model indicated summer elk forage resources were distributed unevenly across the WMA. The High Productivity buffer had greater mean summer elk forage availability than all other generated use-area buffers and the WMA. Mean forage availability estimates within the 6 elk use-areas suggest there is no apparent relationship between mean summer forage availability on the North Cumberland WMA and observed summer elk use.

More than 23% of each generated elk use-area buffer overlapped with private property, which resulted in a minimum of 1,232 ha within each buffer that could not be analyzed. The importance of these private lands to the concentration of elk activity and the forage availability on these lands is unknown. It is possible that the elk use is in part explained by the presence of these private lands because some of these areas are in open fields, which could serve as an alternate source of forage for both summer and winter.

Closed-canopy forest accounted for 80% of the land cover across the North Cumberland WMA. Closed-canopy forest stands provide the most potential for increasing elk forage availability because they are the least productive summer foraging areas for elk across the WMA. Summer elk forage availability in timber harvest treatments ($\leq$ 5 years-old) increased up to tenfold in comparison to closed-canopy forest stands on the North Cumberland WMA (See Chapter 1). Studies in similar regions of the southern Appalachians also reported increases in forage availability for white-tailed deer following canopy reduction (Beck and Harlow 1981, Ford et al. 1993, Lashley et al. 2011). Researchers in western forest systems have reported similar increases in summer forage availability for elk following timber harvest (Regelin et al. 1974, Hett et al. 1978, Collins and Urness 1983, Strong and Gates 2006, Swanson 2012). Implementing partial and/or full canopy reduction treatments in regions of the North Cumberland WMA where closed-canopy forest is overwhelmingly present would increase overall summer elk forage availability and provide elk with greater access to highly productive foraging areas where food resources have been limited.

Decreasing closed-canopy forest cover would, by default, result in an increase in young forest cover, which is the most productive land cover type across the WMA. However, summer elk forage availability began to decline just 5 years following complete canopy removal at North Cumberland WMA (See Chapter 1). Previous research has reported forage availability in young hardwood forest stands decreases to levels similar to mature forest stands 6-8 years after canopy removal as hardwood regeneration advances to a point of canopy closure and reduces available sunlight to the understory (Lashley et al. 2011, McCord et al. 2014). Additional disturbance is necessary to maintain the otherwise short term effects of timber harvest on summer elk forage availability in the eastern United States. Prescribed fire is an effective method of disturbance to increase the quality and quantity of forage for elk and deer when adequate sunlight is available (Cook et al. 1994, Sachro et al. 2005, Van Dyke and Darragh 2007). Data presented in Chapter 1 suggest a $\leq$ 5-year fire-return interval would effectively maintain increased summer elk forage availability following timber harvest at the North Cumberland WMA.

Wildlife openings across the WMA are attractive to elk and provide greater amounts of summer elk forage than other available land cover types with the exception of young forest. However, wildlife openings only account for 2% summer elk forage production across the WMA and are maintained through annual mowing. Converting closed-canopy mature forest to young forest with timber harvest and maintaining increased summer elk forage availability with periodic prescribed fire would likely require less time and money than establishing additional wildlife openings and could have a larger impact on increasing summer elk forage. Wildlife openings currently account for approximately 300 ha across the study area. Converting an additional 300 ha of closed-canopy forest to wildlife openings, if planted in perennial cool-season grasses and maintained with periodic mowing as is currently implemented, would provide an estimated 213,600 kg of additional summer elk forage annually. However, harvesting the same amount of closed-canopy forest would provide an additional 334,800 kg of additional summer elk forage annually. Annual warm-season legume crops, such as iron-clay cowpeas and soybeans, have been documented to produce more summer forage than timber harvest and prescribed fire in mixed-hardwood forest stands in Tennessee (Lashley et al. 2011). Managing annual, warm-season legumes in wildlife openings across the North Cumberland WMA could provide increased nutrition and summer forage availability for elk, but also would come at an additional expense with annual planting and occasional soil amendment.

An inverse relationship exists between elk travel distance and forage availability, indicating increases in forage availability can reduce home range size and minimize energy expenditures of elk (Knight 1970, Craighead et al 1973, Geist 2002, Anderson et al. 2005). This relationship does not always hold true in environments where predation risk is high (Frair et al. 2005). Human predation risks associated with hunting can increase elk movements and influence resource selection during the hunting season. However, continued vigilance and increased movement rates only last for approximately 3 – 5 weeks after hunting pressure has ceased, suggesting predation risks associated with hunting do not impact summer movements and resource selection of elk (Cleveland et al. 2012). The absence of an aggressive elk predator in eastern Tennessee, such as mountain lion (*Puma concolor*), gray wolf (*Canis lupus*), and brown bear (*Ursus arctos*), suggests the availability of forage resources is the primary factor influencing movements and home range sizes of Tennessee elk. Our model suggested that areas of high summer elk forage production are unevenly distributed across the North Cumberland WMA and mean summer elk forage availability was nearly 150 kg/ha less than within the High Productivity buffer. Focused efforts to increase summer forage resources in areas that are currently low in forage availability are needed to provide more evenness in summer forage distribution and may be a useful technique to reduce elk damage to nearby private properties.

MANAGEMENT IMPLICATIONS

The widespread coverage of closed-canopy forest across the WMA provides an opportunity to strategically increase summer forage resources in a way that could decrease elk home range sizes and concentrate summer elk activity on the North Cumberland WMA. Our model suggests converting closed-canopy forest to young forest through timber harvest is the most practical and efficient method for increasing summer elk forage availability on the North Cumberland WMA. Considerations should be made when planning timber harvest to provide a more even distribution of highly productive summer elk foraging areas. Increasing the presence of highly productive young forest (< 5 years-old) by approximately 14% (8,850 ha of timber harvest) would increase mean summer forage availability across the North Cumberland WMA to match mean production of the High Productivity buffer. Harvesting approximately 350 ha of closed-canopy forest per year across a 25-year timeline would accomplish this goal. However, it is clear from our data presented in Chapter 1 and other research that repeated applications of prescribed fire can maintain increased forage availability in young forest stands on a 5 – 8-year fire-return interval. Almost 3,200 ha of young forest 6 – 8 years-old already exist across the WMA and could lessen the need for such intensive harvest of mature closed-canopy forest if prescribed fire is introduced in those stands. Additional forage-based elk habitat components, such as nutritional carrying capacity and winter forage availability, can be modeled for elk in Tennessee using the framework we developed for the summer elk forage availability model. These forage modeling options should be explored to further evaluate habitat quality for elk across the North Cumberland WMA.

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APPENDIX

Table 2.1. Land cover types and associated elk forage values used to model summer elk forage availability across North Cumberland Wildlife Management Area, TN, USA.

Land Cover Type	kg/ha (SE)
Closed-Canopy Forest[a]	147 (21)
Reclaimed Surface Mine[a]	363 (64)
Wildlife Opening[a]	712 (67)
<5yr Young Forest[a]	1116 (98)
6-7yr Young Forest[b]	558 (N/A)
Herbaceous[b]	500 (N/A)
Shrub[b]	500 (N/A)
Developed Land[c]	NoData
Barren Land[c]	NoData
Woody Wetland[c]	NoData
Water[c]	NoData

[a] Site-specific summer elk forage values.

[b] Elk forage values based on expert opinion.

[c] Land cover types unable to be managed for elk forage production.

Table 2.2. Proportions of land cover types (%) within elk use-area buffers and across the North Cumberland WMA, TN, USA.

Land Cover Type	Ch. Ridge	Fr. Grave	H. Knob	Jenny Creek	Massengale	Titus Creek	NCWMA
Closed-Canopy Forest	90.7	88.9	69.0	83.7	82.7	93.5	80.3
Mine	1.8	7.5	15.5	3.7	9.7	1.4	7.5
Wildlife Opening	2.5	0.7	0.9	1.1	0.5	1.2	0.5
<5yr Young Forest	1.1	1.4	10.3	7.9	6.2	0.9	7.3
6-7yr Young Forest	1.8	0.0	2.8	2.5	0.1	0.4	1.9
Herbaceous	2.0	0.9	1.4	0.8	0.6	2.3	1.7
Shrub	0.2	0.6	0.1	0.4	0.4	0.3	0.8
Developed Land	4.5	4.3	1.3	1.8	2.4	2.9	2.2
Barren Land	0.1	0.1	0.0	0.0	0.1	0.2	0.0
Woody Wetland	0.1	0.1	0.0	0.1	0.0	0.2	0.1
Water	0.0	0.0	0.0	0.0	0.0	0.2	0.1

Table 2.3. Percentage of total summer elk forage produced by wildlife openings and young forest stands within elk use-area buffers and across the North Cumberland WMA, TN, USA.

Land Cover Type	Ch. Ridge	Fr. Grave	H. Knob	J. Creek	Massengale	T. Creek	NCWMA
Wildlife Opening	4.8	2.6	3.1	9.4	1.5	1.4	2.1
Young Forest[a]	6.7	8.6	40.5	11.5	29.6	36.4	43.2

[a] Combined production of "<5yr Young Forest" and "6-7yr Young Forest" land cover types.

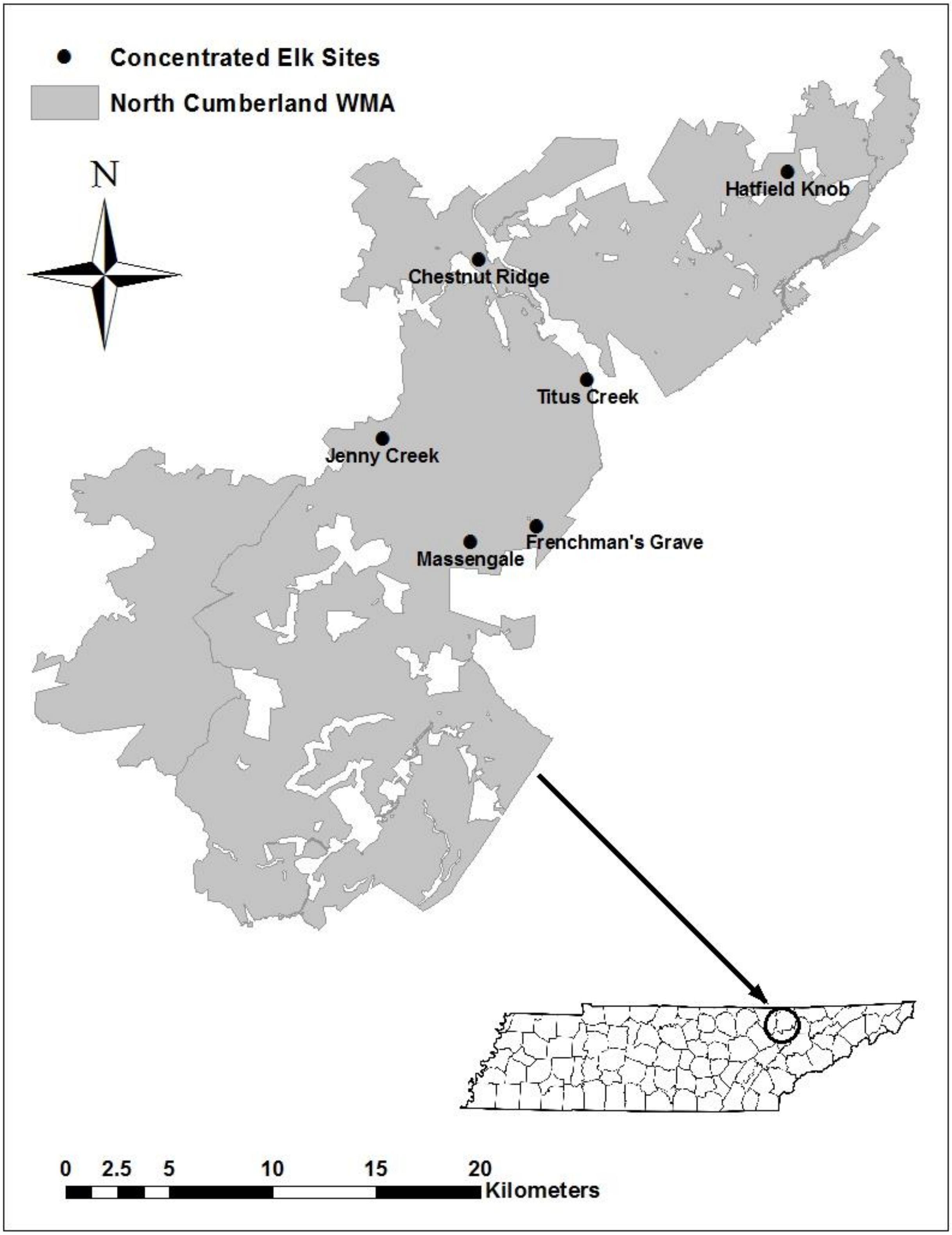

Figure 2.1. Locations of concentrated summer elk use across North Cumberland Wildlife Management Area based on observations by Tennessee Wildlife Resources Agency.

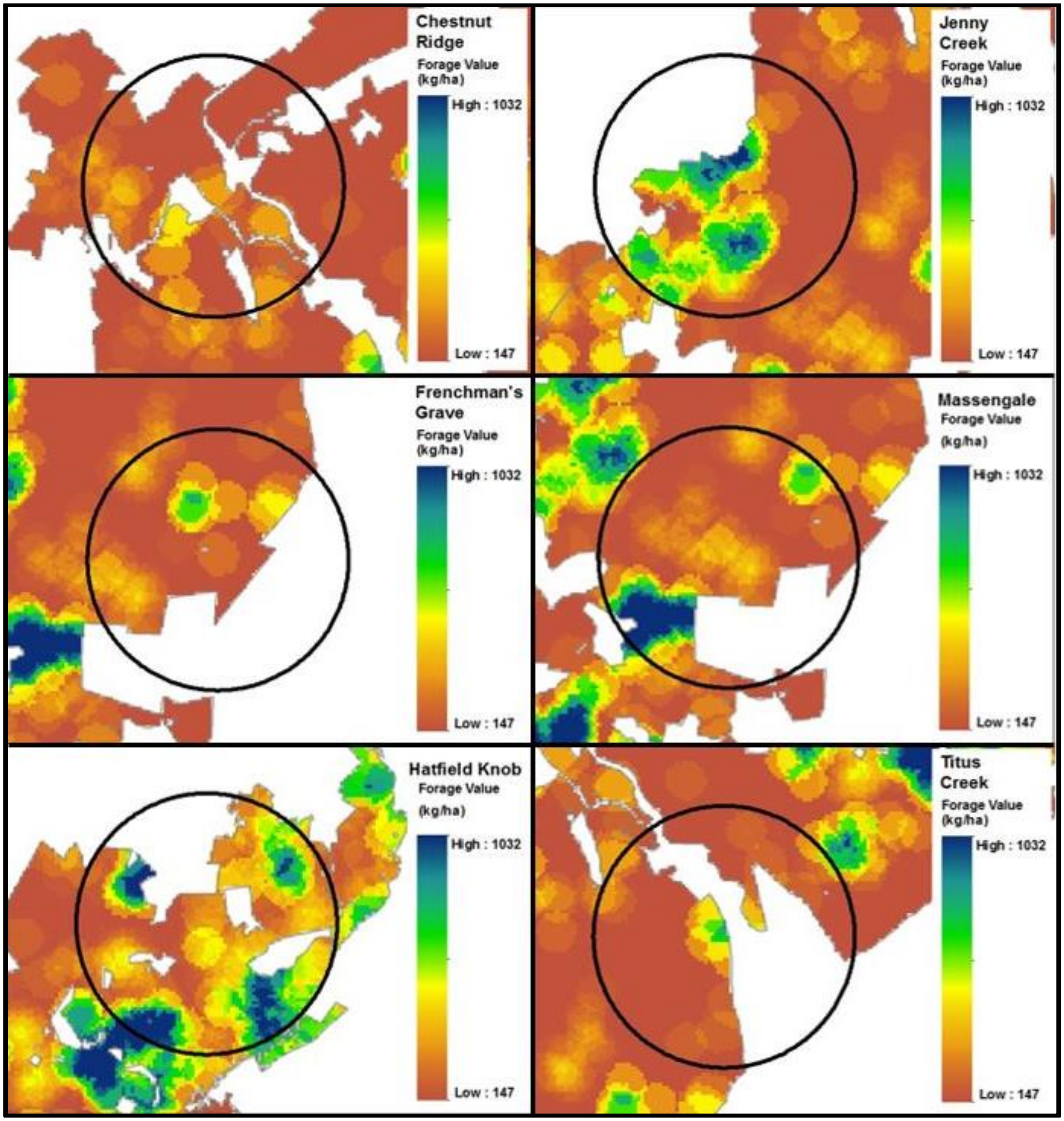

Figure 2.2. Distributions of summer elk forage availability within each elk use-area buffer across the North Cumberland WMA, Tennessee, USA, July-August 2013-15.

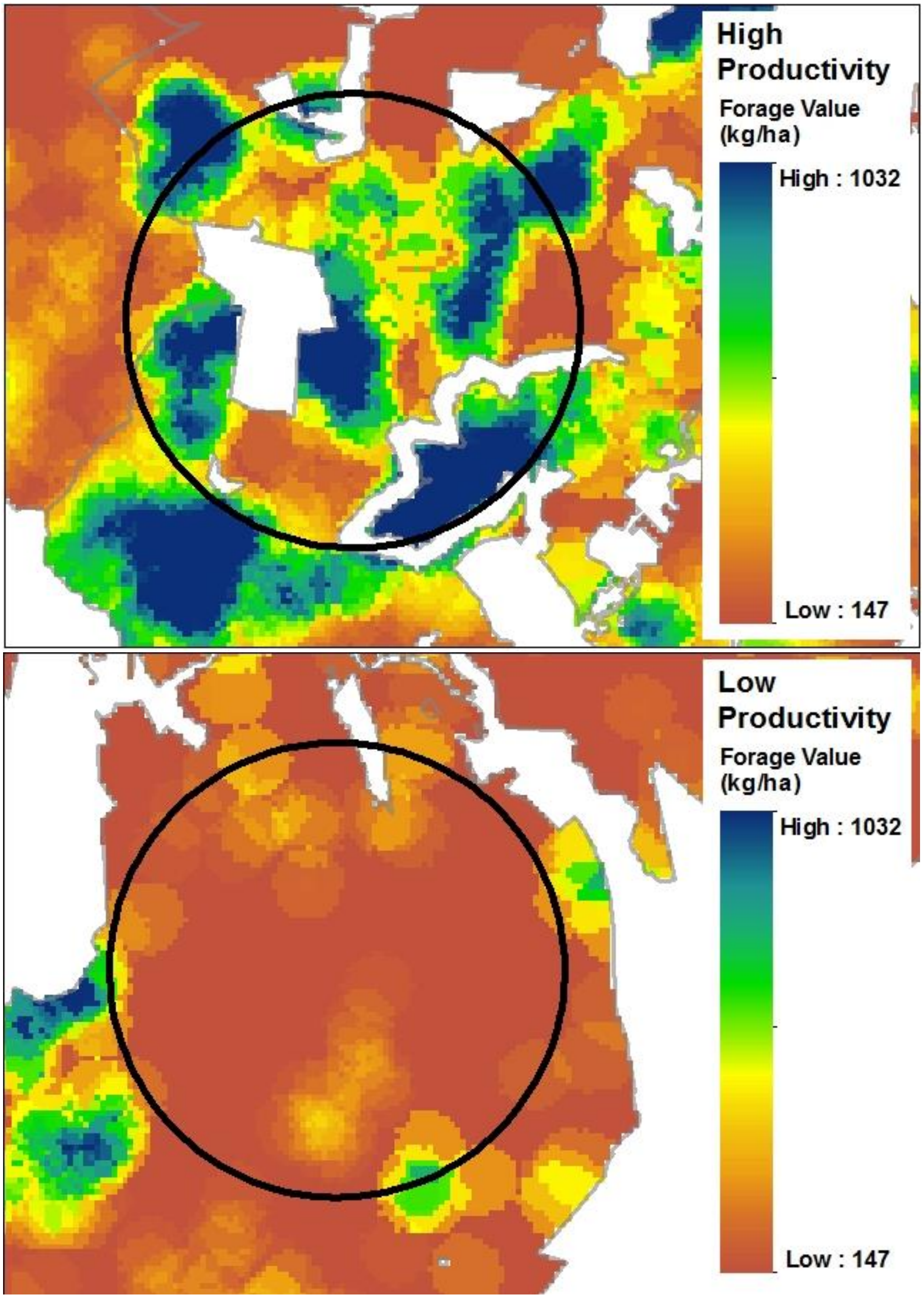

Figure 2.3. Distributions of summer elk forage availability within the High Productivity and Low Productivity area buffers across the North Cumberland WMA, Tennessee, USA, July-August 2013-15.

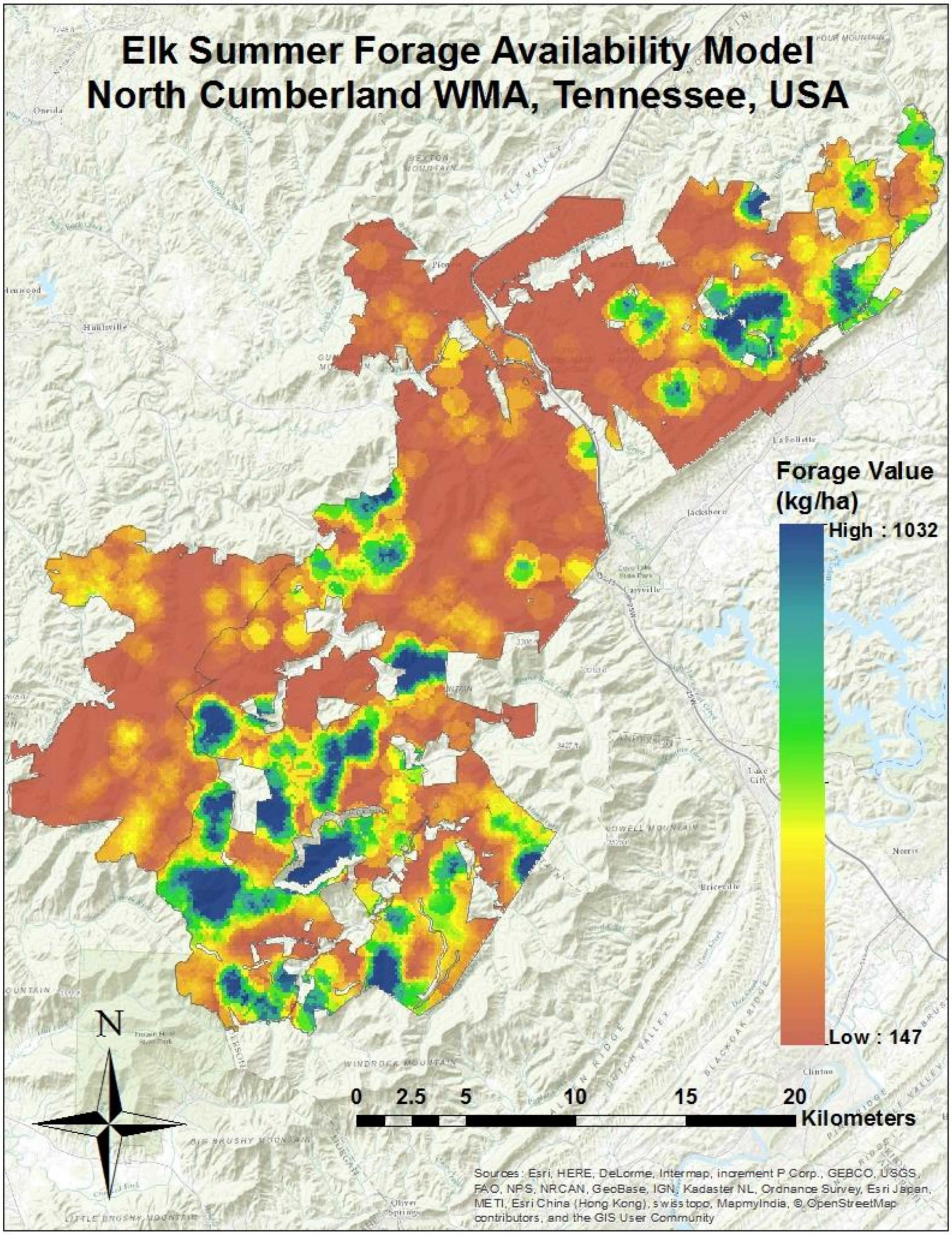

Figure 2.4. Distribution of summer elk forage availability, based on land cover and site-specific forage availability estimates, North Cumberland WMA, Tennessee, USA, July-August 2013-15.

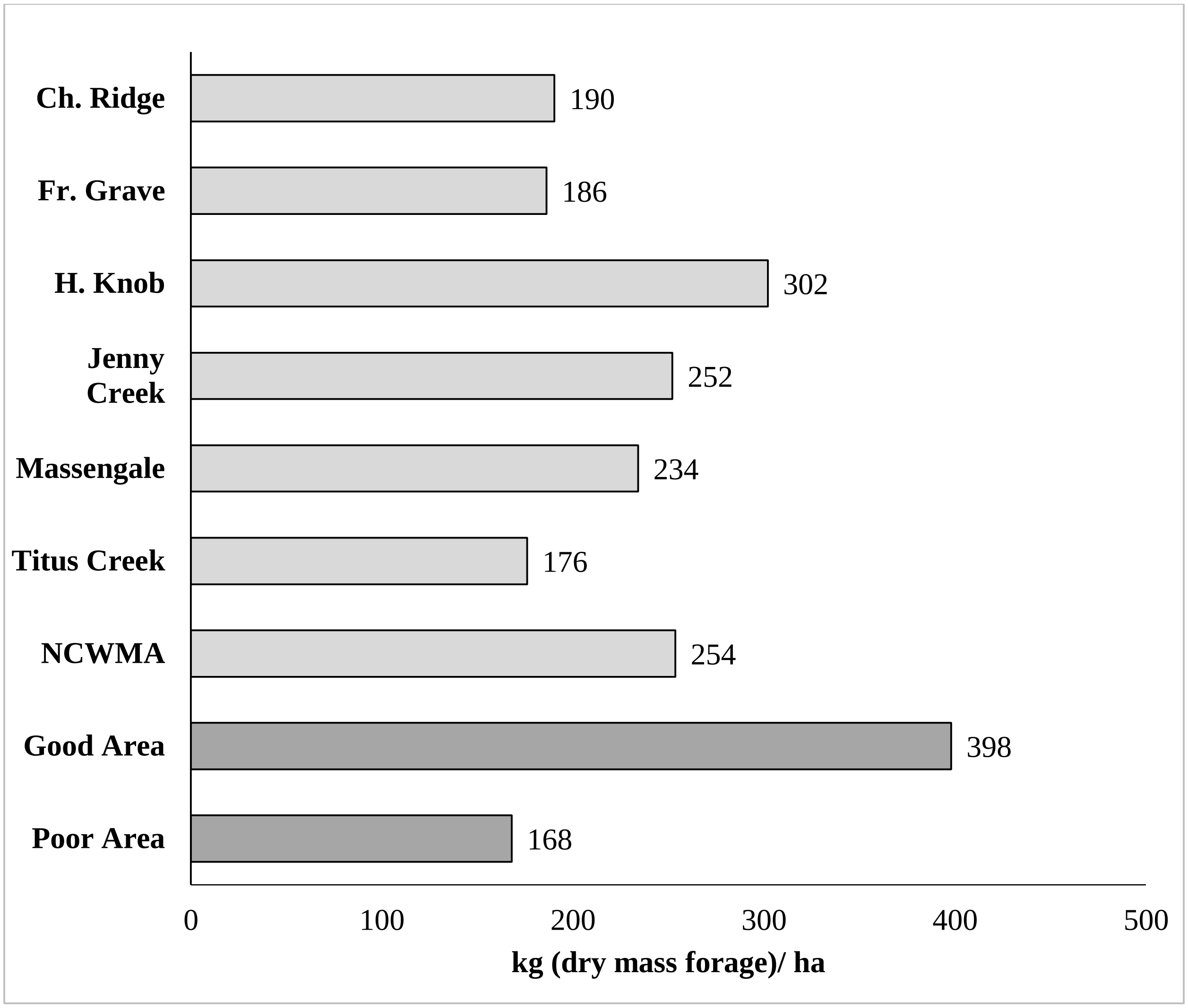

Figure 2.5. Mean elk forage availability (kg/ha) within elk use-area buffers and across the North Cumberland WMA, Tennessee, USA, July-August 2013-15.

CONCLUSION

Full canopy removal followed by repeated prescribed fire or an initial herbicide application followed with repeated prescribed fire will improve and maintain forage availability and NCC for elk and deer in forested landscapes in the eastern United States. Recurring prescribed fire will be required to maintain increased forage availability and NCC. Fire-return intervals should be determined by vegetation response and may vary year to year and across sites. However, it is clear from our data and other research that a fire-return interval within 5 – 8 years will be necessary to maintain increased forage availability in mixed hardwood systems of the eastern United States. If the objective is to convert mixed-hardwood forest stands to early successional plant communities to maximize forage quality for elk and deer, we recommend a targeted herbicide application in recently harvested stands (2 – 3 years post-harvest) to reduce coppice growth and young woody plants followed by periodic prescribed fire. The combination of this herbicide application with periodic prescribed fire will reduce woody competition with herbaceous plants and accelerate the transition of young mixed-hardwood forest stands to early successional plant communities, which will be required to restore and maintain elk habitat on many sites in the eastern United States.

The widespread coverage of closed-canopy forest across the WMA provides an opportunity to strategically increase summer forage resources in a way that could decrease elk home range sizes and concentrate summer elk activity on the North Cumberland WMA. Our model suggests converting closed-canopy forest to young forest through timber harvest is the most practical and efficient method for increasing summer elk forage availability on the North Cumberland WMA. Considerations should be made when planning timber harvest to provide a more even distribution of highly productive summer elk foraging areas. Increasing the presence of highly productive young forest (< 5 years-old) by approximately 14% (8,850 ha of timber harvest) would increase mean summer forage availability across the North Cumberland WMA to match mean production of the High Productivity buffer. Harvesting approximately 350 ha of closed-canopy forest per year across a 25-year timeline would accomplish this goal. As previously mentioned, repeated applications of prescribed fire can maintain increased forage availability in young forest stands on a 5 – 8-year fire-return interval. Almost 3,200 ha of young forest 6 – 8 years-old already exist across the WMA and could lessen the need for such intensive harvest of mature closed-canopy forest if prescribed fire is introduced in those stands. Additional forage-based elk habitat components, such as nutritional carrying capacity and winter forage availability, can be modeled for elk in Tennessee using the framework we developed for the summer elk forage availability model. These forage modeling options should be explored to further evaluate habitat quality for elk across the North Cumberland WMA.

VITA

Jordan Nanney was born and raised in the foothills of western North Carolina where he developed a passion for the outdoors through experiences hunting and fishing with his father, great-uncle, and grandfather. He received an associate's degree in Fish and Wildlife Management Technology from Haywood Community College in 2012 and completed his Bachelor of Science degree in Fisheries, Wildlife, and Conservation Biology at North Carolina State University in 2013 prior to pursuing his Master of Science degree at the University of Tennessee.