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Effects of prescribed fire on eastern box turtles (Terrapene carolina carolina)

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I am submitting herewith a thesis written by Katie Ann Harris entitled "Effects of prescribed fire on eastern box turtles (Terrapene carolina carolina)." 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.

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Spatial ecology, resource selection, and survival of eastern box turtles in fire-maintained systems in east Tennessee

A Thesis Presented for the
Master of Science
Degree
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DEDICATION

I dedicate this thesis to my family, who has guided me, supported me, and made me the person I am today.

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ABSTRACT

Fire is a natural disturbance that was once prevalent throughout the Southeast (Lorimer 2001, Spetich et al. 2011, Ryan et al. 2013). Although many species are adapted to frequent fire, it is important to understand fire effects on nontarget species. I used very high frequency (VHF) transmitters to evaluate home range, resource selection, and the effects of 17 prescribed fires on 118 eastern box turtles (*Terrapene carolina carolina*) across three areas in east Tennessee. Average annual survival of 82 eastern box turtles during 2016–17 was 0.95 ± 0.03 (SE), whereas survival of 109 eastern box turtles during 2017–18 was 0.94 ± 0.02. I used 7,730 and 1,225 telemetry locations from 100 individuals to develop home range estimates and resource-selection models, respectively. Average minimum convex polygon and 50% and 95% kernel density estimate home ranges were 9.3 ha ± 3.0, 1.5 ha ± 0.6, and 8.3 ha ± 2.9, respectively. Eastern box turtles selected areas with increased litter depth, increased bramble cover, increased coarse woody debris cover, increased visual obstruction, and greater numbers of 10- and 100-hr fuels than would be expected at random. Individuals were less likely to select areas with reduced vegetation cover. Average annual survival of eastern box turtles occurring in management units during a prescribed fire event was 0.90 ± 0.04, whereas average annual survival for those that did not occur in a burn unit during a prescribed fire was 0.98 ± 0.01. My results indicate eastern box turtles are susceptible to prescribed fire, especially fires occurring during the early portion of their active season (Mar–May). Wildlife managers can increase habitat quality for eastern box turtles by increasing bramble cover, visual obstruction, coarse woody debris cover, and litter depth. Prescribed fire, herbicide application, and mechanical treatment can be used to manipulate vegetation to accomplish those objectives, but prescribed fire practitioners should avoid early growing-season prescribed fire where box turtles are a concern.

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INTRODUCTION

Eastern box turtles (*Terrapene carolina carolina*) are culturally and ecologically important in the United States (Liu et al. 2004, Jones et al. 2007, Gillreath-Brown and Peres 2018). Recent research has documented declining population trends of eastern box turtles that have resulted in the classification status as a vulnerable species by the International Union for Conservation of Nature (Dodd 2001, Van Dijk 2011). This downward trend is attributed to habitat fragmentation, road mortality, mowing, and pet collection (Gibbons et al. 2000, Brown and Sleeman 2002, Nazdrowicz et al. 2008). Long-term monitoring has revealed >50% reductions of select eastern box turtle populations in recent decades (Williams and Parker 1987, Hall et al. 1999). Despite declining populations, knowledge gaps persist regarding eastern box turtle ecology. Movement, habitat use, and response to habitat manipulation are poorly understood.

Declining population trends are alarming because eastern box turtles live upwards of 50 years, do not reach sexual maturity until 6–10 years, and spend their life in a small area (Ernst et al. 1994, Dodd 1997, Dodd 2001). It is necessary to understand habitat use and effects of habitat manipulation to conserve eastern box turtle populations. My graduate committee and I developed a study to measure eastern box turtle habitat use, resource selection, and response to prescribed fire to address this concern.

I used these data to develop 2 chapters. Chapter 1 investigates the direct and indirect effects of fire events. Chapter 2 evaluates eastern box turtle movements and resource selection from May to August. Chapters were formatted to meet Journal of Wildlife Management guidelines.

CHAPTER I. DIRECT AND INDIRECT EFFECTS OF FIRE ON EASTERN BOX TURTLES

ABSTRACT Relatively little is known about the effects of fire on the eastern box turtle (*Terrapene carolina carolina*). We used very high frequency (VHF) transmitters to monitor mortality, movement, and habitat use of 118 box turtles in response to prescribed fire across three sites in east Tennessee. Managers conducted 11 early growing-season burns (Apr–May), 4 late growing-season burns (Sept–Oct), 1 dormant-season burn (Mar), and 1 summer burn (June) during 2016–2018. We recorded 11 mortalities, including 6 as a result of prescribed fire and 3 from wildfire. Average annual survival of 42 box turtles that experienced a fire event was 0.90 ± 0.04 (SE), whereas survival of 76 control box turtles that did not experience a fire event was 0.98 ± 0.01. All fire-related mortalities occurred during growing-season fires. Additionally, 14% of box turtles we captured exhibited presumed fire damage to their carapace. Box turtles avoided mortality during growing-season fires by occupying areas that did not burn, moving to unburned areas, or burrowing. Box turtles exhibited site fidelity and did not change home range size following burn events and sinuosity of movements did not differ between burned and unburned units. Box turtles did not exhibit selection for or against areas that were burned regardless of time since fire. Our results indicate that though box turtles are susceptible to prescribed fire during their active season, they possess behavioral and physical traits that reduce the direct effects of prescribed fire. Our results suggest prescribed fire practitioners can alter prescribed fire seasonality, firing pattern, and intensity to reduce mortality of box turtles during prescribed fires.
KEY WORDS prescribed fire, direct effects, indirect effects, survival, *Terrapene carolina carolina*, eastern box turtle, habitat management.
Land managers use prescribed fire to influence vegetation composition and structure for various wildlife species and for ecosystem maintenance and restoration (McShea and Healy 2002, Van Lear and Harlow 2002). Effects of fire on vegetation and wildlife are well described for some

ecosystems, such as the longleaf pine (*Pinus palustris*) or tallgrass ecosystems, but less understood for others (Conner et al. 2001, Van Lear et al. 2005, Knapp et al. 2009, Stambaugh et al. 2015). Fire is being increasingly used in hardwood ecosystems of the southeastern United States, and the effects of fire on various plant and animal species continue to be investigated (Russell et al. 1999, Harper et al. 2016). The effects of fire are poorly understood for eastern box turtles (*Terrapene carolina carolina;* hereafter box turtle). The need for this information is growing as box turtles are declining throughout much of their distribution (Gibbons et al. 2000, Van Dijk 2011, Keister and Willey 2015).

Limited mobility, long active seasons, and unpredictable movements likely make box turtles vulnerable to fire events (Congdon et al. 1989, Dodd 2001, Budischak et al. 2006, Laarman et al. 2018). Research has documented prescribed fire having direct negative effects on box turtles, including mortality, physical injury, and decreased body condition (Babbit and Babbit 1951, Rose 1986, Platt et al. 2010, Howey and Roosenburg 2013, Roe et al. 2019). Altering the season in which fire is implemented has been suggested to influence the direct effects of prescribed fire on reptiles (Platt et al. 2010, Beaupre and Douglas 2012, Cross et al. 2015). Only one study has investigated direct effect of fire on adult box turtles using radio telemetry (Roe et al. 2019). Inferences from this study are limited because burn regime parameters were not reported.

The most frequent effects of fire on wildlife are indirect (Harper et al. 2016). Fire modifies vegetation composition and structure, which alters the distribution and availability of food and cover. Reptile presence is closely associated with vegetation composition (Lindenmayer et al. 2008, Moorman et al. 2011). Prescribed fire has been suggested as an important contributor to improved habitat quality for box turtles (Russell 1999, Keyser et al.

2004, Greenberg and Waldrop 2008). Habitat quality influences the presence, movements, and home range size of individuals. From a population standpoint, density, survival, and reproductive potential within a given area can be altered by changes in habitat quality (Greenberg et al. 1994). The reduction in basal area and increase in forb cover following fire events can favor box turtle occurrence because of improved conditions for foraging, nesting, and thermoregulation (Kilpatrick et al. 2010, Laarman et al. 2018). These indirect effects of prescribed fire are influenced by fire intensity, seasonality, frequency, and ignition pattern (Lashley et al. 2015).

The lack of detailed information on direct and indirect effects of prescribed fire on box turtles is concerning as an increasing number of agencies and landowners are using prescribed fire (Ryan et al. 2013, Kobziar et al. 2015). It is logical to assume box turtles occurring in fire-adapted ecosystems are physically and/or behaviorally adapted to fire (Babbit and Babbitt 1951, Rose 1986, Russell et al. 1999, Perry et al. 2012). However, recent population stressors (i.e., habitat fragmentation, habitat loss, pet collection) may have reduced population stability in certain localities (Gibbons et al. 2000, Brown and Sleeman 2002, Nazdrowicz et al. 2008). Therefore, we developed an experiment to investigate fire effects on box turtles. Our objectives were to determine both direct (i.e., mortality and injury via shell condition) and indirect effects (i.e., changes in resource selection) of prescribed fire on box turtles.

STUDY AREA

We implemented field experiments on 3 study sites in east Tennessee, USA. Each location varied in predominant vegetation types, topography, management, burn history, and burn regimes.

Catoosa Wildlife Management Area (WMA; 36.063° N, 84.882° W) encompassed 32,374 ha in the Cumberland Plateau and Mountains physiographic region and was managed by the Tennessee Wildlife Resources Agency. Catoosa WMA spanned portions of Cumberland, Morgan, and Fentress counties. Routine prescribed burning began in 2002 with the initiation of an oak-savanna restoration project. Primary vegetation types across the study area were shortleaf pine-oak woodlands (61%) and shortleaf pine-oak savannas (25%). Closed-canopy deciduous forest (9%), closed-canopy mixed forest (3%), and wildlife openings (2%) also were present. Managers aimed for a fire-return interval of 2–3-years to maintain woodlands and savannas.

Kyker Bottoms Waterfowl Refuge and WMA (35.605° N, 84.115° W) encompassed 230 ha in the Blue Ridge physiographic region of southern Blount County and was owned and managed by the Tennessee Wildlife Resource Agency. Kyker Bottoms was dominated by early successional plant communities (61%) and closed-canopy deciduous forest (32%). Hardwood woodlands (4%) and closed-canopy eastern redcedar (*Juniperus virginiana*) stands (3%) also were present. Lowland areas were flooded for waterfowl, whereas uplands were managed primarily for northern bobwhite (*Colinus virginianus*). Prescribed fire has been implemented since 1997.

Tanasi Girl Scout Camp (36.246° N, 83.966° W) encompassed 237 ha in the Ridge and Valley physiographic region of Tennessee and was privately owned and managed. Tanasi bordered Norris Lake and was dominated by closed-canopy deciduous forest (43%) and closed-canopy eastern redcedar stands (29%). Closed-canopy mixed forests (21%), oak woodlands (3%), wildlife food plots (3%), and old-fields (1%) also were present. All vegetation types at Tanasi were burned periodically since 2004 to enhance habitat for eastern wild turkey (*Meleagris gallopavo*) and white-tailed deer (*Odocoileus virginianus*).

METHODS

Turtle Capture

We captured adult box turtles using opportunistic finds, active searches, and wildlife detector dogs (Refsnider et al. 2011, Kapfer et al. 2012). Box turtles were considered adults if carapace length was >95 mm and mass was >170 g (Dolbeer 1969, Donaldson and Echternacht 2005). Opportunistic finds were incidental captures while researchers were not actively searching for box turtles (e.g., turtles found crossing roads). Active searches were visual searches along meandering transects in predefined search areas (Currylow et al. 2012). Lastly, 5 wildlife detector dogs (*Canis lupus familiaris*, boykin spaniel) were used to find turtles through olfaction (Kapfer et al. 2012). Wildlife detector dogs were not leashed but responded to auditory commands. We walked directional paths with wildlife detector dogs across predetermined study areas. Search efforts were concentrated in areas scheduled to be burned during the study period. All procedures were approved by the University of Tennessee Institutional Animal Care and Use Committee (UT-IACUC #2473-0616).

We recorded the initial capture location of each turtle using a handheld global positioning system (GPS; Garmin GPSMAP 64st, Garmin International, Olathe, KS, USA). We measured body mass with a Pesola Medio-Line spring scale to the nearest 10 g. We recorded the gender of each turtle using external physical characteristics including eye color, plastron shape, rear claw length, and cloaca position (Dodd 2001). We measured carapace length with a 20-cm Pittsburgh digital caliper to the nearest millimeter. We noted any injuries or defects to the plastron, carapace, eyes, digits, limbs, and/or skin. We recorded any illness or health issues, such as discharge from the eyes, mouth, nose, and/or vent. We photographed each turtle before transmitter attachment.

Radio Telemetry

We affixed a very high frequency (VHF) radio transmitter (model R2020, Advanced Telemetry Systems, Isanti, MN, USA) to the second pleural scute on the left side of each turtle using 5-minute epoxy. We affixed transmitters to the center of 1 scute to avoid inhibiting scute development. Transmitters weighed 15 g (approximately 4% of average mass of an adult box turtle). We monitored box turtle movement 1–3 times per week from July to November of 2016, May to August of 2017, and March to November of 2018 using the homing method and direct observation with a folding 3-element Yagi antenna and an Advanced Telemetry Systems R-1000 telemetry receiver (Communications Specialist Inc., Orange, CA, USA). We recorded ≥1 location per month from December to April of 2017 and 2018. We removed all transmitters at the end of the study using a jeweler's saw.

Fire Events

We radiolocated all box turtles in burn units within 4 hours prior to each prescribed fire and considered turtles to have experienced a fire if they occurred in a prescribed fire unit within the 4-hr period prior to ignition. We defined box turtles that experienced a prescribed fire as the treatment group for the duration of the study, whereas box turtles that did not experience a prescribed fire during our study were defined as the control group. We attached a temperature data logger (iButton model DS1922L, Maxim Integrated, San Jose, CA, USA) to the carapace of each box turtle in the burn unit during the 4-hr period prior to ignition. We affixed the iButton to the center of the second pleural scute on the turtle's right side using 5-minute epoxy. The iButtons were programmed to record carapace temperatures at a 1-second interval. iButtons were removed within 2 hours following the completion of the burn. We calculated the distance of turtle locations to the nearest firebreak prior to fire events using the point distance tool in ArcMap 10.5 (ESRI, Redlands, CA, USA).

We recorded weather conditions and measured fire intensity during each prescribed fire. We measured weather parameters, including ambient temperature, relative humidity, and wind speed using a Kestrel© 3500 fire weather meter (Nielsen-Kellerman, Boothwyn, PA, USA). We measured fire intensity with Tempilaq® heat-sensitive indicator paint (Tempil, Elk Grove Village, IL, USA) applied to ceramic tiles. Twelve temperatures were represented, ranging from 79° C to 427° C in roughly 14°-C increments. We wrapped tiles in aluminum foil to avoid charring. We placed 3 tiles 3 m away from each turtle prior to the fire event at random azimuths.

We measured litter depth before each fire event at 1-m intervals along 4 5-m transects in each cardinal direction. Sample points were centered at each turtle location. We recorded the activity of each box turtle within scheduled burn units prior to ignition by visual observation. We walked firebreaks during fire events to estimate the number of turtles that left burn units. We located each turtle within prescribed burn units within 2 hours after the completion of the burn and recorded behavior, injuries, and mortality status. We delineated burn coverage by walking the perimeter of burned areas with a handheld GPS unit. We calculated the area of burn units using ArcMap 10.5.

We calculated 100% minimum convex polygon, 50% kernel density, and 95% kernel density home range estimates prior to and following prescribed fire events. We calculated minimum convex polygon home range analysis in ArcGIS 10.5 (ESRI, Redlands, CA, USA). We used Geospatial Modelling Environment (GME, Spatial Ecology 2012) and the plugin bandwidth to calculate 50% and 95% kernel density home range estimates (Gitzen et al. 2006, Rittenhouse et al. 2007, Bauder et al. 2015). We used telemetry data from turtles with >40 locations to calculate home ranges (Seaman et al. 1999).

Resource Selection

We used a discrete-choice model to determine changes in resource selection from prescribed fire as part of a larger resource selection study (see Chapter 2). Discrete-choice models calculate the probability of an individual selecting a resource as a function of available resources using the multinomial logit model of logistic regression (Cooper and Millspaugh 1999). Discrete-choice models allow resource availability to be defined separately for individuals over time and space. Selection is estimated by comparing used telemetry locations to available locations for individuals. The pair of used and available locations are defined as the choice set (Hoffman 2010). We used telemetry locations from May to August of 2017 and 2018 to develop our choice set. We defined our choice set using an integrated step-selection function (Fortin et al. 2005, Avgar et al. 2016).

We used the movement.ssfsamples tool in Geospatial Modelling Environment (GME, Spatial Ecology 2012) to generate our step-selection model. Movement.ssfsamples generates sampled steps along an observed movement path using telemetry data (Beyer 2012). Available locations were generated by selecting step lengths and turn angle distributions from binned frequency distributions of observed movement paths (Beyer 2012). We used observed step lengths (i.e., distances between successive observed locations) and turning angle distributions (i.e., deviations from previous bearings) to generate 1 available point for each telemetry point. Generated step lengths and turn angles were derived from empirical data of turtles with equivalent telemetry intervals. We grouped observed turn angles and step lengths into 18 20-degree bins and 18–26 40-m bins to create equal step-length categories, respectively. We used the extract by points tool in ArcMap 10.5 and detailed shapefiles of burn units to determine whether observed and available points were in burned or unburned areas. We classified observed and available points into 3 categories to represent the number of growing seasons elapsed since fire: no fire since study initiation, 1 growing season since fire (1–12 months), and 2 growing seasons since fire (13–24 months).

Statistical Analysis

We performed statistical analysis using Program R 3.3.1 (R Core Team 2016) unless otherwise noted. We checked normality and equality of variances using the Shapiro-Wilk's test and the Levene's test, as appropriate. We log-transformed home range estimates to approximate normal distributions and equal variances if data failed to meet assumptions. Statistical significance was accepted when $\alpha \leq 0.05$.

We used logistic regression in Program Mark 8.2 to estimate survival rates (Agresti 1996, White and Burnham 1999). We used known-fate models in a maximum likelihood framework to determine how year, treatment, season of burn, distance to firebreak or edge of burn unit, pyrometer tile temperature, outer carapace temperature, litter depth, ignition pattern, burn coverage, and burn size were related to turtle survival. We used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank candidate models. We considered models with AIC_c values < 2 as competing models.

We used the COXPH and COXME package in Program R 3.3.1(R Core Team 2016) to conduct our discrete-choice analysis (Therneau 2013, Brooke et al. 2015). We did not detect differences in selection between years; therefore, we pooled locations from 2017 and 2018. We performed a correlation analysis and removed 1 variable of any pair of correlated variables (i.e., Pearson's $|r| > 0.75$) based on their biological significance. We used the purposeful model-building strategy to determine candidate step-selection models (Hosmer et al. 2013). We first developed 36 univariate models, including 9 models with random effects, to analyze each variable's influence on resource selection. We retained variables with a $P < 0.25$, which we used to create a global model (Brooke et al. 2015). We removed non-significant variables ($P > 0.05$) individually from the global model, based on the magnitude of their *P*-value, until our model only contained significant ($P < 0.05$) variables (Brooke et al. 2015). We added variables that were eliminated in the first step, 1 by 1, into the reduced global model to determine any significance change between variables (Brooke et al. 2015). We fit 18 additional models with random terms to determine if selection variation among individuals and study sites was needed to improve the model (Duchesne et al. 2010, Brooke et al. 2015). We fit 56 additional models to determine interaction and quadratic effects. We used Akaike's Information Criterion (AIC) to compare models and considered models with ΔAIC <2 competing models. We used the most parsimonious model when ΔAIC <2 (Burnham and Anderson 2002). We used the most-supported model to predict probability of use given the significant variables. We created selection ratios through slope estimate (β) exponentiations to measure the odds of selection (McDonald et al. 2006). We only considered variables with confidence limits not overlapping zero.

We used a used a 2-sample t-test to analyze the effects of prescribed burning on home range size. We used the log transformation to meet normality assumptions. We compared turtle movement sinuosity between burned and unburned areas using a 2-sample t-test. We calculated sinuosity using the calculate sinuosity tool in ArcMap 10.1 (ESRI, Redlands, CA, USA). We calculated sinuosity for turtles with ≥40 locations and ≥10 consecutive locations in a single management unit.

We performed a 1-way analysis of covariance (ANCOVA) to determine if fire events were related to turtle mass when carapace length was used as a covariate, because carapace length is positively correlated with body mass (Dodd 2001, Howey and Roosenburg 2013). We used Tukey's honestly significant difference test to compare means between treatments (Welkowitz et al. 2012). We used a 2-sample t-test to compare average pyrometer tile measurements, average maximum iButton temperatures, and average litter depth between survival outcomes.

RESULTS

We captured, radiomarked, and recorded locations for 118 individual adult box turtles from July 2016 to October 2018 (61M:57F). We documented 17 prescribed fires and 1 wildfire event (Table 1.1) and recorded 11 mortalities of radiomarked-turtles over the course of the study, 6 of which resulted from prescribed fire. The remaining mortalities were the result of wildfire ($n = 3$), vehicle strike ($n = 1$), and unknown causes ($n = 1$). Average annual survival rate across all 3 sites was 0.95 ± 0.02. Annual survival for the first year (July 2016–June 2017) was 0.95 ± 0.03, whereas survival for the second year (July 2017–June 2018) was 0.94 ± 0.02. Survival was negatively related to prescribed fire treatments ($\Delta AIC_c = 2.54$, $\beta = 6.20$, 95% CI =5.40–7.00, Table 1.2). Average annual survival of the treatment group across all sites was 0.90 ± 0.04, whereas survival of the control group across all sites was 0.98 ± 0.01. Of the 42 turtles in the treatment group, 40% occurred in microsites that did not burn during prescribed fires. Average annual survival was 0.83 ± 0.06 for treatment turtles that occurred in burned portions of burn units. Survival rates did not differ amongst the 3 sites or between years (Figure 1.1).

Resource managers conducted 11 early growing-season prescribed fires from 11 April and 17 May during 2017 and 2018 (Table 1.3). Mean emergence date for box turtles was 23

April (Table 1.4). We documented 5 mortalities of 25 turtles that experienced early growing-season prescribed fires. Average annual survival for turtles that experienced an early growing-season burn was 0.85 ± 0.06. Burn coverage averaged 57.5% for the 11 burns. Average annual survival for turtles that occurred in burned portions of early growing-season units was 0.77 ± 0.08. Pyrometer tile temperatures between surviving turtles and turtles that experienced mortality approached statistical significance (P = 0.078), with the average pyrometer tile temperature for surviving and deceased turtles being 110.4° C ± 52.5 (n = 10) and 184.6° C ± 61.8, respectively (n = 5). The average maximum iButton temperature of turtles that experienced mortality was 68.7° C ± 15.5 (n = 5 turtles), whereas the average maximum iButton temperature for turtles that survived and encountered a fire was 80.7° C ± 7.6 SE (n = 3 turtles). Turtles that survived fires were in areas with shallower litter depths than turtles that experienced mortality (P = 0.048). The average litter depth for surviving and deceased turtles was 1.9 cm ± 1.9 and 4.0 cm ± 1.5, respectively. We recorded 2 turtles leaving burn units during early growing-season burns (1 radiomarked, 1 unmarked).

Resource managers conducted 1 summer prescribed fire on 6 June 2018 (Table 1.5). Burn coverage was 32% during this fire. One turtle was present in the burn unit, but moved to a portion of the unit that did not burn and survived. The average pyrometer tile temperature for that turtle was 62° C.

Resource managers conducted 4 late growing-season prescribed fires from 8 September and 5 October during 2016 and 2017 (Table 1.6). Burn coverage averaged 99% for the 4 burns. We documented 1 mortality of 13 turtles that experienced a late growing-season prescribed fire, with an average annual survival of 0.95 ± 0.05. Annual average survival for turtles that occurred in burned portions of late growing-season units was 0.92 ± 0.08. The average pyrometer tile measurement of the turtle that experienced mortality was 135° C, whereas the average pyrometer tile measurement of surviving turtles in areas that burned (n = 9 turtles) was 151.9° C ± 63.5. The average maximum iButton temperature of turtles that encountered late growing-season burns was 84.2° C ± 11.2 (n = 5 turtles). We recorded 22 turtles leaving burn units during late growing-season burns (1 radiomarked, 21 unmarked).

Resource managers conducted 1 dormant-season prescribed fire on 4 March 2018 (Table 1.5). The dormant-season burn included 3 turtles, all of which were brumating underground. Dormant-season prescribed fire did not result in any box turtle mortalities and box turtles did not exhibit abnormal behavior following the fire event.

A series of wildfires, totaling approximately 600 ha, occurred in treatment and control units at Catoosa WMA in October 2016 (Table 1.5). Drought conditions preceded and followed these fire events. Eight turtles survived the wildfire event, whereas 3 turtles died, and 2 transmitter failures occurred during the fires. The 3 turtles that died during wildfire survived a prescribed fire 10 days prior by moving to an unburned unit. Average annual survival for turtles that experienced a wildfire was 0.80 ± 0.11.

Only 2 covariates were important predictors of survival: iButton temperature during early growing-season fires and fire intensity during early growing-season fires. The β-estimate for iButton temperatures during the early growing season was −0.0273 (95% CI = −0.048–−0.006), indicating that survival decreased as iButton temperature increased. The β-estimate for fire intensity was −0.011 (95% CI = −0.0201–−0.002) indicating that survival decreased as fire intensity increased. Burn unit size was not a predictor of survival.

Fire events were not related to turtle mass (P = 0.450). Average turtle mass in burned units was 399.2 g ± 10, whereas average turtle mass in unburned units was 406.5 g ± 7.4.

However, 3% of turtles that experienced a fire demonstrated scute loss (Figure 1.2). We recorded preexisting carapace damage that was presumed a result of previous fire events in 14% of radiomarked turtles (Figure 1.2).

Habitat Use

We used 1,225 telemetry locations and 1,225 associated available locations from 100 individuals from May to August of 2017 and 2018 to develop step-selection models to measure resource use related to prescribed burning. We excluded 18 box turtles that moved to private property or experienced transmitter loss or failure from our step-selection analysis. Box turtles did not exhibit selection for any specific elapsed time-since-fire classifications ($P = 0.391$) or for burned areas when they were available ($P = 0.253$). Neither burn variable met inclusion criteria for our global model (AIC = 1383.21).

Minimum convex polygon, 95% kernel density, and 50% kernel density home range estimates did not change following fire events ($P = 0.431$, $P = 0.445$, $P = 0.767$, respectively). Turtles exhibited similar movement patterns in burned and unburned units as sinuosity did not differ ($P = 0.457$). Mean sinuosity in burned units was 0.15 ± 0.02, whereas mean sinuosity in unburned units was 0.19 ± 0.02.

DISCUSSION

Prescribed fire can negatively influence box turtle survival, and our data indicate differential survival rates according to season of burn. All fire-related mortalities occurred during growing-season fires, but the preponderance occurred during the early growing season when turtles may be more susceptible because of lethargy. Box turtles avoided mortality during growing-season burns by occurring in areas that did not burn, moving to areas during the burn that did not burn, or burrowing. Box turtles were not susceptible to mortality during the dormant season because they were brumating in underground hibernacula. Sinuosity of movements and home range estimates did not differ between burned and unburned units suggesting box turtles exhibit site fidelity and do not abandon home ranges following burn events. Our results indicate that though box turtles are susceptible to prescribed fire during their active season, they possess behavioral and physical traits that may reduce direct effects of prescribed fire.

The box turtles that survived prescribed fire most commonly did so by being in areas with insufficient fuel or high moisture that were less conducive to fire. Of 118 turtles that were radiomarked, 65% occurred in such areas where burning was not possible. Of 35% of turtles that occurred in burn units, 15% survived by occupying microsites that did not burn, whereas 11% survived by moving to refuge within the burn unit (e.g., creek beds, stump holes, overhanging rocks) during the burn. Similarly, 2% of the turtles that experienced a burn survived by leaving the burn unit after ignition and moving to adjacent unburned units. We documented 24 (2 radiomarked, 22 unmarked) turtles, including 1 hatchling, crossing firebreaks, presumably to avoid fire.

In addition to behavior, box turtles have physical traits that can lessen the direct effects of prescribed fire (Rose 1986, Howey and Roosenburg 2013). We documented surviving box turtles experiencing carapace temperatures up to 90.1° C. However, prescribed fires adversely impacted shell condition of 3.6% individuals that experienced a fire event. Burn injuries ranged from mild scute discoloration to severe carapace damage that involved carapace regeneration (Figure 1.2). We did not document any mass differences between turtles that experienced burns and those that did not.

We did not document any mortalities during summer or dormant-season prescribed fires. Our sample size of fires during these times was low because resource managers on the sites we studied did not burn during the dormant season or midsummer often. High moisture and relative humidity reduce opportunities to conduct summer (Jun–Aug) prescribed fires in our region. Summer burns likely are a reduced threat to box turtle survival because vegetation moisture and relative humidity are often high, and few burns are conducted during the summer in the Central Hardwoods and Appalachian region. If conditions allow a summer burn, fire spread is relatively slow and patches of unburned refuge are common (Knapp et al. 2009, Platt et al. 2010, Harper et al. 2016). Survival was not impacted during the dormant season because box turtles were brumating below ground at depths ranging from 0–15 cm (Congdon 1989, Claussen et al. 1991, Gibson 2009, Currylow et al. 2013). However, scute loss following dormant-season burns can occur for turtles with shallow hibernacula that expose portions of the carapace (Figure 1.2). Box turtles may surface and briefly emerge during warm periods when soil temperatures approach 8° C and may be susceptible to fire-related morality, but such behavior during the dormant season is uncommon (Dodd 2001, Woodley 2013). Like Roe et al. (2017), we did not document any abnormal behavior because of dormant-season fire.

Box turtles appear more susceptible to mortality from prescribed fire immediately after hibernacula emergence, likely because of low physiological reserves and favorable fire weather. Survival was 0.85 for turtles that experienced an early growing-season burn. Recently emerged box turtles remain lethargic for 1–2 weeks, which increases vulnerability to prescribed fire (Woodley 2013). Emergence typically occurs when fire weather is favorable and relative humidity is low (Knapp et al. 2009, Waldrop and Goodrick 2012). However, turtles do not synchronously emerge. Instead, turtles emerge over a 1–3-month period and we recorded emergence from 22 March until 31 May (Woodley 2013, DeGregorio et al. 2016).

Average maximum iButton temperature during the early growing season was greater for turtles that survived and encountered a fire than turtles that experienced mortality, suggesting mortality may be an effect of increased cumulative temperatures and residence time opposed to maximum temperatures. Residence time has been documented as an important contributor of vegetation mortality, with slow, less-intensive fire behavior resulting in similar mortality as faster-moving hot fires (Waldrop and Goodrick 2012).

Late growing-season fires resulted in 1 mortality despite average burn coverage of 99%. The turtle that experienced mortality was burrowed underneath a fallen tree during the fire. Although the turtle was alive following the fire, the tree continued to burn throughout the night and as the stump and roots caught fire the turtle was killed. The probability of mortality during the late growing season was 10% less likely than during the early growing season. Box turtles were more apt to move in response to fire during the late growing season compared to early growing-season burns. We captured an average of 5.5 turtles ± 2.7 per burn crossing firebreaks to avoid prescribed fire, whereas, 0.18 ± 0.60 turtles per burn were captured crossing a firebreak during early growing-season burns.

Survivorship varied between individuals, and we did not detect any predictors of survival across all treatments other than prescribed fire. However, fire regimes (seasonality, frequency, intensity, and/or ignition pattern) can be altered to improve box survival. For example, frequent burning in forests and woodlands may lessen mortality concern as frequent burning can lessen fuel loads and result in less-intense fires. Fire intensity was a predictor of survival only during early growing-season fires. However, resource managers in our study primarily used low-intensity fire during late growing-season burns, and we suspect fire intensity has an effect on box turtle survival regardless of season. Low-intensity fires increase opportunities for box turtles to retreat to refuge, and is less likely to consume coarse woody debris that is important refuge during prescribed fires. Burn unit size was not a predictor of survival likely because unburned areas of refuge were common within the prescribed fire units. Survival was greater during late growing-season fires than in early growing-season fires despite 41% greater burn coverages during the late growing season. This suggest that, even when burn coverages were high, many box turtles were able to move to refuge to survive late growing-season burns. Average burn coverage was 58% for early growing-season burns, but low burn coverage (<25%) of 2 prescribed fires skewed the average burn coverage estimate for early growing-season fires.

The population-level impacts of prescribed burning on box turtles remain unclear. Whether increased mortality rates result in population declines will depend on recruitment levels. Dodd et al. (2016) reported greater population-level impacts when mortalities occurred prior to egg deposition. Burning during the early growing season raises concerns for long-term population viability if areas are frequently burned and mortalities include gravid females (Dodd et al. 2016). We contend land managers can meet vegetation-management goals and reduce box turtle mortality by burning prior to or following box turtle emergence.

It should be noted that prescribed fire was not novel to any of our 3 study sties, having been routinely implemented for >12 years prior to our study. Our average annual survival estimate, with and without fire treatments, of 0.95 was above or similar to previously documented stable populations (Dodd 2006, Roe et al. 2019). Roe (2019) reported box turtle populations can be resilient to high-mortality disturbance if the population growth rate is increasing or stable, the population is initially relatively large, and if habitat quality is high. However, intensively managed sites that rely on early growing-season burns may function as reproductive sinks if mortality routinely includes gravid females (Congdon et al. 1993, Heppell

1998, Dodd 2016). Although adult survival is crucial for box turtles, reproductive output and juvenile survival is critical for population persistence. Mortality from prescribed fires may be compensatory if recruitment increases from improved habitat quality and nest site availability (Laarman et al. 2018). Although we noted evidence of recruitment in burned areas, our study lacks information on reproductive output and juvenile survival. Future research that includes recruitment following prescribed fires is needed to offer a more comprehensive view of population-level effects.

MANAGEMENT IMPLICATIONS

Box turtles are susceptible to prescribed fire, and fires occurring during the early portion (Mar–May) of the active season increase mortality potential. We suggest prescribed fire practitioners avoid using early growing-season prescribed fire if box turtles are a concern or management objective. Dendrochronological evidence suggests growing-season fire was historically less common than dormant-season fire in our region, and early growing-season burns elicit vegetation effects similar to dormant-season burns (Flatley et al. 2013, McCord et al. 2014, Glitzenstein et al. 2015, Harper et al. 2016). Therefore, other than increased burn opportunities, there is little biological or historical justification to burn during the early portion of the growing season in our region. Dormant-season burning can promote vegetation structure, cover, and composition similar to early growing-season fire. However, land managers rely on growing-season burns to control woody encroachment and increase vegetation heterogeneity (Lewis et al. 1964, Gruchy et al. 2009, Knapp et al. 2009, Harper et al. 2016). Burning during the latter portion of the growing season may be used to elicit differential vegetation effects and lessen negative effects on box turtles. Burning when fuel moisture is relatively high (but still allows burning) and using less-intense firing patterns can create areas of reduced fuel or unburned microsites that are important refuge for box turtles (Cole et al. 1997). Slow-moving fires with relatively low flame lengths increase the probability that box turtles can move to an area of refuge. Small-scale fires or fires that result in a mosaic of burned patches can increase opportunities for turtles to escape to unburned refuge.

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APPENDIX 1: TABLES AND FIGURES

Table 1.1. Average weather statistics occurring between 1130–1500 hours during fire events experienced by eastern box turtles, Tennessee, USA, 2016–18.

Date	Site	Season of burn	Temperature (°C)	Dew point (°C)	Relative humidity (%)	Wind speed (kph)
9/8/2016	Kyker	late growing season	33	16	35	13
10/5/2016	Catoosa	late growing season	26	12	42	8
10/5/2016	Catoosa	late growing season	26	12	42	8
10/15/2016	Catoosa	wildfire	23	13	52	16
4/26/2017	Tanasi	early growing season	24	13	42	6
5/17/2017	Kyker	early growing season	31	12	31	21
5/17/2017	Kyker	early growing season	31	12	31	21
10/4/2017	Kyker	late growing season	27	12	40	7
3/4/2018	Catoosa	dormant	14	−9	20	5
4/11/2018	Tanasi	early growing season	26	10	36	10
4/20/2018	Kyker	early growing season	16	0	36	19
4/20/2018	Kyker	early growing season	16	0	36	19
4/30/2018	Catoosa	early growing season	21	−1	24	10

Table 1.1. Continued

Date	Site	Season of burn	Temperature (°C)	Dew point (°C)	Relative humidity (%)	Wind speed (kph)
4/30/2018	Catoosa	early growing season	21	−1	24	10
5/1/2018	Tanasi	early growing season	25	8	34	5
5/1/2018	Tanasi	early growing season	25	8	34	5
5/1/2018	Tanasi	early growing season	25	8	34	5
6/20/2018	Kyker	summer	31	19	54	14

Table 1.2. Model comparisons of survival rates of eastern box turtles, depending on prescribed treatment, prescribed fire seasonality[a], and prescribed fire variables[b], Tennessee, USA, 2016–18.

Model	AIC_c	ΔAIC_c	AIC_c weights	Model likelihood	Deviance
treatment + EGS + EGS_iButton	134.05	0.00	0.46	1	126.04
treatment + EGS + EGS_pyrometertile	135.32	1.27	0.24	0.52	127.31
treatment + EGS + EGS_firebreak	137.62	3.57	0.08	0.16	129.61
treatment + EGS + EGS_litter	138.16	4.10	0.06	0.12	130.15
treatment + EGS	138.84	4.79	0.04	0.09	132.84
treatment + EGS + EGS_ignition	139.58	5.53	0.03	0.06	131.57
treatment + EGS + EGS_size	139.91	5.86	0.02	0.05	131.90
treatment + EGS + EGS_coverage	140.85	6.79	0.02	0.03	132.84
treatment	142.32	8.27	0.01	0.01	138.31
treatment + LGS + LGS_size	142.97	8.92	0.01	0.01	134.97
treatment + dorm	143.43	9.37	0.00	0.00	137.42
treatment + number of fires	143.62	9.57	0.00	0.00	137.62
treatment + LGS	143.64	9.59	0.00	0.00	137.64
treatment + wild	144.01	9.96	0.00	0.00	138.01

Table 1.2. Continued

Model	AIC_c	ΔAIC_c	AIC_c weights	Model likelihood	Deviance
treatment + site	144.20	10.15	0.00	0.00	136.19
treatment + LGS + LGS_firebreak	144.54	10.49	0.00	0.00	136.53
no treatment	144.86	10.81	0.00	0.00	142.85
treatment + LGS + LGS_pyrometertile	145.08	11.02	0.00	0.00	137.07
treatment + LGS + LGS_ignition	145.25	11.20	0.00	0.00	137.24
treatment + LGS + LGS_coverage	145.37	11.32	0.00	0.00	137.36
treatment + dorm + dorm_size	145.43	11.37	0.00	0.00	137.42
treatment + dorm + dorm_coverage	145.43	11.37	0.00	0.00	137.42
treatment + dorm + dorm_firebreak	145.43	11.37	0.00	0.00	137.42
treatment + dorm + dorm_ignition	145.43	11.37	0.00	0.00	137.42
no treatment + site	145.58	11.53	0.00	0.00	139.58
treatment + LGS + LGS_litter	145.65	11.59	0.00	0.00	137.64
treatment + LGS + LGS_iButton	352.70	218.65	0.00	0.00	344.69

[a] Seasonality: LGS = late growing season, EGS = early growing season, dorm = dormant, wild = wildfire.

[b] iButton = external carapace temperature, coverage = percent of management area burned, litter = average litter depth, pyrometertile = fire intensity, size = burn area size, ignition = ignition pattern used, firebreak = distance of box turtle to a firebreak before ignition.

Table 1.3. Synopsis of early growing-season prescribed fires experienced by eastern box turtles, Tennessee, USA, 2017–18.

Date	Site	Unit size (ha)	Ignition pattern	Number of marked box turtles in burn unit	Number of marked box turtle mortalities	Burn coverage (%)	Surviving strategy
4/11/17	Tanasi	2.3	backing, flanking	3	1	30	1 overwintering 1 moved to coarse woody debris
4/26/17	Tanasi	5.8	heading	4	0	50	3 in unburned vegetation 1 moved to unburned vegetation
5/17/17	Kyker	0.5	strip-heading	2	0	10	2 in unburned vegetation
5/17/17	Kyker	1.0	strip-heading	2	0	6	2 in unburned vegetation
4/20/18	Kyker	1.0	backing, flanking	3	1	100	1 overwintering 1 moved to unburned vegetation
4/20/18	Kyker	0.7	heading	1	0	100	moved to coarse woody debris
4/30/18	Catoosa	38.3	ring	2	1	100	unknown
4/30/18	Catoosa	6.3	flanking	4	1	100	1 overwintering 1 burrowed 1 left burn unit
5/1/18	Tanasi	35.0	heading	2	0	26	2 overwintering

Table 1.3. Continued

Date	Site	Unit size (ha)	Ignition pattern	Number of marked box turtles in burn unit	Number of marked box turtle mortalities	Burn coverage (%)	Surviving strategy
5/1/18	Tanasi	0.6	heading	1	0	85	moved to unburned vegetation
5/1/18	Tanasi	2.4	heading	1	1	25	n/a

Table 1.4. Emergence dates of eastern box turtles, Tennessee, USA, 2018.

Date	Number of emerging turtles during week	Percentage of emerging turtles during week	Total percentage of emerged turtles
3/11/2018–3/17/2018	0	0%	0%
3/18/2018–3/24/2018	3	3%	3%
3/25/2018–3/31/2018	3	3%	6%
4/1/2018–4/7/2018	4	4%	10%
4/8/2018–4/14/2018	21	21%	31%
4/15/2018–4/21/2018	7	7%	38%
4/22/2018–4/28/2018	23	23%	61%
4/29/2018–5/5/2018	30	30%	91%
5/6/2018–5/12/2018	6	6%	97%
5/13/2018–5/19/2018	1	1%	98%
5/20/2018–5/26/2018	1	1%	99%
5/27/2018–6/2/2018	1	1%	100%
6/3/2018–6/9/2018	0	0%	100%

Table 1.5. Synopsis of dormant-season prescribed fire, summer prescribed fire, and a wildfire event experienced by eastern box turtles, Tennessee, USA, 2016–18.

Date	Site	Season	Unit size (ha)	Ignition pattern	Number of marked box turtles in burn unit	Number of marked box turtle mortalities	Burn coverage (%)	Surviving strategy
3/4/18	Catoosa	dormant	97.7	ring	3	0	88	2 overwintering 1 in unburned vegetation
6/20/18	Kyker	summer	1.8	flanking	1	0	32	moved to unburned vegetation
10/15/16	Catoosa	wild	≈ 600	n/a	13	3[a]	100	unknown

[a] Two transmitter failures occurred in addition to the 3 mortalities of radio-marked turtles.

Table 1.6. Synopsis of late growing-season prescribed fires experienced by eastern box turtles, Tennessee, USA, 2016–18.

Date	Site	Unit size (ha)	Ignition pattern	Number of marked box turtles in burn unit	Number of marked box turtle mortalities	Burn coverage (%)	Surviving strategy
9/8/16	Kyker	6.2	flanking	1	0	94	in unburned vegetation
10/5/16	Catoosa	223	ring	6	0	100	2 moved to unburned vegetation 2 in unburned vegetation 1 burrowed in root ball 1 moved to creek
10/5/16	Catoosa	43.9	flanking	3	0	100	1 moved to unburned unit 1 burrowed under creek bank 1 burrowed in stump hole
10/4/17	Kyker	3.2	flanking	3	1	100	1 unknown 1 moved under tin coverboard

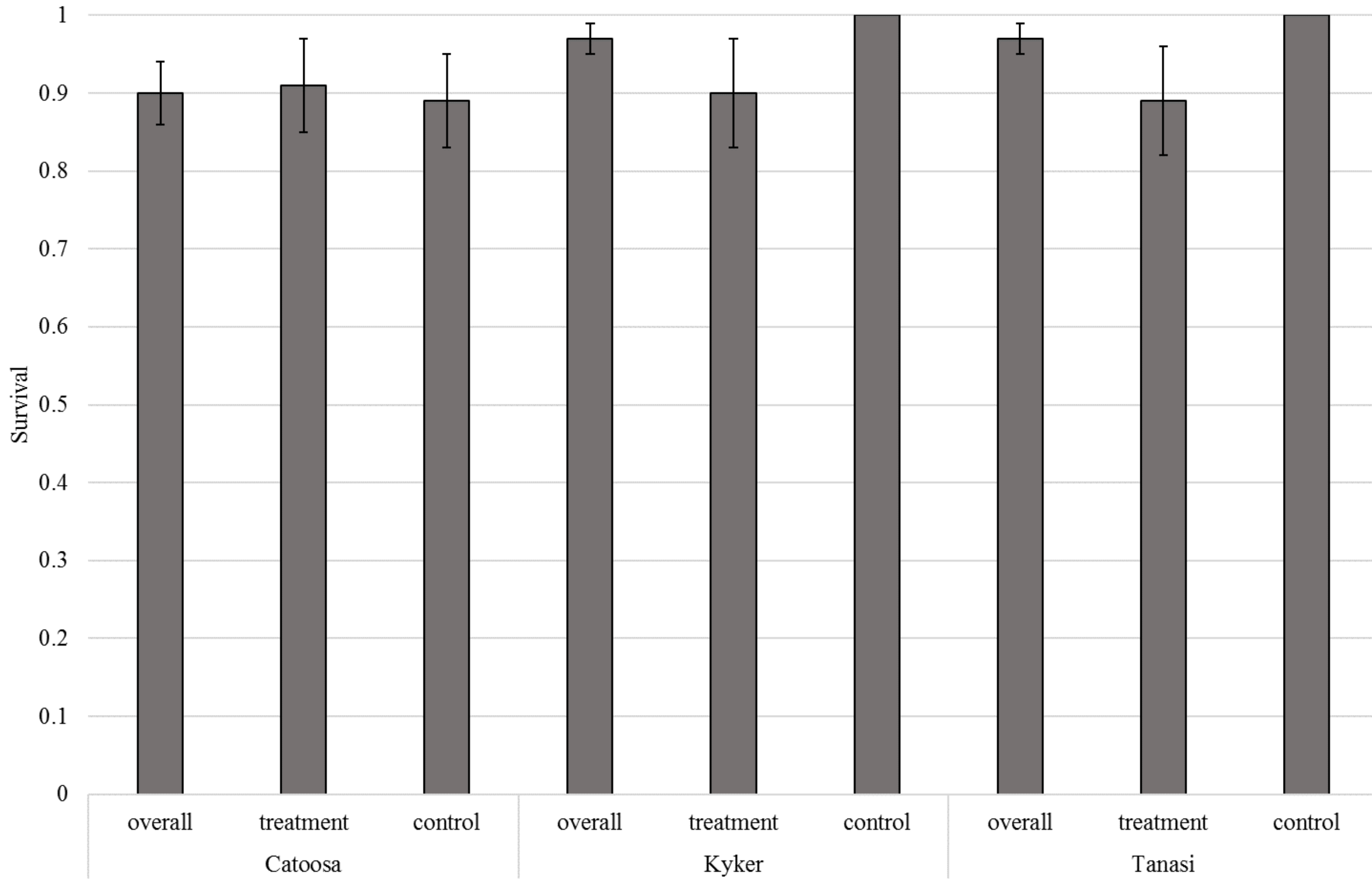

Figure 1.1. Average annual known-fate survival rates for control and treatment eastern box turtles at Catoosa Wildlife Management Area, Kyker Bottoms Wildlife Management Area, and Tanasi Girl Scout Camp, Tennessee, USA, 2016–18.

Figure 1.2. Photographs of eastern box turtles with carapace burn damage, Tennessee, USA, 2016–18. Turtles were alive and continued to live with scute damage.

[a]Turtles with preexisting carapace damage prior to transmitter attachment. Damages were presumed to be a result of fire.

[b]Scute loss following prescribed burns. The red circle highlights scute loss following a dormant-season burn.

CHAPTER II. SPATIAL ECOLOGY AND RESOURCE SELECTION OF EASTERN BOX TURTLES

ABSTRACT Eastern box turtles (*Terrapene carolina carolina*) are widely distributed throughout the eastern United States. Although common throughout much of its distribution, eastern box turtles have experienced precipitous declines in local populations. Understanding habitat use and resource selection is important to the conservation of this species. However, scant habitat use and resource selection data exist. We estimated home range and resource selection for 100 individuals from 2016 to 2018 in the Blue Ridge, Ridge and Valley, and Cumberland Plateau and Mountains physiographic regions in east Tennessee. Home range sizes averaged 9.3 ha ± 3.0 (SE) via minimum convex polygon analysis, 8.25 ha ± 2.88 via 95% kernel density analysis, and 1.50 ha ± 0.56 via 50% kernel density analysis. We created 109 discrete-choice models to investigate eastern box turtle resource selection at 2 spatial scales between May and August 2017–18. We used a step-selection function to define resource use and availability for individuals and over time. We identified vegetation type, measured vegetation composition and structure, and recorded time since fire and coarse woody debris abundance at 1,225 used telemetry locations and 1,225 associated available points. Box turtles selected areas with increased litter depths, increased visual obstruction at the 0–0.25-m level, and increased 10-hr and 100-hr fuel compared with available locations. Box turtles were more likely to select areas with increased cover of brambles and coarse woody debris and less likely to select areas with reduced vegetation cover. Our data indicate land managers can promote understory vegetation cover, increase visual obstruction at the 0–0.25-m level, and increase bramble cover to enhance habitat quality for eastern box turtles.

KEY WORDS discrete choice**,** eastern box turtle, habitat use, resource selection, step-selection function, *Terrapene carolina*.

Eastern box turtles (*Terrapene carolina carolina;* hereafter box turtle) are widely distributed from southern Maine to Georgia and west to the Mississippi River (Dodd 2001, Van Dijk 2011). Although once common, this species has experienced declines in recent decades (Williams and Parker 1987, Hall et al. 1999). Long-term monitoring has revealed >50% reductions of box turtle populations in some areas over the past 50 years (Williams and Parker 1987, Hall et al. 1999). Population declines have resulted in revision of the box turtle's classification status as a vulnerable species by the International Union for Conservation of Nature, which denotes species of high risk of future extinction (Van Dijk 2011). This downward population trend is attributed to pet collection, habitat fragmentation, road mortality, and disease (Gibbons et al. 2000, Brown and Sleeman 2002, Nazdrowicz et al. 2008).

Despite population declines, scant data exist on habitat use and resource selection. Box turtles generally are associated with mature mesic hardwoods and floodplains (Williams and Parker 1987, Conant and Collins 1991, Sutton and Sutton 1985). However, habitat requirements of the species are not well defined. Moreover, microhabitat needs are even less understood. Microhabitat characteristics are arguably more influential drivers of resource selection as a result of the thermal needs, hydric requirements, and site fidelity of box turtles (Dodd 2001, Rossell et al. 2006). As an ectotherm, a box turtle's body temperature depends on external sources and box turtles can reduce overall metabolic costs by selecting appropriate microclimates. Body temperatures of 24–32 °C allow for maximum activity (Adams et al. 1989). Box turtles behaviorally thermoregulate by selecting specific microclimates, limiting physical activity, basking, and by seeking aquatic resources (Adams et al. 1989, Huey 1991, Donaldson and Echternacht 2005). Additionally, box turtles create shallow depressions in a variety of substrates during unfavorable climatic conditions (Stickel 1950, Dodd 2001). These depressions, known as forms, can be constructed in leaf litter, herbaceous vegetation, or soil where the plastron can come in contact with relatively cool soil (Dodd 2001). Box turtles may use aquatic resources during hot, dry periods and often make abrupt linear movements towards ephemeral ponds to soak or bury in the mud (Donaldson and Echternacht 2005). Aggregations of more than 30 box turtles have been recorded using ephemeral ponds for more than 20 consecutive days (Donaldson and Echternacht 2005).

The importance of understanding underlying resource selection relationships is urgent as box turtles exhibit site fidelity and generally have home ranges <10 ha (Stickel 1989, Donaldson and Echternacht 2005, Refsnider et al. 2012, Howey and Roosenburg 2013). Relatively small home ranges and site fidelity can increase effects of local disturbance or habitat management (Currylow et al. 2012, Currylow et al. 2013). Understanding box turtle resource selection allows land managers to knowledgably manipulate vegetation communities either to meet habitat requirements or improve existing habitat quality (Dickson 2001, Morrison et al. 2006). Presumably, species should experience greater fitness in areas that contain selected variables (Boyce et al. 1999, McLoughlin et al. 2010). Positive habitat management results cannot be achieved if the response to management practices, or lack thereof, is unknown. High-quality box turtle habitat and appropriate microclimates reduce overall metabolic costs and impact individual survival, recruitment, and dispersal (Huey and Slatkin 1976, Huey 1991).

Step-selection functions are a powerful modelling approach that allow researchers to evaluate resource selection. Step-selection functions incorporate resource availability differences over time and between individuals that allows researchers to detect fine-scale variation in resource use that may not be apparent in resource-selection functions (Avgar et al. 2016, Thurfjell et al. 2014). Step-selection functions compare used locations and locations that were available, but not chosen, along observed movement paths that animals were likely to travel (Fortin et al. 2005, Thurfjell et al. 2014).

We used a step-selection function in a 2-year radio-telemetry study to determine movement patterns and resource selection of adult box turtles from May to August of 2017 and 2018. Specifically, our objectives were to (1) determine movement patterns, including daily movement rates and home range size, (2) determine macrohabitat resource selection, and (3) determine the influence of vegetation composition and structure on resource selection of box turtles at the microhabitat scale.

STUDY AREA

We conducted our research on 3 study sites in east Tennessee, USA. Each location varied in predominant vegetation types, topography, and management.

Catoosa Wildlife Management Area (WMA; 36.063° N, 84.882° W) encompassed 32,374 ha in the Cumberland Plateau and Mountains physiographic region and was managed by the Tennessee Wildlife Resources Agency. Catoosa WMA spanned portions of Cumberland, Morgan, and Fentress counties. Routine prescribed burning began in 2002 with the initiation of an oak-savanna restoration project. Primary vegetation types across the study area were shortleaf pine-oak woodlands (61%) and shortleaf pine-oak savannas (25%). Closed-canopy deciduous forest (9%), closed-canopy mixed forest (3%), and wildlife openings (2%) also were present. Managers aimed for a fire-return interval of 2–3-years to maintain woodlands and savannas.

Kyker Bottoms Waterfowl Refuge and WMA (35.605° N, 84.115° W) encompassed 230 ha in the Blue Ridge physiographic region of southern Blount County and was owned and managed by the Tennessee Wildlife Resource Agency. Kyker Bottoms was dominated by early successional plant communities (61%) and closed-canopy deciduous forest (32%). Hardwood woodlands (4%) and closed-canopy eastern redcedar (*Juniperus virginiana*) stands (3%) also were present. Lowland areas were flooded for waterfowl, whereas uplands were managed primarily for northern bobwhite (*Colinus virginianus*). Prescribed fire has been implemented since 1997.

Tanasi Girl Scout Camp (36.246° N, 83.966° W) encompassed 237 ha in the Ridge and Valley physiographic region of Tennessee and was privately owned and managed. Tanasi bordered Norris Lake and was dominated by closed-canopy deciduous forest (43%) and closed-canopy eastern redcedar stands (29%). Closed-canopy mixed forests (21%), oak woodlands (3%), wildlife food plots (3%), and old-fields (1%) also were present. All vegetation types at Tanasi were burned periodically since 2004 to enhance habitat for eastern wild turkey (*Meleagris gallopavo*) and white-tailed deer (*Odocoileus virginianus*).

METHODS

Turtle Capture

We captured adult box turtles using opportunistic finds, active searches, and wildlife detector dogs (Refsnider et al. 2011, Kapfer et al. 2012). Box turtles were considered adults if carapace length was >95 mm and mass was >170 g (Dolbeer 1969, Donaldson and Echternacht 2005). Opportunistic finds were incidental captures while researchers were not actively searching for box turtles (e.g., turtles found crossing roads). Active searches were visual searches along meandering transects in predefined search areas (Currylow et al. 2012). Lastly, 5 wildlife detector dogs (*Canis lupus familiaris*, boykin spaniel) were used to find turtles through olfaction (Kapfer et al. 2012). Wildlife detector dogs were not leashed but responded to auditory commands. We walked directional paths with the wildlife detector dogs across predetermined study areas. All procedures were approved by the University of Tennessee Institutional Animal Care and Use Committee (UT-IACUC #2473-0616).

We recorded the initial capture location of each box turtle using a handheld global positioning system (GPS; Garmin GPSMAP 64st, Garmin International, Olathe, KS, USA). We measured body mass with a Pesola Medio-Line spring scale to the nearest 10 g. We recorded the gender of each turtle using external physical characteristics including eye color, plastron shape, rear claw length, and cloaca position (Dodd 2001). We measured carapace length with a 20-cm Pittsburgh digital caliper to the nearest millimeter.

Radio Telemetry

We affixed a very high frequency (VHF) radio transmitter (model R2020, Advanced Telemetry Systems, Isanti, MN, USA) to the second pleural scute on the left side of each turtle using 5-minute epoxy. We affixed transmitters to the center of 1 scute to avoid inhibiting scute development. Transmitters weighed 15 g (approximately 4% of average mass of an adult box turtle). We monitored box turtle movement using the homing method and direct observation with a folding 3-element Yagi antenna and an Advanced Telemetry Systems R-1000 telemetry receiver (Communications Specialist Inc., Orange, CA, USA). We recorded box turtle locations 1–3 times per week from April to October in 2016 and 2017 and from April to August in 2018. We recorded intermittent locations throughout the inactive season (Dec–Mar) of 2016 and 2017. GPS locations were recorded at each telemetry location. We removed all transmitters at the end of the study using a jeweler's saw.

Home Range and Movement

We calculated 100% minimum convex polygon home ranges in ArcGIS 10.5 (ESRI, Redlands, CA, USA). We used Geospatial Modelling Environment (GME, Spatial Ecology 2012) and the plugin bandwidth to calculate 95% and 50% kernel density home range estimates (Gitzen et al. 2006, Rittenhouse et al. 2007, Bauder et al. 2015). We used movement data from turtles with >40 locations during the active season (Apr–Nov) to analyze home ranges (Seaman et al. 1999). We estimated daily movement by dividing the total straight-line distance by the number of days between locations. We used the movement.pathmetrics tool in GME to calculate the straight-line distance between successive locations. We excluded inactive months (Dec–Mar) from average daily movement analysis.

Resource Selection

We used discrete-choice models to determine resource selection from May to August of 2017–18. Discrete-choice models calculate the probability an individual will select a resource based on the availability of all other resources through time (Cooper and Millspaugh 1999). Discrete choice assumes an animal's choice is a result of the utility gained from choosing a given resource compared to choosing alternative choice sets (Cooper and Millspaugh 1999, Hoffman et al. 2010). It is assumed an animal will choose resources with maximum utility within a given set of available resources (Cooper and Millspaugh 1999, Hoffman et al. 2010). Resource selection is estimated by comparing characteristics of used telemetry locations to characteristics of the choice set (available locations).

We defined our choice set using movement.ssfsamples in GME. This tool was designed to facilitate step-selection function (SSF) models and generates sampled steps along a movement path (Fortin et al. 2005). The SSF model employed a use versus availability design in which each observed step was compared to a sample of available steps at each point along the path (Beyer 2012). We used observed step lengths (i.e., distances between successive observed locations) and turning angle distributions (i.e., deviations from previous bearings) to generate 1 available point for each telemetry point. Generated step lengths and turn angles were derived from empirical data of turtles with equivalent telemetry intervals. We grouped observed turn angles and step lengths into 18 20-degree bins and 18–26 bins to create equal step-length categories within each telemetry interval, respectively. We conducted resource measurements at 1 associated available point for each telemetry point (Table 2.1). We excluded 18 box turtles that moved to private property or experienced transmitter loss or failure from our step-selection analysis.

Microhabitat Selection

We used a 4-m modified point-intercept transect to measure vegetation cover (Goodall 1952, Bonham 2013). Point-intercept transects were centered at the turtle telemetry location with 1-m oriented in each cardinal direction. We systematically placed a 1.37-m tall, narrow-diameter sampling pin at 20-cm intervals along the transect. We recorded any plant species that touched the pin, along with the substrate (i.e., litter, bare ground, coarse woody debris, rock, other). We used percent cover of brambles, forbs, grasses, shrubs, trees, ferns, and vines as plant composition variables. We calculated percent cover by dividing the number of occurrences by the total number of points (n = 21) along the transects for each turtle telemetry location.

We recorded litter depths and downed woody debris along the same 4-m transect. We recorded litter depths at the turtle location and at 60 cm from the turtle location in each cardinal direction. We recorded any downed woody debris that intersected the transect. Downed woody debris included any dead twig, branch, stem, or trunk on the ground (Brown 1974). We classified downed woody debris as 1-hr, 10-hr, 100-hr, 1,000-hr, and 10,000-hr fuels with the following diameter classes: 1 hr = 0–0.5 cm, 10 hr = 0.5–2.5 cm, 100 hr = 2.5–7.5 cm, 1,000 hr = 7.5–20.0 cm, and 10,000 hr >20.0 cm (Fahnestock 1970). We measured vertical structure using a modified Nudds board divided into 5 strata, with stratum 1 being the uppermost stratum and stratum 5 being the closest to the ground (Nudds 1977). The top 3 strata measured 0.5 m × 0.18 m, whereas the bottom 2 strata measured 0.25 m × 0.18 m. We used 0.25-m dimensions for the bottom 2 strata to discern more appropriate structural differences relevant to box turtle height, opposed to original Nudds stratification. We measured vertical structure using the modified Nudds 5-m east and 5-m west of the turtle location. One researcher kneeled and estimated the percent cover of each stratum, assigning a value of 0 to 5 for each stratum, whereby 0 = no vegetation, 1 = 1–20% obstruction, 2 = 21–40% obstruction, etc. We averaged litter depth, downed woody debris classes, and each Nudds stratum for each telemetry point, giving 1 value for each measurement. Each microhabitat measurement was repeated for 1 paired available point.

Macrohabitat Selection

We used land cover data from the 2011 National Land Cover Database along with aerial imagery from Google Earth (Google, Mountain View, CA, USA) to delineate vegetation types. Vegetation types were ground-truthed and adjusted accordingly. We categorized vegetation types into the following 8 primary categories:

1) deciduous- areas dominated by deciduous forest with at least 80% canopy closure
2) early succession- areas maintained in early successional vegetation (old-fields) by periodic prescribed burning, mowing, or disking
3) evergreen- areas dominated by closed-canopy pines (*Pinus* spp.) or eastern redcedar
4) mowed- areas mowed for aesthetics (i.e. lawns)
5) mixed forest- areas dominated by a mix of closed-canopy deciduous forest and closed-canopy evergreen forest
6) no vegetation- areas absent of vegetation (e.g., bare ground, gravel)
7) food plot- areas planted as a supplementary food source for wildlife

8) woodland- areas with 30–80% canopy closure with an understory dominated by grasses, forbs, and shrubs

We used the extract by points tool in ArcMap to extract the vegetation type associated with each telemetry and available point. Similarly, we extracted the time since fire of each telemetry and available point. We classified telemetry and available points into 3 categories to represent the number of growing seasons elapsed since fire: no fire since study initiation, 1 growing season since fire (1–12 months), and 2 growing seasons since fire (13–24 months).

We measured thermal variation within and between each vegetation type at each site. We recorded thermal variation of surface temperatures within each vegetation type using a handheld infrared thermometer (Omegascope, model OS530 series, Norwalk, CT, USA). We randomly placed 15 transects in each vegetation type at each site. We generated random transect locations using the create random points tool in ArcMap 10.5. We recorded surface temperatures at 1-m increments along a 10-m transect under maximum solar radiation (1100–1400 hours) between 20 July and 14 August in 2018.

We measured daily temperature fluctuations in relation to ambient temperatures between vegetation types by randomly placing 10 thermal stations in each vegetation type at each site. We generated random thermal-station locations using the create random points tool in ArcMap 10.5. Thermal stations were temperature data loggers (iButton model DS1921G-F5, Maxim Integrated, San Jose, CA, USA) attached to a wooden stake via small-diameter string. We attached iButtons to string and to the ground using clear double-sided tape. We programmed each iButton to record temperatures at a 1-hr interval for at least a full 48-hr period. We recorded ambient temperatures from weather stations within 9.5 km of respective study sites.

Statistical Analysis

We performed a 2-way analysis of covariance (ANCOVA) using Program R 3.3.1 (R Core Team 2016) to compare mass between male and female box turtles and between study sites. Carapace length was used as a covariate for mass analyses because carapace length is positively correlated with body mass (Dodd 2001, Howey and Roosenburg, 2013). We checked normality and equality of variances using the Shapiro-Wilk test and the Levene's test respectively. We used the Tukey's honestly significant difference test to compare means at $\alpha = 0.05$ (Welkowitz et al. 2012). We performed a 2-way analysis of variance (ANOVA) to compare 100% minimum convex polygon home range estimates, kernel density estimates, and average daily movement between male and female box turtles and between study sites. We used a log transformation prior to conducting ANOVAs on home range and movement data. We used a 1-way ANOVA and least-squares mean to compare thermal variation within and between vegetation types. We performed Kruskal–Wallis tests and used least-squares mean to compare fuel loads and litter depths between major vegetation types and time since fire classifications.

We used the COXPH and COXME package in Program R 3.3.1 to fit a Cox proportional hazards regression model to perform our discrete-choice analysis (Therneau 2013, Brooke et al. 2015). We did not detect differences in resource selection of any variable between years or study sites (Table 2.2). Therefore, we pooled data for analyses. We used 1,225 telemetry locations and 1,225 associated available locations from 100 box turtles to develop step-selection models. We performed a correlation analysis and removed 1 variable of any pair of correlated variables (i.e., Pearson's $|r| > 0.75$) based on their biological significance. We removed the following variables as a result of our correlation analysis: visual obstruction at the 0.25–0.50 level, visual obstruction at the 1.0–1.5 level, and leaf litter cover.

We used the purposeful model-building strategy to determine candidate step-selection models (Fortin et al. 2005, Hosmer et al. 2013, Brooke et al. 2015). We first developed a univariate model to analyze each variable independently to determine its influence on resource selection (Brooke et al. 2015). We used variables with a $P < 0.25$ to create a global model (Brooke et al. 2015). We removed non-significant variables ($P > 0.05$) individually from the global model, based on the magnitude of their *P*-value, until our model only contained significant ($P < 0.05$) variables (Brooke et al. 2015). We added variables that were eliminated in the first step, 1 by 1, into the reduced global model to determine any significance change between variables (Brooke et al. 2015). Once we created the best main effect model, we incorporated quadratic and interaction terms (McCracken et al. 1998, Brooke et al. 2015). We fit 109 models, including 27 univariate models without random effects and 9 with random effects, to determine resource selection of box turtles. We fit 18, 9, 9, and 20 models, respectively, to develop the best main effects model, main effect + quadratic terms, main effect + interaction terms, main effect + quadratic terms + interaction terms. We fit 18 additional models with site and turtle identifier as random terms to determine if selection variation among box turtles or study sites was needed to improve the model (Duchesne et al. 2010).

We used Akaike's Information Criterion (AIC) to compare models and considered models with ΔAIC <2 competing models. We used the most parsimonious model when ΔAIC <2 (Burnham and Anderson 2002). We used the most-supported model to predict the odds of selection given the significant variables. We created selection ratios through slope estimate (βi) exponentiations and only considered variables with confidence limits not overlapping zero as significant influences of resource selection (McDonald et al. 2006). We used a variable adequacy analysis to estimate the importance of variables within the top model (Harrell 2001, Brooke et al. 2015).

RESULTS

We captured and radiomarked 118 adult box turtles from July 2016 to July 2018, including 61 males and 57 females. We collected ≥40 locations for 100 box turtles [x = 68 ± 2.4 (SE)] from which we calculated home range and analyzed movements. Box turtle mass did not differ between sites ($P = 0.134$), but did differ by sex ($P < 0.001$). The average mass of male turtles was 389 g ± 8.1, whereas the average mass of females was 417 g ± 8.6.

Movement rates and home ranges did not differ between male and female box turtles (Table 2.3). Kernel density estimates and average daily movement differed by site (Table 2.4). The average minimum convex polygon home range was 9.3 ha ± 3.00. The average 95% and 50% kernel density estimate were 8.25 ha ± 2.88 and 1.50 ha ± 0.56, respectively (Table 2.4). Average movement sinuosity was 0.061 ± 0.008. The average daily movement rate during the active season was 11 m per day ± 0.21. We documented 22 turtles changing hibernacula locations at least once during inactive periods.

Resource Selection

Our top model contained 7 variables and 1 quadratic term: average litter depth, visual obstruction at the 0–0.25-m level, number of 10-hr and 100-hr fuels, bramble cover, coarse woody debris cover, no vegetation cover, and a quadratic no vegetation term (Table 2.5). Box turtles selected areas with increased cover of brambles, increased coarse woody debris, increased litter depth, increased visual obstruction at the 0–0.25-m level, and increased 10-hr and 100-hr fuel abundance compared with available points and were less likely to select areas with reduced vegetation cover (Table 2.6).

Selection ratios indicated the odds of a turtle selecting a location increased 43.8% with every 1-cm increase in litter depth. Probability of selection for increased litter depths was 100% when litter depths were ≥4 cm. Odds of selection increased 4.4% and 12.9% with the addition of every 10-hr and 100-hr fuel per 2-m transect, respectively. Probability of selection was 100% when the average number of 10-hr and 100-hr fuels were ≥13 and ≥ 8 per 2-m transect, respectively. Odds of selection increased 0.8% with every 1% increase in visual obstruction at the 0–0.25-m level. Probability of selection was 100% once visual obstruction at the 0–0.25-m level was ≥31%. Odds of selection decreased 3.9% with every 1% increase in cover of no vegetation. The model was improved with the addition of a quadratic percent cover of no vegetation term (ΔAIC = 8.27). We calculated a selection ratio of 1.00 for the no vegetation quadratic term, indicating odds of selection for percent cover of no vegetation stabilized at 73%. The odds of a box turtle selecting a location increased 1.4% with every 1% increase in bramble cover, whereas, selection increased 2.3% with every 10% increase in cover of coarse woody debris. Probability of selection was 100% once bramble cover and coarse woody debris cover was ≥22% and ≥18%, respectively. Litter depths and fuel loads differed between time since fire classification and major vegetation type (Table 2.7, 2.8). Box turtles did not exhibit selection or avoidance for any major vegetation type ($P = 0.248$) or any elapsed time-since-fire classification ($P = 0.391$).

Mowed areas experienced the greatest temperatures under the same ambient conditions than all other vegetation types at Catoosa WMA and Tanasi (Figure 2.1, Figure 2.2). Mowed areas were not available at Kyker Bottoms WMA. Mixed forest, deciduous forest, and evergreen forests experienced lower temperatures than woodlands and early succession under the same ambient conditions at each study site (Figure 2.1, Figure 2.2, Figure 2.3). Mowed areas experienced the greatest surface temperatures during peak solar radiation at Tanasi and Catoosa WMA, whereas woodlands experienced the greatest average surface temperatures during peak solar radiation at Kyker Bottoms WMA (1100–1400 hours, Figure 2.4). Mowed areas at Catoosa WMA experienced the greatest variability in surface temperatures during peak solar radiation than all other available vegetation types. Woodlands experienced the greatest surface temperature variability at Tanasi and Kyker Bottoms WMA during peak solar radiation. Deciduous forests experienced the lowest temperatures with the least variable surface temperatures at all sites during peak solar radiation.

DISCUSSION

We aimed to identify movement rates and variables important to eastern box turtle resource selection. Our results suggest box turtle home ranges vary considerably, and microhabitat characteristics are more influential in resource selection than variables at the macrohabitat scale, with vegetation cover, litter depth, bramble cover, coarse woody debris, and vegetation structure driving resource selection.

Our reported average MCP home range (9.3 ha) was 4.5 times larger than the 1.9 ha reported by Donaldson and Echternacht (2005) based on 13 turtles in east Tennessee. Our MCP home range estimates were more similar to average home range estimates (10.3 ha) of box turtles in fire-maintained longleaf pine (*Pinus palustris*) stands in Georgia (Greenspan et al. 2015). We documented a long-distance movement of 1 adult male, which inflated average home range estimate by 2.74 ha. The male turtle made a linear movement of 3.46 km from its core home range. The actual distance would have been longer because the transmitter was removed while the turtle was continuing to move away from the core home range. Long-range movements of up to 1.9 km have been documented previously (Greenspan et al. 2015). To our knowledge, this is the longest reported linear movement of a tracked eastern box turtle that was not translocated.

We recorded 6 females making abrupt, linear excursions to nest. It is not known why box turtles travel long distances to nest, though it may be that females return to their own natal region or that nesting sites are uncommon (Dodd 2001, Kipp 2003). Nesting locations were commonly associated with management activities, especially soil disturbance. Of the 6 recorded nesting females, 2 excavated nests along disked firebreaks, whereas others excavated nests in a disked field, a recently burned pine stand, a recently thinned hardwood stand, and along a roadside. Similarly, we documented annual movements up to 1.26 km from core home ranges for an additional 12 females. The purpose of these movements is unknown, but likely represented nesting activity that we were unable to observe because box turtles can deposit eggs and cover nests in <2 hrs (Congello 1978). These long-distance movements occurred annually for each of the 12 females and followed the same travel path during successive years. Exploratory excursions, feeding forays, and trips to overwintering or nesting sites of 900 m from the core home range have been previously reported (Stickel 1950, Dodd 2001, Greenspan et al. 2015). Our average daily movement of 11 m per day was lower than previously documented reports of 26–40 m per day (Strang 1983, Donaldson and Echternacht 2005, Iglay et al. 2007). However, Strang (1983) and Donaldson and Echternacht (2005) used thread trailers that provide more fine-scale movement data than VHF telemetry data.

Turtles did not exhibit selection or avoidance for major vegetation types, despite differences in temperature between vegetation types, with deciduous forests being 2.5° C cooler than ambient temperatures under maximum solar radiation, and 11.1° C and 5.9° C cooler than mowed areas and early succession during the same ambient conditions, respectively. Early succession at Kyker Bottoms WMA experienced temperatures similar to ambient conditions under maximum solar radiation, whereas temperatures in early succession at Catoosa WMA and Tanasi Girl Scout Camp were warmer than ambient temperatures under maximum solar radiation. Temperatures in early succession at Kyker Bottoms WMA were similar to ambient conditions as a result of increased vegetation coverage and vertical structure compared to other sites. Woodlands experienced consistently warmer surface temperatures under maximum solar radiation than deciduous forests at each site. Woodlands at Catoosa WMA experienced temperatures cooler than ambient temperatures under maximum solar radiation because of increased canopy cover and a well-developed herbaceous layer. However, despite cooler temperatures during summer months, turtles did not exhibit selection towards cooler vegetation types. Furthermore, variation in surface temperatures in early succession was 4 times greater than that in deciduous forests under maximum solar radiation. Temperatures in woodlands were consistently more variable than temperatures in evergreen forests. The lack of selection coupled with temperature differences between vegetation types suggests thermal regimes of vegetation types are not driving selection in our region. It is more likely that microhabitat temperature regimes control selection. Microsite thermal characteristics may be more influential in resource selection than broad-scale temperature variation between vegetation types, as box turtles reduce overall metabolic costs by selecting appropriate microclimates within vegetation types (Stickel 1950, Dodd 2001, Donaldson and Echternacht 2005, Rossell et al. 2006).

Microsite temperature variation is largely determined by vegetation composition and structure. Variable adequacy analysis suggests percent cover of no vegetation was the most important predictor of selection, followed by bramble cover and visual obstruction at the 0–0.25-m level, respectively. Vegetation growth habits (e.g. bramble, forb, grass, shrub, tree, vine) were not important variables of resource selection, except for brambles. Bramble cover was the second most influential variable of resource selection. Blackberry (*Rubus* spp.) and wineberry (*Rubus phoenicolasius*) were the most common bramble species among study areas. The increase in selection for bramble cover may be a result of increased food availability. Turtles were commonly observed eating *Rubus* spp. fruits at each site.

Box turtles selected greater leaf litter depths than would be expected at random. Concealment in leaf litter lessens the risk of evaporative water loss and can aid in maintaining a thermal optimum (Stickel 1950, Dodd 2001). Box turtles are physiologically incapable of sustaining high body temperature and prefer body temperatures of 24–32° C (Adams et al. 1989). Coarse woody debris also was used for concealment and thermoregulation in areas with reduced vegetation cover. Box turtles were commonly documented burrowed alongside coarse woody debris when ambient temperatures exceeded 27° C.

Dodd (2001) reported greater box turtle densities in areas with increased plant diversity, considerable structural diversity, and multiple vegetation types occurring in proximity. We did not document selection for areas with greater species richness or greater structural diversity above the 0.5-m level.

Although litter depth and 10-hr and 100-hr fuel loads were predictors of selection and differed between vegetation types and time since fire, we did not document selection for or against major vegetation types or time since fire classifications. Lack of selection for major vegetation types and time since fire is like a result of site fidelity. Box turtles typically do not abandon home ranges despite disturbance (Stickel 1950, Dodd 2001). It should be realized that though litter depth and fuel loading were important indicators of resource selection, total vegetation cover, bramble cover, and visual obstruction were more important predictors of resource selection. Increased litter depths and fuel abundance were less important if vegetation cover was ≥35% and visual obstruction at the 0–0.25-m level was ≥31%. Increased litter depths and fuel abundance became important if vegetation cover was limited.

MANAGEMENT IMPLICATIONS

Our results suggest managers can positively influence box turtle habitat by manipulating vegetation structure and composition. Managers wishing to enhance box turtle habitat quality should concentrate on increasing total vegetation cover, with emphasis on vegetation cover at the 0–0.25-m level. Timber harvests, forest thinning, prescribed fire, and herbicide application can be used to improve understory vegetation cover, increase visual obstruction at the 0–0.25-m level, and increase bramble cover. Vegetation cover and structure can be increased through canopy removal to allow at least 20% full sunlight to reach the forest floor (Royo et al. 2010, McCord et al. 2014). Prescribed fire can be used to maintain increased understory vegetation cover and bramble cover (Iglay et al. 2014, McCord et al. 2014, Vander Yatch et al. 2017), but early growing-season burns (Apr–May) should be limited because they can decrease turtle survival rates (Chapter 1). Bramble cover can be increased by implementing dormant-season prescribed fire on a 3–5-year return interval in conjunction with canopy removal (Waldrop and Goodrick 2012, Nanney et al. 2018). Low-intensity prescribed fire during the dormant season or late growing season following overstory thinning should be used increase vegetation cover while also retaining coarse woody debris and alleviating box turtle mortality concern. Managers should consider allowing litter and coarse woody debris to accumulate if management areas are dominated by closed-canopy forest. Burning in closed-canopy forest with low-intensity fire consumes leaf litter and elicits little change in groundcover (Greenberg and Waldrop 2008, Shaw et al. 2010, McCord et al. 2014), which led to reduced selection in our study.

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APPENDIX 2: TABLES AND FIGURES

Table 2.1. Variables used to assess resource selection for eastern box turtles during the active season, Tennessee, USA, 2016–18.

Variable	Description	Units
avg_depth	average litter depth	cm
N1–N5	visual obstruction estimate, (1 for each stratum)	0–5
avgfuel_1	average count of 1-hr fuels	count/2-m transect
avgfuel_10	average count of 10-hr fuels	count/2-m transect
avgfuel_100	average count of 100-hr fuels	count/2-m transect
avgfuel_1k	average count of 1,000-hr fuels	count/2-m transect
avgfuel_10k	average count of 10,000-hr fuels	count/2-m transect
species_rich	species richness	count/2-m transect
bram	absolute cover of brambles	%
fern	absolute cover of ferns	%
grass	absolute cover of grass	%
forb	absolute cover of forbs	%
shrub	absolute cover of shrubs	%
tree	absolute cover of trees	%
vine	absolute cover of vines	%
nosp	absolute cover of no vegetation	%
litter	absolute cover of litter	%
bg	absolute cover of bare ground	%
rock	absolute cover of rock	%
cwd	absolute cover of coarse woody debris	%

Table 2.1. Continued

Variable	Description	Units
macro	vegetation type[a]	1–8
burn	elapsed time since fire[b]	1–3

[a] 1 = deciduous, 2 = early succession, 3 = evergreen 4 = mowed, 5 = mixed forest, 6 = no vegetation, 7 = food plot, 8 = woodland.

[b] 1 = no fire since study initiation, 2 = 1 growing season since fire (1–12 months), 3 = 2 growing seasons since fire (13–24 months).

Table 2.2. Beta value confidence intervals for variables[a] used to determine resource selection for eastern box turtles at Catoosa Wildlife Management Area, Kyker Bottoms Wildlife Management Area, and Tanasi Girl Scout Camp, Tennessee, USA, 2016–18. Confidence intervals suggest resource selection was similar between years and study areas.

	2017		2018		Catoosa		Kyker		Tanasi	
Variable	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
avg_depth	0.32	0.59	0.15	0.33	0.12	0.58	0.20	0.49	0.16	0.41
N1	0.07	0.27	0.11	0.28	-0.06	0.25	0.03	0.28	0.09	0.33
N3	0.26	0.50	0.20	0.37	0.28	0.68	0.10	0.43	0.29	0.57
N5	0.25	0.50	0.26	0.47	0.02	0.20	0.01	0.12	0.01	0.11
avgfuel_1	0.00	0.05	-0.01	0.02	-0.05	0.41	-0.11	0.26	-0.09	0.24
avgfuel_10	0.03	0.14	0.04	0.12	-0.26	0.61	-0.20	0.52	-0.08	0.41
avgfuel_100	0.09	0.37	0.10	0.36	-0.67	0.47	0.28	2.25	-0.45	0.35
avgfuel_1k	-0.05	0.42	0.10	0.57	0.03	0.14	-0.05	0.05	0.01	0.09
avgfuel_10K	-0.42	0.58	-0.14	0.45	0.00	0.02	0.01	0.03	0.01	0.03
species_rich	0.01	0.08	0.02	0.09	-0.02	0.08	0.00	0.02	-0.02	0.02

Table 2.2. Continued

	2017		2018		Catoosa		Kyker		Tanasi	
Variable	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
bram	1.15	2.60	1.76	3.04	-0.01	0.01	0.00	0.01	0.00	0.01
fern	-1.20	2.10	-0.17	2.09	0.00	0.02	-0.02	0.00	0.00	0.01
grass	-0.21	0.83	-0.24	0.64	-0.01	0.02	-0.01	0.01	0.00	0.02
forb	-0.31	0.83	-0.52	0.48	0.01	0.03	0.00	0.02	0.00	0.02
shrub	0.11	2.51	-0.41	1.18	0.00	0.03	0.00	0.02	0.00	0.01
tree	1.07	2.59	0.50	1.52	-0.03	-0.01	0.00	0.02	0.00	0.02
vine	0.77	2.14	0.31	1.67	0.00	0.03	0.00	0.02	0.00	0.01
nosp	-2.79	-1.48	-2.44	-1.36	-0.03	-0.01	-0.03	-0.01	-0.03	-0.01
rock	-7.55	-1.69	-4.77	-1.22	-0.06	0.01	-0.05	0.01	-0.10	-0.01
cwd	0.58	2.70	0.63	2.40	0.00	0.03	-0.01	0.02	0.01	0.04
macro1	-1.21	0.16	-0.69	0.07	-1.40	0.50	-0.26	1.24	-0.97	0.23
macro2	-0.81	1.48	-1.24	0.26	-0.15	4.04	-2.82	0.32	-1.24	0.94

Table 2.2. Continued

	2017		2018		Catoosa		Kyker		Tanasi	
Variable	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI	Lower 95% CI	Upper 95% CI
macro3	-1.15	0.58	-0.67	0.38	-1.89	0.51	-1.05	1.05	-0.72	0.61
macro4	-0.52	0.94	-0.13	0.82	-0.76	0.95	-0.77	1.35	-0.37	0.86
macro5	-0.21	1.60	-0.02	0.95	-1.21	1.78	-1.52	0.50	-0.40	1.37
macro6	-1.21	1.78	-1.52	0.50	-0.40	1.37	-0.88	1.28	-1.45	0.88
macro7	-0.95	0.75	-1.02	0.80	-0.41	1.61	-0.19	1.54	-1.50	1.29
macro8	-0.20	1.41	-0.01	1.35	-0.92	0.70	-0.51	1.12	-0.05	0.97
burn1	-1.15	1.00	-0.04	1.12	-0.79	0.57	-0.02	1.23	-1.00	1.34
burn2	-0.99	0.99	-0.16	1.55	-0.21	0.71	-0.03	0.80	-0.08	1.07
burn3	-0.88	1.45	-0.17	1.16	-0.35	0.79	-0.15	0.99	-0.47	1.00

[a] avg_depth = average litter depth, N1 = visual obstruction at the 1.5–2.0-m level, N3 = visual obstruction at the 0.5–1.0-m level, N5 = visual obstruction at the 0–0.25-m level, avgfuel_1 = count of 1-hr fuels, avgfuel_10 = count of 10-hr fuels, avgfuel_100 = count of 100-hr fuels, avgfuel_1K = count of 1,000-hr, avgfuel_10K = count of 10,000-hr fuels, species_rich = species richness, bram = percent cover of brambles, fern = percent cover of ferns, grass = percent cover of grass, forb = percent cover of forbs, shrub = percent

cover of shrubs, tree = percent cover of trees, vine = percent cover of vines, nosp = percent cover of no vegetation, rock = percent cover of rock, cwd = percent cover of coarse woody debris, macro1 = deciduous , macro2 = early succession, macro3 = evergreen, macro4 = mowed, macro5 = mixed forest, macro6 = no vegetation, macro7 = food plot, macro8 = woodland, burn1 = no fire since study initiation, burn2 = 1 growing season since fire (1–12 months), burn3 = 2 growing seasons since fire (13–24 months).

Table 2.3. Male and female eastern box turtle average daily movement and home range estimate comparisons during the active season, Tennessee, USA, 2016–18. Values with the same letters are not different.

		P-Value	F-Value	Tukey letter	Minimum	Average ± SE	Maximum
average daily movement[a]	male	0.294	1.113	A	4.8	11 ± 0.6	22.6
	female			A	4.6	11 ± 0.6	25.8
minimum convex polygon[b]	male	0.629	0.236	A	0.4	11.6 ± 5.6	282.2
	female			A	0.5	6.8 ± 1.6	67.7
50% kernel density[b]	male	0.769	0.087	A	0.1	7.6 ± 1.1	54.1
	female			A	0.1	1.4 ± 0.2	9.3
95% kernel density[b]	male	0.519	0.473	A	0.6	38.7 ± 6.6	270.8
	female			A	0.7	10.5 ± 1.7	69.2

[a] Unit = m per day.

[b] Unit = hectare.

Table 2.4. Eastern box turtle average daily movement and home range estimate comparisons between study areas during the active season, Tennessee, USA, 2016–18. Values with the same letters are not different.

		P-Value	F-Value	Tukey letter	Minimum	Average ± SE	Maximum
average daily movement[a]	Catoosa WMA			A	5.2	13 ± 1.0	25.8
	Kyker Bottoms	0.001	7.16	B	4.9	9 ± 0.6	20.5
	Tanasi			AB	4.6	10 ± 0.6	19.8
				Overall:	4.6	11 ± 1.5	25.6
minimum convex polygon[b]	Catoosa WMA			A	0.6	19.8 ± 9.1	282.2
	Kyker Bottoms	0.869	0.14	A	0.4	4.5 ± 1.1	38.5
	Tanasi			A	0.5	4.3 ± 0.6	15.5
				Overall:	0.4	9.3 ± 3.0	282.2
50% kernel density[b]	Catoosa WMA			A	0.1	3.5 ± 1.7	54.1
	Kyker Bottoms	0.002	6.58	B	0.1	0.6 ± 0.1	1.8
	Tanasi			B	0.2	0.5 ± 0.1	2.2
				Overall:	0.1	1.5 ± 0.6	54.1

Table 2.4. Continued

		P-Value	F-Value	Tukey letter	Minimum	Average ± SE	Maximum
	Catoosa WMA			A	0.7	18.9 ± 8.8	270.8
95% kernel density[b]	Kyker Bottoms	0.003	6.13	B	0.6	3.3 ± 0.5	13.6
	Tanasi			B	0.7	3.1 ± 0.5	11.6
				Overall:	0.6	8.3 ± 2.9	270.8

[a] Unit = m per day.

[b] Unit = hectares.

Table 2.5. Models explaining resource selection of eastern box turtles during the active season, Tennessee, 2016–18. Support for each model is indicated by the Akaike's Information Criterion values (AIC) and log likelihood (log(*L*)).

Model[a]	df	log(*L*)	AIC	ΔAIC	Model weight	Model likelihood
avg_depth + N5 + avgfuel_10 + avgfuel_100 + bram + nosp + cwd + nosp2 + (avg_depth|site) + (N5|site) + (avgfuel_10|site) + (avgfuel_100|site) + (cwd|site) + (nosp2|site) + (bram|site) + (nosp|site)	10	-676.90	1374.23	0	0.58	1.00
avg_depth +N5 +avgfuel_10 + avgfuel_100 + bram + nosp + cwd + nosp2	8	-679.47	1374.94	0.71	0.48	0.70
avg_depth +N5 +avgfuel_10 + avgfuel_100 + bram +grass + nosp+ cwd	8	-683.60	1383.21	8.98	0.01	0.01
avg_depth +N5 +avgfuel_10 + avgfuel_100 + bram + nosp + cwd + nosp2 + (nosp|ID)	21	-670.75	1383.95	9.72	0.00	0.01
avg_depth +N5 +avgfuel_10 + avgfuel_100 + bram + nosp + cwd + nosp2 + (nosp|ID) + (nosp2|ID)	21	-670.75	1383.96	9.73	0.00	0.01
avg_depth +N5 +avgfuel_10 + avgfuel_100 + bram + nosp+ cwd + nosp2 + (avg_depth|ID)	32	-660.34	1386.21	11.97	0.00	0.00

Table 2.5. Continued

Model[a]	df	log(L)	AIC	ΔAIC	Model weight	Model likelihood
avg_depth + N5 +avgfuel_10 + avgfuel_100 + bram + nosp+ cwd + nosp2 + (avg_depth|ID) + (nosp2|ID)	34	-659.69	1387.36	13.13	0.00	0.00
avg_depth + N5 +avgfuel_10 + avgfuel_100 + bram + nosp + cwd + nosp2 + (avg_depth|ID) + (nosp|ID) + (nosp|ID)	42	-654.37	1393.43	19.20	0.00	0.00
avg_depth + N5 + avgfuel_10 + avgfuel_100 + bram + nospecies + cwd + nospecies2 + (avg_depth|ID) + (nospecies|ID)	42	-654.29	1394.46	19.23	0.00	0.00
Null	0	-839.40	1678.80	304.57	0.00	0.00

[a]nosp = percent cover of no vegetation, bram = percent cover of brambles, N5 = visual obstruction at the 0–0.25-m level, avg_depth = average litter depth, $nosp^2$ = percent cover of no vegetation quadratic term, avgfuel_10 = count of 10-hr fuels per 2-m transect, avgfuel_100 = count of 100-hr fuels per 2-m transect, cwd = percent cover of coarse woody debris, ID = turtle identification, site = study site.

Table 2.6. Model coefficients, standard errors, confidence intervals, and selection ratios for the top model for eastern box turtle resource selection, Tennessee, USA, 2016–18. Rank is based on variable adequacy analysis. Variables with the most importance (positive or negative) are ranked starting at 1.

Variable [a]	Estimate	SE	95% CI		Selection ratio	Rank
no_sp	−0.039	0.007	−0.052	−0.026	0.961	1
bram	0.014	0.003	0.009	0.019	1.014	2
N5	0.008	0.003	0.002	0.012	1.008	3
litter_depth	0.364	0.044	0.276	0.45	1.438	4
no_sp^2	<0.001	<0.001	0.0001	0.0004	1.000	5
avgfuel_10hr	0.043	0.018	0.008	0.078	1.044	6
avgfuel_100hr	0.121	0.057	0.009	0.234	1.129	7
cwd	0.023	0.004	0.014	0.031	1.023	8

[a] no_sp = percent cover of no vegetation, bram = percent cover of brambles, N5 = visual obstruction at the 0–0.25-m level, litter_depth = average litter depth, no_sp^2 = percent cover of no vegetation quadratic term, avgfuel_10hr = count of 10-hr fuels per 2-m transect, avgfuel_100hr = count of 100-hr fuels per 2-m transect, cwd = percent cover of coarse woody debris.

Table 2.7. Litter depth and fuel comparisons for time since fire classifications, Tennessee, USA, 2016–18. Values with the same letters are not different. Tukey letters are respective to each variable.

Variable[a]	Burn classification	P-value	F-Value	Average	Standard error	Tukey letter
litter depth	no burn			1.42	0.04	a
litter depth	0-12 months	<0.01	63.89	0.87	0.05	b
litter depth	13-24 months			1.97	0.09	c
1-hr fuel	no burn			6.29	0.20	a
1-hr fuel	0-12 months	<0.01	7.03	5.76	0.24	ab
1-hr fuel	13-24 months			6.51	0.37	b
10-hr fuel	no burn			2.74	0.08	a
10-hr fuel	0-12 months	<0.01	7.17	2.79	0.13	a
10-hr fuel	13-24 months			3.48	0.20	b
100-hr fuel	no burn			0.60	0.03	a
100-hr fuel	0-12 months	0.01	4.49	0.65	0.04	ab
100-hr fuel	13-24 months			0.52	0.05	b
1,000-hr fuel	no burn			0.20	0.01	a
1,000-hr fuel	0-12 months	0.01	4.49	0.27	0.02	b
1,000-hr fuel	13-24 months			0.18	0.03	ab
10,000-hr fuel	no burn			0.07	0.01	a
10,000-hr fuel	0-12 months	<0.01	4.47	0.09	0.02	b
10,000-hr fuel	13-24 months			0.07	0.01	b

[a] litter depth = average litter depth, 1-hr fuel = count of 1-hr fuels per 2-m transect, 10-hr fuel = count of 10-hr fuels per 2-m transect, 100-hr fuel = count of 100-hr fuels per 2-m transect, 1,000-hr fuel = count of 1,000-hr fuels per 2-m transect, 10,000-hr fuel = count of 10,000-hr fuels per 2-m transect.

Table 2.8. Litter depth and fuel comparisons within vegetation types, Tennessee, USA, 2016–18. Values with the same letters are not different. Tukey letters are respective to each variable.

Variable	Vegetation Type	P-value	F-Value	Average	Standard Error	Tukey Letter
litter depth	deciduous	<0.001	54.72	2.01	0.09	c
litter depth	early succession			0.26	0.05	a
litter depth	evergreen			1.07	0.06	b
litter depth	food plot			0.17	0.13	a
litter depth	mixed forest			1.45	0.07	c
litter depth	mowed			0.10	0.10	abc
litter depth	no vegetation			1.60	0.20	abc
litter depth	woodland			1.40	0.05	c
1-hr fuel	deciduous	0.005	2.88	6.26	0.29	b
1-hr fuel	early succession			9.41	0.79	b
1-hr fuel	evergreen			6.73	0.45	b
1-hr fuel	food plot			1.46	0.64	a
1-hr fuel	mixed forest			5.27	0.22	b
1-hr fuel	mowed			3.25	0.75	ab
1-hr fuel	no vegetation			3.75	0.75	ab
1-hr fuel	woodland			5.48	0.19	b

Table 2.8. Continued.

Variable	Vegetation Type	P-value	F-Value	Average	Standard Error	Tukey Letter
10-hr fuel	deciduous	<0.001	11.41	3.01	0.16	b
10-hr fuel	early succession			2.38	0.25	a
10-hr fuel	evergreen			3.16	0.17	b
10-hr fuel	food plot			0.36	0.23	a
10-hr fuel	mixed forest			2.72	0.12	b
10-hr fuel	mowed			2.25	2.25	ab
10-hr fuel	no vegetation			2.00	2.00	ab
10-hr fuel	woodland			2.83	0.10	b
100-hr fuel	deciduous	<0.001	20.51	0.65	0.04	b
100-hr fuel	early succession			0.23	0.06	a
100-hr fuel	evergreen			0.63	0.06	b
100-hr fuel	food plot			0.00	0.00	a
100-hr fuel	mixed forest			0.76	0.06	b
100-hr fuel	mowed			0.75	0.75	ab
100-hr fuel	no vegetation			0.00	0.00	ab
100-hr fuel	woodland			0.60	0.03	b

Table 2.8. Continued.

Variable	Vegetation Type	P-value	F-Value	Average	Standard Error	Tukey Letter
1,000-hr fuel	deciduous	<0.001	10.63	0.28	0.02	c
1,000-hr fuel	early succession			0.03	0.01	a
1,000-hr fuel	evergreen			0.19	0.03	b
1,000-hr fuel	food plot			0.07	0.07	abc
1,000-hr fuel	mixed forest			0.22	0.03	bc
1,000-hr fuel	mowed			0.00	0.00	abc
1,000-hr fuel	no vegetation			0.00	0.00	abc
1,000-hr fuel	woodland			0.23	0.02	bc
10,000-hr fuel	deciduous	<0.001	4.61	0.08	0.01	b
10,000-hr fuel	early succession			0.01	0.01	a
10,000-hr fuel	evergreen			0.06	0.02	ab
10,000-hr fuel	food plot			0.36	0.36	ab
10,000-hr fuel	mixed forest			0.08	0.02	b
10,000-hr fuel	mowed			0.00	0.00	ab
10,000-hr fuel	no vegetation			0.00	0.00	ab
10,000-hr fuel	woodland			0.09	0.01	b

[a] litter depth = average litter depth, 1-hr fuel = count of 1-hr fuels per 2-m transect, 10-hr fuel = count of 10-hr fuels per 2-m transect, 100-hr fuel = count of 100-hr fuels per 2-m transect, 1,000-hr fuel = count of 1,000-hr fuels per 2-m transect, 10,000-hr fuel = count of 10,000-hr fuels per 2-m transect.

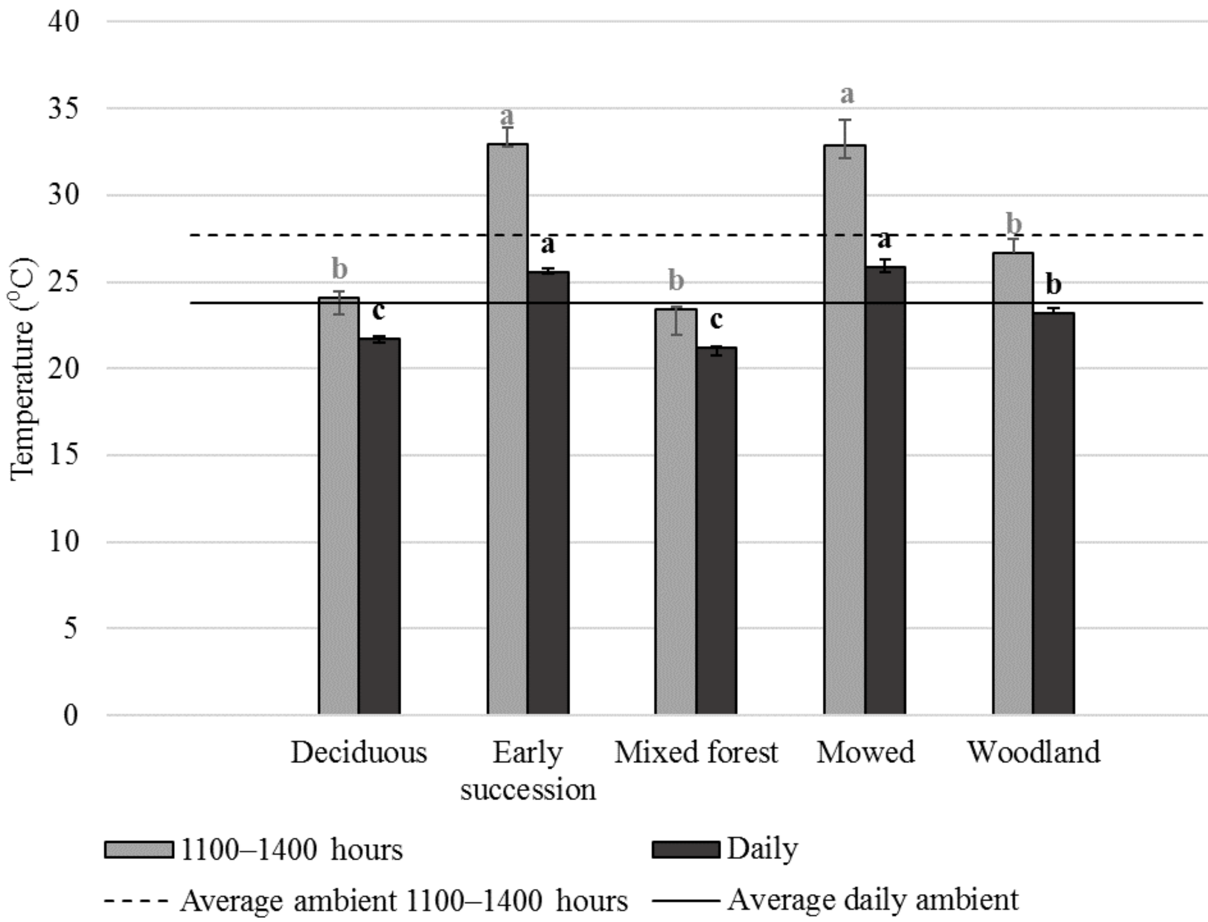

Figure 2.1. Average daily temperature and average temperatures during maximum solar radiation for vegetation types at Catoosa Wildlife Management Area, Tennessee, USA, August 2018. Gray letters represent Tukey comparisons of average temperatures during maximum solar radiation (1100–1400 hours), whereas black letters represent Tukey comparisons of average daily temperatures. Averages with the same letters are not different. The dashed line represents ambient temperatures collected under maximum solar radiation. The solid line represents average daily ambient temperatures. Ambient temperatures were recorded from weather stations within 9.5 km of respective study sites. Daily temperature fluctuations between vegetation types were measured using thermal stations within in each vegetation type.

Figure 2.2. Average daily temperature and average temperatures during maximum solar radiation for vegetation types at Tanasi Girl Scout Camp, Tennessee, USA, August 2018. Gray letters represent Tukey comparisons of average temperatures during maximum solar radiation (1100–1400 hours), whereas black letters represent Tukey comparisons of average daily temperatures. Averages with the same letters are not different. The dashed line represents ambient temperatures collected under maximum solar radiation. The solid line represents average daily ambient temperatures. Ambient temperatures were recorded from weather stations within 9.5 km of respective study sites. Daily temperature fluctuations between vegetation types were measured using thermal stations within in each vegetation type.

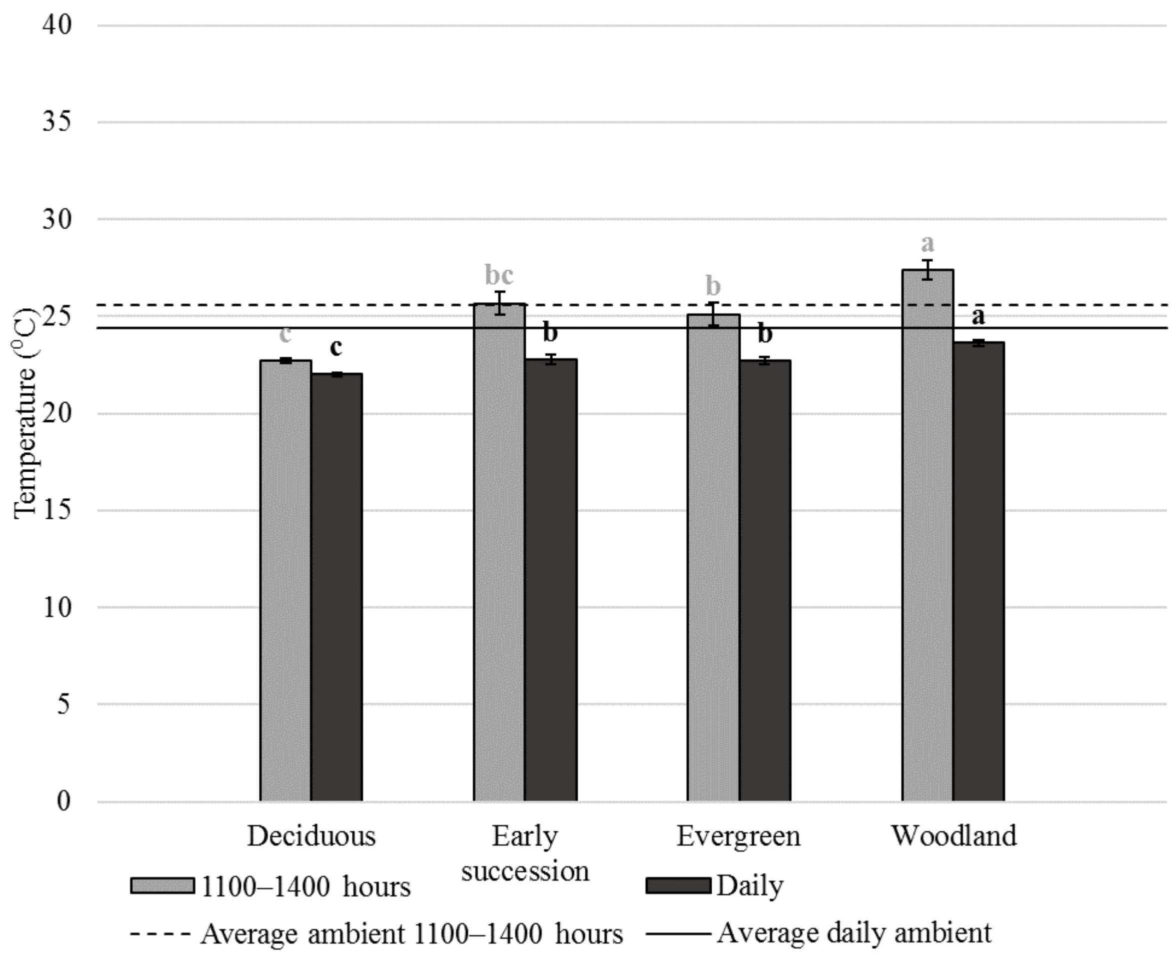

Figure 2.3. Average daily temperature and average temperatures during maximum solar radiation for vegetation types at Kyker Bottoms Wildlife Management Area, Tennessee, USA, August 2018. Gray letters represent Tukey comparisons of average temperatures during maximum solar radiation (1100–1400 hours), whereas black letters represent Tukey comparisons of average daily temperatures. Averages with the same letters are not different. The dashed line represents ambient temperatures collected under maximum solar radiation. The solid line represents average daily ambient temperatures. Ambient temperatures were recorded from weather stations within 9.5 km of respective study sites. Daily temperature fluctuations between vegetation types were measured using thermal stations within in each vegetation type.

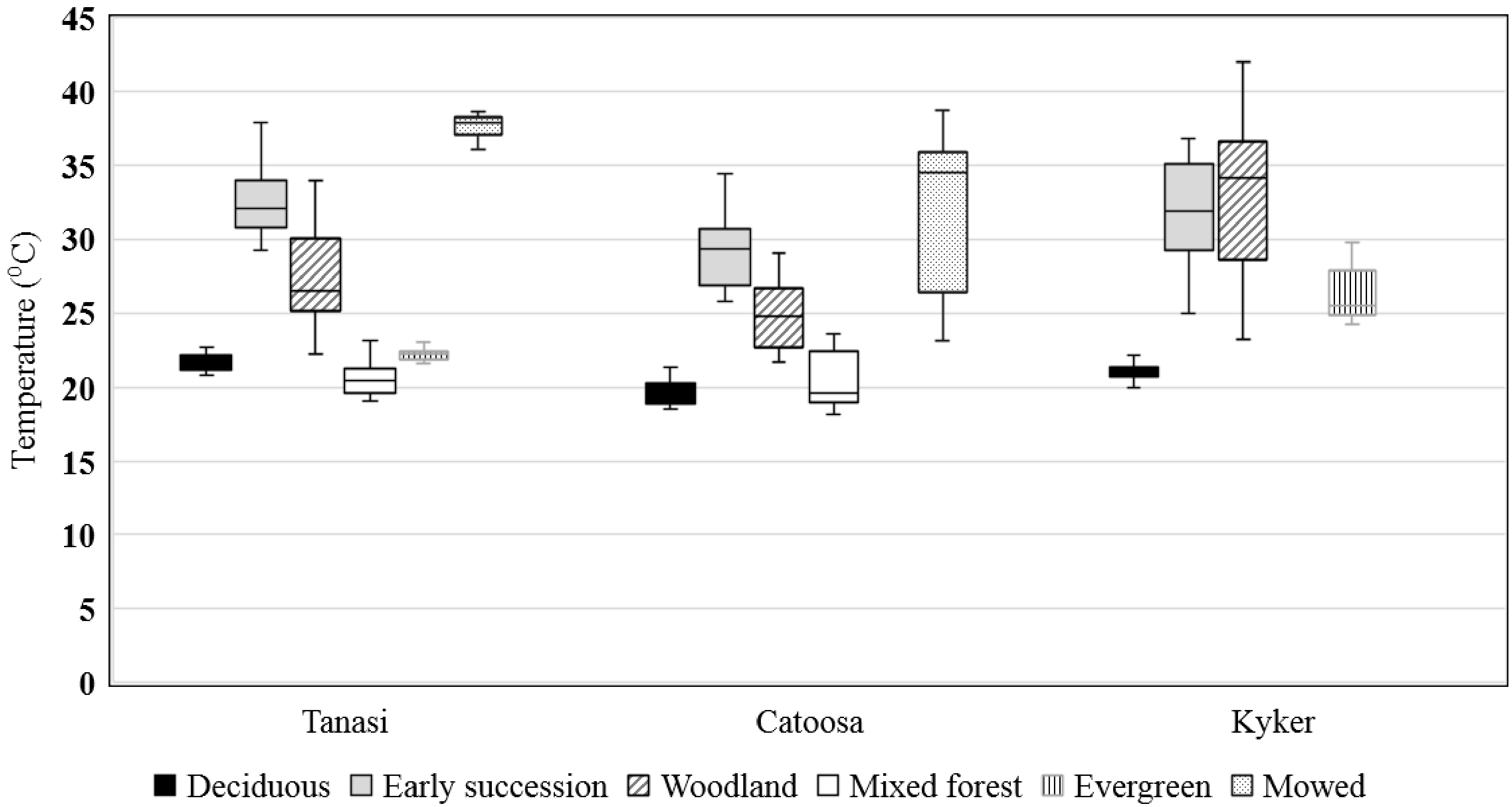

Figure 2.4. Average surface temperatures during peak solar radiation (1100–1400 hours) within available vegetation types, Tennessee, USA, August 2018. Thermal variation of surface temperatures within each vegetation type was measured using a handheld infrared thermometer.

APPENDIX 3: PLANT SPECIES ENCOUNTERED

Table 3.1. Common and scientific names of all species encountered during resource selection sampling at Tanasi Girl Scout Camp, Tennessee, USA, 2017–18.

Common name	Scientific name
Brambles	
black raspberry	*Rubus occidentalis*
blackberry	*Rubus* spp.
bristly greenbrier	*Smilax tamnoides*
cat greenbrier	*Smilax glauca*
common greenbrier	*Smilax rotundifolia*
multiflora rose	*Rosa multiflora*
northern dewberry	*Rubus flagellaris*
red raspberry	*Rubus phoenicolasius*
saw greenbrier	*Smilax bona-nox*
Ferns	
bracken fern	*Pteridium aquilinum*
Christmas fern	*Polystichum acrostichoides*
cinnamon fern	*Osmunda cinnamomea*
ebony spleenwort	*Asplenium platyneuron*
maidenhair fern	*Adiantum* sp.
rattlesnake fern	*Botrychium virginianum*
royal fern	*Osmunda regalis*
southern ladyfern	*Athyrium filix-femina*
Forbs	
agrimony	*Agrimonia* spp.
alfalfa	*Medicago sativa*
American bellflower	*Campanulastrum americanum*
American burnweed	*Erechtites hieraciifolius*
American lopseed	*Phryma leptostachya*
angularfruit milkvine	*Matelea gonocarpos*
arrowleaf violet	*Viola sagittata*
aster	*Aster* spp.
avens	*Geum* spp.
bedstraw	*Galium* spp.
bellwort	*Uvularia* sp.
berseem clover	*Trifolium alexandrinum*
bicolor lespedeza	*Lespedeza bicolor*
bitter dock	*Rumex obtusifolius*
black cohosh	*Actaea racemose*
black medic	*Medicago lupulina*

Table 3.1. Continued.

Common name	Scientific name
Forbs continued	
black snakeroot	*Sanicula canadensis*
blackeyed Susan	*Rudbeckia hirta*
blue mistflower	*Conoclinium coelestinum*
broadleaf enchanter's nightshade	*Circaea lutetiana*
bull thistle	*Cirsium vulgare*
buttercup	*Ranunculus* spp.
Canada goldenrod	*Solidago canadensis*
Canada violet	*Viola Canadensis*
Carolina elephantsfoot	*lephantopus carolinianus*
Carolina geranium	*Geranium carolinianum*
Carolina horsenettle	*Solanum carolinense*
catchweed bedstraw	*Galium aparine*
clearweed	*Pilea pumila*
clover	*Trifolium* spp.
common cinquefoil	*Potentilla simplex*
common dandelion	*Taraxacum officinale*
common fleabane	*Erigeron philadelphicus*
common moonseed	*Menispermum canadense*
common mullein	*Verbascum thapsus*
common plantain	*Plantago major*
common ragweed	*Ambrosia artemisiifolia*
common yarrow	*Achillea millefolium*
cowpea	*Vigna unguiculata*
creeping lespedeza	*Lespedeza repens*
crimson clover	*Trifolium incarnatum*
crown vetch	*Securigera varia*
curly dock	*Rumex crispus*
daisy fleabane	*Erigeron strigosus*
deptford pink	*Dianthus armeria*
downy skullcap	*Scutellaria incana*
downy yellow violet	*Oxalis stricta*
dwarf crested iris	*Iris cristata*
eastern gray beardtongue	*Penstemon canescens*
false Solomon's seal	*Maianthemum racemosum*
field madder	*Sherardia arvensis*
field thistle	*Cirsium discolor*

Table 3.1. Continued.

Common name	Scientific name
Forbs continued	
flowering spurge	*Euphorbia corollata*
foamflower	*Tiarella cordifolia*
fragrant goldenrod	*Solidago odora*
goldenrod	*Solidago* spp.
goldenseal	*Hydrastis canadensis*
grain sorghum	*Sorghum bicolor*
groundnut	*Apios Americana*
hairy bedstraw	*Galium pilosum*
hairy lespedeza	*Lespedeza hirta*
heartleaved aster	*Symphyotrichum cordifolium*
hogpeanut	*Amphicarpaea bracteata*
honewort	*Cryptotaenia canadensis*
horseweed	*Conyza canadensis*
Indian hemp	*Apocynum cannabinum*
Indian pink	*Silene californica*
jewelweed	*Impatiens capensis*
ladino clover	*Trifolium repens*
lateflowering thoroughwort	*Eupatorium serotinum*
little brown jug	*Hexastylis arifolia*
lyre-leaf sage	*Salvia lyrata*
marsh elder	*Iva annua*
mayapple	*Podophyllum peltatum*
moneywort	*Lysimachia nummularia*
morningglory	*Ipomoea purpurea*
nakedflower ticktrefoil	*Desmodium nudiflorum*
narrowleaf plantain	*Plantago lanceolata*
oxeye daisy	*Leucanthemum vulgare*
panicledleaf ticktrefoil	*Desmodium paniculatum*
partridge pea	*Chamaecrista fasciculata*
Pennsylvania smartweed	*Polygonum pensylvanicum*
pipevine	*Aristolochia macrophylla*
plantainleaf pussytoes	*Antennaria plantaginifolia*
pokeweed	*Phytolacca americana*
prickly lettuce	*Lactuca serriola*
prostrate ticktrefoil	*Desmodium rotundifolium*
purple passionflower	*Passiflora incarnata*
Queen Anne's lace	*Daucus carota*

Table 3.1. Continued.

Common name	Scientific name
Forbs continued	
rabbit tobacco	*Gnaphalium obtusifolium*
red clover	*Trifolium pratense*
richweed	*Collinsonia canadensis*
rue anemone	*Thalictrum thalictroides*
sand violet	*Viola affinis*
sericea lespedeza	*Lespedeza cuneata*
showy goldenrod	*Solidago speciosa*
skullcap	*Scutellaria* spp.
slender lespedeza	*Lespedeza virginica*
smartweed	*Polygunum* spp.
smooth Solomon's seal	*Polygonatum biflorum*
smooth ticktrefoil	*Desmodium laevigatum*
spotted spurge	*Chamaesyce maculata*
spotted wintergreen	*Chimaphila maculata*
squaw root	*Conopholis americana*
St. Andrew's cross	*Hypericum hypericoides*
St. Johnswort	*Hypericum* spp.
stiff ticktrefoil	*Desmodium obtusum*
stinging nettle	*Urtica dioica*
stinking chamomile	*Anthemis cotula*
stonecrop	*Sedum ternatum*
stoneroot	*Collinsonia verticillata*
tall ironweed	*Vernonia gigantea*
tall lettuce	*Lactuca canadensis*
tall thimbleweed	*Anemone virginiana*
three-lobe violet	*Viola triloba var. triloba*
tick-trefoil	*Desmoduim* spp.
trailing lespedeza	*Lespedeza procumbens*
trillium	*Trillium* sp.
Venus looking glass	*Triodanis perfoliata*
violet	*Viola* spp.
Virginia knotweed	*Persicaria virginiana*
Virginia pepperweed	*Lepidium virginicum*
Virginia threeseed mercury	*Acalypha virginica*
water hemlock	*Cicuta maculate*
water plantain	*Alisma subcordatum*
wavyleaf aster	*Symphyotrichum undulatum*

Table 3.1. Continued.

Common name	Scientific name
Forbs continued	
white avens	*Geum candense*
white clover	*Melilotus albus*
white crownbeard	*Verbesina virginica*
white snakeroot	*Ageratina altissima*
white sweet clover	*Melilotus officinalis*
whiteflower leafcup	*polymnia canadensis*
whorled coreopsis	*Coreopsis major*
whorled pogonia	*Isotria verticillata*
wild comfrey	*Cynoglossum virginianum*
wild garlic	*Allium vineale*
wild petunia	*Ruellia caroliniensis*
wild potato	*Ipomoea pandurata*
wild quanine	*Parthenium integrifolium*
wild senna	*Senna marilandica*
wild strawberry	*Fragaria virginiana*
wild yam	*Dioscorea virginiana*
wingstem	*Verbesina alternifolia*
wood nettle	*Laportea canadensis*
woodland sunflower	*Helianthus divaricatus*
wrinkleleaf goldenrod	*Solidago rugose*
yellow hop-clover	*Trifolium campestre*
yellow passionflower	*Passiflora lutea*
yellow pimpernil	*Taenidia integerrima*
yellowroot	*Xanthorhiza simplicissima*
Graminoids	
annual bluegrass	*Poa annua*
beaked panicgrass	*Panicum anceps*
big bluestem	*Andropogon gerardii*
broomsedge bluestem	*Andropogon virginicus*
caric sedge	*Carex* spp.
cheatgrass	*Bromus secalinus*
crabgrass	*Digitaria* spp.
deer tongue	*Dichanthelium clandestinum*
Dicantheilum	*Dichanthelium* spp.
downy brome	*Bromus tectorum*
eastern bottlebrush grass	*Elymus hystrix*
flatsedge	*Cyperus* spp.

Table 3.1. Continued.

Common name	Scientific name
Graminoids continued	
Johnsongrass	*Sorghum halepense*
low panicgrass	*Panicum* spp.
needle grass	*Piptochaetium avenaceum*
Nepalese browntop	*Microstegium vimineum*
nimblewill	*Muhlenbergia schreberi*
orchard grass	*Dactylis glomerata*
panicgrass	*Dichanthelium* spp.
poverty grass	*Danthonia* spp.
purpletop	*Tridens flavus*
rush	*Juncus* spp.
silver plumegrass	*Saccharum alopecuroides*
slender wood oats	*Chasmanthium laxum*
tall fescue	*Schedonorus arundinaceus*
Virginia rye	*Elymus virginicus*
whip nutrush	*Scleria triglomerata*
winter wheat	*Triticum aestivum*
yellow foxtail	*Setaria pumila*
Shrubs	
Amur honeysuckle	*Lonicera maackii*
autumn olive	*Elaeagnus umbellata*
blueberry	*Vaccinium* spp.
Carolina buckthorn	*Frangula caroliniana*
Chinese privet	*Ligustrum sinense*
common buttonbush	*Cephalanthus occidentalis*
deerberry	*Vaccinium stamineum*
new jersey tea	*Ceanothus americanu*
smooth sumac	*Rhus glabra*
southern arrowwood	*Viburnum dentatum*
spicebush	*Lindera benzoin*
strawberry bush	*Euonymus americanus*
wild hydrangea	*Hydrangea arborescens*
winged sumac	*Rhus copallinum*
Trees	
American beech	*Fagus grandifolia*
American elm	*Ulmus Americana*
American holly	*Ilex opaca*
American hornbeam	*Carpinus caroliniana*

Table 3.1. Continued.

Common name	Scientific name
Trees continued	
American sycamore	*Platanus occidentalis*
bitternut hickory	*Carya cordiformis*
black cherry	*Prunus serotine*
black locust	*Robinia pseudoacacia*
black oak	*Quercus velutina*
black walnut	*Juglans nigra*
blackgum	*Nyssa sylvatica*
boxelder	*Acer negundo*
chestnut oak	*Quercus montana*
cucumbertree	*Magnolia acuminata*
downy serviceberry	*Amelanchier arborea*
eastern redbud	*Cercis canadensis*
eastern redcedar	*Juniperus virginiana*
eastern white pine	*Pinus strobus*
flowering dogwood	*Cornus florida*
green ash	*Fraxinus pennsylvanica*
hackberry	*Celtis occidentalis*
hophornbeam	*Ostrya virginiana*
mimosa	*Albizia julibrissin*
mockernut hickory	*Carya tomentosa*
northern red oak	*Quercus rubra*
pawpaw	*Asimina triloba*
persimmon	*Diospyros virginiana*
pignut hickory	*Carya glabra*
princess tree	*Paulownia tomentosa*
red maple	*Acer rubrum*
red mulberry	*Morus rubra*
sassafras	*Sassafras albidum*
scarlet oak	*Quercus coccinea*
shagbark hickory	*Carya ovata*
shortleaf pine	*Pinus echinata*
slippery elm	*Ulmus rubra*
sourwood	*Oxydendrum arboreum*
southern red oak	*Quercus falcate*
sugar maple	*Acer saccharum*
sweetgum	*Liquidambar styraciflua*
tree of heaven	*Ailanthus altissima*

Table 3.1. Continued.

Common name	Scientific name
Trees continued	
tuliptree	*Liriodendron tulipifera*
Virginia pine	*Pinus virginiana*
white oak	*Quercus alba*
winged elm	*Ulmus alata*
yellow buckeye	*Aesculus flava*
Woody Vines	
crossvine	*Bignonia capreolata*
English ivy	*Hedera helix*
grape	*Vitis* spp.
Japanese honeysuckle	*Lonicera japonica*
muscadine	*Vitis rotundifolia*
oriental bittersweet	*Celastrus orbiculatus*
poison ivy	*Toxicodendron radicans*
trumpet creeper	*Campsis radicans*
Virginia creeper	*Parthenocissus quinquefolia*

Table 3.2. Common and scientific names of all species encountered during resource selection sampling at Kyker Bottoms Wildlife Management Area, Tennessee, USA, 2017–18.

Common name	Scientific name
Brambles	
black raspberry	*Rubus occidentalis*
blackberry	*Rubus* spp.
cat greenbrier	*Smilax glauca*
common greenbrier	*Smilax rotundifolia*
multiflora rose	*Rosa multiflora*
northern dewberry	*Rubus flagellaris*
red raspberry	*Rubus phoenicolasius*
Ferns	
Christmas fern	*Polystichum acrostichoides*
maidenhair fern	*Adiantum* spp.
Forbs	
agrimony	*Agrimonia* spp.
alfalfa	*Medicago sativa*
American burnweed	*Erechtites hieraciifolius*
angularfruit milkvine	*Matelea gonocarpos*
Asiatic dayflower	*Commelina communis*
aster	*Aster* spp.
avens	*Geum* spp.
bedstraw	*Galium* spp.
bellwort	*Uvularia* sp.
bicolor lespedeza	*Lespedeza bicolor*
bitter dock	*Rumex obtusifolius*
black cohosh	*Actaea racemose*
black snakeroot	*Sanicula canadensis*
blackeyed Susan	*Rudbeckia hirta*
bog smartweed	*Polygonum setaceum*
broadleaf cattail	*Typha latifolia*
bull thistle	*Cirsium vulgare*
buttercup	*Ranunculus* spp.
butterfly pea	*Clitoria mariana*
Canada goldenrod	*Solidago canadensis*
Canada violet	*Viola Canadensis*
Carolina elephantsfoot	*lephantopus carolinianus*
Carolina false-dandelion	*Pyrrhopappus carolinianus*
Carolina geranium	*Geranium carolinianum*
Carolina horsenettle	*Solanum carolinense*
catchweed bedstraw	*Galium aparine*

Table 3.2. Continued.

Common name	Scientific name
Forbs continued	
clammy groundcherry	*Physalis heterophylla*
clearweed	*Pilea pumila*
clover	*Trifolium* spp.
common cinquefoil	*Potentilla simplex*
common fleabane	*Erigeron philadelphicus*
common milkweed	*Asclepias syriaca*
common mullein	*Verbascum thapsus*
common plantain	*Plantago major*
common ragweed	*Ambrosia artemisiifolia*
common yarrow	*Achillea millefolium*
creeping lespedeza	*Lespedeza repens*
crimson clover	*Trifolium incarnatum*
crown vetch	*Securigera varia*
curly dock	*Rumex crispus*
cutleaf toothwort	*Cardamine concatenata*
daisy fleabane	*Erigeron strigosus*
dogfennel	*Eupatorium capillifolium*
downy skullcap	*Scutellaria incana*
downy yellow violet	*Oxalis stricta*
dwarf crested iris	*Iris cristata*
eastern gray beardtongue	*Penstemon canescens*
false Solomon's seal	*Maianthemum racemosum*
field thistle	*Cirsium discolor*
firepink	*Silene virginica*
flowering spurge	*Euphorbia corollata*
foamflower	*Tiarella cordifolia*
fragrant goldenrod	*Solidago odora*
giant ragweed	*Ambrosia trifida*
goldenrod	*Solidago* spp.
groundnut	*Apios Americana*
hairy bedstraw	*Galium pilosum*
hairy lespedeza	*Lespedeza hirta*
hairy skullcap	*Scutellaria elliptica*
hoary mountain mint	*Pycnanthemum incanum*
hogpeanut	*Amphicarpaea bracteata*
honewort	*Cryptotaenia canadensis*
horseweed	*Conyza canadensis*
hyssop-leaved-throughwort	*Eupatorium hyssopifolium*
Illinois bundleflower	*Desmanthus illinoensis*

Table 3.2. Continued.

Common name	Scientific name
Forbs continued	
Indian cucumber root	*Medeola virginiana*
Indian hemp	*Apocynum cannabinum*
Indian pink	*Silene californica*
Indian tobacco	*Lobelia inflata*
Jack in the pulpit	*Arisaema triphyllum*
jewelweed	*Impatiens capensis*
Joe-pye weed	*Eutrochium fistulosum*
lambsquarters	*Chenopodium album*
lateflowering thoroughwort	*Eupatorium serotinum*
licorice bedstraw	*Galium circaezans*
little brown jug	*Hexastylis arifolia*
lyre-leaf sage	*Salvia lyrata*
marsh elder	*Iva annua*
mint	*Lamiaceae*
moneywort	*Lysimachia nummularia*
morningglory	*Ipomoea purpurea*
narrowleaf mountian mint	*Pycnanthemum tenuifolium*
narrowleaf plantain	*Plantago lanceolata*
oldfield milkvine	*Matelea decipiens*
oxeye daisy	*Leucanthemum vulgare*
panicledleaf ticktrefoil	*Desmodium paniculatum*
partrideberry	*Mitchella repens*
partridge pea	*Chamaecrista fasciculata*
Pennsylvania smartweed	*Polygonum pensylvanicum*
plantainleaf pussytoes	*Antennaria plantaginifolia*
pokeweed	*Phytolacca americana*
prarie tea	*Croton monanthogynus*
prickly lettuce	*Lactuca serriola*
prostrate ticktrefoil	*Desmodium rotundifolium*
purple passionflower	*Passiflora incarnata*
Queen Anne's lace	*Daucus carota*
rabbit tobacco	*Gnaphalium obtusifolium*
red clover	*Trifolium pratense*
richweed	*Collinsonia canadensis*
round leaf thorughwort	*Eupatorium rotundifolium*
rue anemone	*Thalictrum thalictroides*
sand violet	*Viola affinis*
seedbox	*Ludwigia alternifolia*
sericea lespedeza	*Lespedeza cuneata*

Table 3.2. Continued.

Common name	Scientific name
Forbs continued	
sheep sorrel	*Rumex acetosella*
showy goldenrod	*Solidago speciosa*
slender lespedeza	*Lespedeza virginica*
Small's ragwort	*Packera anonyma*
smooth Solomon's seal	*Polygonatum biflorum*
smooth ticktrefoil	*Desmodium laevigatum*
Spanish needles	*Bidens bipinnata*
St. Johnswort	*Hypericum* spp.
stiff ticktrefoil	*Desmodium obtusum*
stinging nettle	*Urtica dioica*
stoneroot	*Collinsonia verticillata*
tall ironweed	*Vernonia gigantea*
tall lettuce	*Lactuca canadensis*
tall thimbleweed	*Anemone virginiana*
tick-trefoil	*Desmoduim* spp.
trailing lespedeza	*Lespedeza procumbens*
Venus looking glass	*Triodanis perfoliata*
downy yellow violet	*Viola pubescens*
violet	*Viola* spp.
Virginia buttonweed	*Diodia virginiana*
Virginia knotweed	*Persicaria virginiana*
Virginia pepperweed	*Lepidium virginicum*
Virginia threeseed mercury	*Acalypha virginica*
water hemlock	*Cicuta maculata*
water plantain	*Alisma subcordatum*
wavyleaf aster	*Symphyotrichum undulatum*
white avens	*Geum candense*
white clover	*Melilotus albus*
white snakeroot	*Ageratina altissima*
white sweet clover	*Melilotus officinalis*
whiteflower leafcup	*polymnia canadensis*
whorled coreopsis	*Coreopsis major*
whorled pogonia	*Isotria verticillata*
wild comfrey	*Cynoglossum virginianum*
wild garlic	*Allium vineale*
wild petunia	*Ruellia caroliniensis*
wild potato	*Ipomoea pandurata*
wild quanine	*Parthenium integrifolium*
wild senna	*Senna marilandica*

Table 3.2. Continued.

Common name	Scientific name
Forbs continued	
wild strawberry	*Fragaria virginiana*
wild yam	*Dioscorea virginiana*
wingstem	*Verbesina alternifolia*
wood nettle	*Laportea canadensis*
woodland sunflower	*Helianthus divaricatus*
wrinkleleaf goldenrod	*Solidago rugosa*
yellow hop-clover	*Trifolium campestre*
yellow passionflower	*Passiflora lutea*
yellow pimpernil	*Taenidia integerrima*
yellowroot	*Xanthorhiza simplicissima*
Graminoids	
annual bluegrass	*Poa annua*
beaked panicgrass	*Panicum anceps*
big bluestem	*Andropogon gerardii*
broomsedge bluestem	*Andropogon virginicus*
caric sedge	*Carex* spp.
corn	*Zea mays*
crabgrass	*Digitaria* spp.
dallisgrass	*Paspalum dilatatum*
deer tongue	*Dichanthelium clandestinum*
Dicantheilum	*Dichanthelium* spp.
downy brome	*Bromus tectorum*
flatsedge	*Cyperus* spp.
Johnsongrass	*Sorghum halepense*
knotroot foxtail	*Setaria parviflora*
little bluestem	*Schizachyrium scoparium*
low panicgrass	*Panicum* spp.
needle grass	*Piptochaetium avenaceum*
Nepalese browntop	*Microstegium vimineum*
nimblewill	*Muhlenbergia schreberi*
panicgrass	*Dichanthelium* spp.
poverty grass	*Danthonia* spp.
purpletop	*Tridens flavus*
rice cutgrass	*Leersia oryzoides*
river cane	*Arundinaria gigantea*
river oats	*Chasmanthium latifolium*
rush	*Juncus* spp.
silver plumegrass	*Saccharum alopecuroides*
slender wood oats	*Chasmanthium laxum*

Table 3.2. Continued.

Common name	Scientific name
Graminoids continued	
tall fescue	*Schedonorus arundinaceus*
whip nutrush	*Scleria triglomerata*
winter wheat	*Triticum aestivum*
yellow foxtail	*Setaria pumila*
yellow nutsedge	*Cyperus esculentus*
Shrubs	
Amur honeysuckle	*Lonicera maackii*
autumn olive	*Elaeagnus umbellata*
blueberry	*Vaccinium* spp.
Carolina buckthorn	*Frangula caroliniana*
Chinese privet	*Ligustrum sinense*
devil's walking stick	*Aralia spinosa*
elderberry	*Sambucus canadensis*
farkleberry	*Vaccinium arboreum*
lowbush blueberry	*Vaccinium angustifolium*
smooth sumac	*Rhus glabra*
spicebush	*Lindera benzoin*
strawberry bush	*Euonymus americanus*
wild azalea	*Rhododendron canescens*
wild hydrangea	*Hydrangea arborescens*
winged sumac	*Rhus copallinum*
Trees	
American beech	*Fagus grandifolia*
American elm	*Ulmus americana*
American holly	*Ilex opaca*
American hornbeam	*Carpinus caroliniana*
American plum	*Prunus americana*
American sycamore	*Platanus occidentalis*
bitternut hickory	*Carya cordiformis*
black cherry	*Prunus serotina*
black locust	*Robinia pseudoacacia*
black oak	*Quercus velutina*
black walnut	*Juglans nigra*
black willow	*Salix nigra*
blackgum	*Nyssa sylvatica*
boxelder	*Acer negundo*
butternut	*Juglans cinerea*
Callery pear	*Pyrus calleryana*
chestnut oak	*Quercus montana*

Table 3.2. Continued.

Common name	Scientific name
Trees continued	
chinquapin	*Castanea pumila*
cucumbertree	*Magnolia acuminata*
eastern redbud	*Cercis canadensis*
eastern redcedar	*Juniperus virginiana*
flowering dogwood	*Cornus florida*
green ash	*Fraxinus pennsylvanica*
honey locust	*Gleditsia triacanthos*
hophornbeam	*Ostrya virginiana*
mimosa	*Albizia julibrissin*
mockernut hickory	*Carya tomentosa*
northern red oak	*Quercus rubra*
oak	*Quercus* spp.
pawpaw	*Asimina triloba*
persimmon	*Diospyros virginiana*
pignut hickory	*Carya glabra*
post oak	*Quercus stellata*
princess tree	*Paulownia tomentosa*
red maple	*Acer rubrum*
red mulberry	*Morus rubra*
sassafras	*Sassafras albidum*
scarlet oak	*Quercus coccinea*
shagbark hickory	*Carya ovata*
silky dogwood	*Cornus amomum*
slippery elm	*Ulmus rubra*
sourwood	*Oxydendrum arboreum*
southern red oak	*Quercus falcata*
sugar maple	*Acer saccharum*
sweetgum	*Liquidambar styraciflua*
tuliptree	*Liriodendron tulipifera*
umbrella-tree	*Magnolia tripetala*
Virginia pine	*Pinus virginiana*
white oak	*Quercus alba*
winged elm	*Ulmus alata*
yellow buckeye	*Aesculus flava*
Vines	
crossvine	*Bignonia capreolata*
English ivy	*Hedera helix*
grape	*Vitis* spp.
Japanese honeysuckle	*Lonicera japonica*

Table 3.2. Continued.

Common name	Scientific name
Trees continued	
kudzu	*Pueraria montana*
muscadine	*Vitis rotundifolia*
oriental bittersweet	*Celastrus orbiculatus*
poison ivy	*Toxicodendron radicans*
trumpet creeper	*Campsis radicans*
Virginia creeper	*Parthenocissus quinquefolia*

Table 3.3. Common and scientific names of all species encountered during resource selection sampling at Catoosa Wildlife Management Area, Tennessee, USA, 2017–18.

Common Name	Scientific Name
Brambles	
black raspberry	*Rubus occidentalis*
blackberry	*Rubus* spp.
Carolina rose	*Rosa carolina*
cat greenbrier	*Smilax glauca*
common greenbrier	*Smilax rotundifolia*
multiflora rose	*Rosa multiflora*
northern dewberry	*Rubus flagellaris*
red raspberry	*Rubus phoenicolasius*
saw greenbrier	*Smilax bona-nox*
Ferns	
American climbing fern	*Lygodium palmatum*
bracken fern	*Pteridium aquilinum*
Christmas fern	*Polystichum acrostichoides*
cinnamon fern	*Osmunda cinnamomea*
maidenhair fern	*Adiantum* spp.
royal fern	*Osmunda regalis*
southern ladyfern	*Athyrium filix-femina*
southern woodfern	*Dryopteris ludovician*
Forbs	
agrimony	*Agrimonia* spp.
American burnweed	*Erechtites hieraciifolius*
arrowleaf violet	*Viola sagittata*
aster	*Aster* spp.
avens	*Geum* spp.
bedstraw	*Galium* spp.
bellwort	*Uvularia* spp.
bicolor lespedeza	*Lespedeza bicolor*
bitter dock	*Rumex obtusifolius*
black cohosh	*Actaea racemosa*
black medic	*Medicago lupulina*
black snakeroot	*Sanicula canadensis*
Bowman's root	*Gillenia trifoliata*
burdock	*Arctium* spp.
buttercup	*Ranunculus* spp.
Canada goldenrod	*Solidago canadensis*

Table 3.3. Continued.

Common Name	Scientific Name
Forbs Continued	
Canada violet	*Viola canadensis*
Carolina elephantsfoot	*lephantopus carolinianus*
Carolina geranium	*Geranium carolinianum*
Carolina horsenettle	*Solanum carolinense*
catchweed bedstraw	*Galium aparine*
clammy groundcherry	*Physalis heterophylla*
clearweed	*Pilea pumila*
common cinquefoil	*Potentilla simplex*
common dandelion	*Taraxacum officinale*
common fleabane	*Erigeron philadelphicus*
common plantain	*Plantago major*
common ragweed	*Ambrosia artemisiifolia*
creeping lespedeza	*Lespedeza repens*
crown vetch	*Securigera varia*
curly dock	*Rumex crispus*
deptford pink	*Dianthus armeria*
dodder	*Cuscuta* spp.
dogfennel	*Eupatorium capillifolium*
downy rattlesnake plantain	*Goodyera pubescens*
downy skullcap	*Scutellaria incana*
downy yellow violet	*Oxalis stricta*
dwarf crested iris	*Iris cristata*
entireleaf yellow false foxglove	*Aureolaria laevigata*
false Solomon's seal	*Maianthemum racemosum*
field thistle	*Cirsium discolor*
flat whitetopped aster	*Doellingeria umbellata*
flowering spurge	*Euphorbia corollata*
foamflower	*Tiarella cordifolia*
fragrant goldenrod	*Solidago odora*
giant ragweed	*Ambrosia trifida*
goldenrod	*Solidago* spp.
grass leaved aster	*Chrysopsis graminifolia*
great blue lobelia	*Lobelia siphilitica*
groundnut	*Apios americana*
hairy angelica	*Angelica venenosa*
hairy bedstraw	*Galium pilosum*
hairy hawkweed	*Hieracium longipilum*

Table 3.3. Continued.

Common Name	Scientific Name
Forbs Continued	
hairy lespedeza	*Lespedeza hirta*
hoary mountain mint	*Pycnanthemum incanum*
hogpeanut	*Amphicarpaea bracteata*
horseweed	*Conyza canadensis*
hyssop-leaved-throughwort	*Eupatorium hyssopifolium*
Indian cucumber root	*Medeola virginiana*
Indian hemp	*Apocynum cannabinum*
Indian pink	*Silene californica*
jewelweed	*Impatiens capensis*
ladino clover	*Trifolium repens*
lateflowering thoroughwort	*Eupatorium serotinum*
licorice bedstraw	*Galium circaezans*
little brown jug	*Hexastylis arifolia*
littleleaf sensitive-briar	*Mimosa microphylla*
lyre-leaf sage	*Salvia lyrata*
mint	*Lamiaceae*
moneywort	*Lysimachia nummularia*
musk thistle	*Carduus nutans*
narrowleaf plantain	*Plantago lanceolata*
oxeye daisy	*Leucanthemum vulgare*
panicledleaf ticktrefoil	*Desmodium paniculatum*
partrideberry	*Mitchella repens*
partridge pea	*Chamaecrista fasciculata*
pipevine	*Aristolochia macrophylla*
pokeweed	*Phytolacca americana*
prarie tea	*Croton monanthogynu*
prickly lettuce	*Lactuca serriola*
prostrate ticktrefoil	*Desmodium rotundifolium*
Queen Anne's lace	*Daucus carota*
rabbit tobacco	*Gnaphalium obtusifolium*
roundleaf thorughwort	*Eupatorium rotundifolium*
rue anemone	*Thalictrum thalictroides*
sand violet	*Viola affinis*
sericea lespedeza	*Lespedeza cuneata*
showy goldenrod	*Solidago speciosa*
slender lespedeza	*Lespedeza virginica*
Small's ragwort	*Packera anonyma*

Table 3.3. Continued.

Common Name	Scientific Name
Forbs Continued	
smooth Solomon's seal	*Polygonatum biflorum*
smooth ticktrefoil	*Desmodium laevigatum*
southern chervil	*Chaerophyllum tainturieri*
spotted wintergreen	*Chimaphila maculata*
St. Johnswort	*Hypericum* spp.
steeplebush	*Spiraea tomentosa*
stiff ticktrefoil	*Desmodium obtusum*
stonecrop	*Sedum ternatum*
stoneroot	*Collinsonia verticillata*
tall lettuce	*Lactuca canadensis*
three-lobe violet	*Viola triloba var. triloba*
tick-trefoil	*Desmoduim* spp.
trailing lespedeza	*Lespedeza procumbens*
Venus looking glass	*Triodanis perfoliata*
violet	*Viola* spp.
Virginia threeseed mercury	*Acalypha virginica*
water hemlock	*Cicuta maculata*
water plantain	*Alisma subcordatum*
white clover	*Melilotus albus*
white snakeroot	*Ageratina altissima*
white sweet clover	*Melilotus officinalis*
whorled coreopsis	*Coreopsis major*
whorled loosestrife	*Lysimachia quadrifolia*
whorled pogonia	*Isotria verticillata*
wild bergamot	*Monarda fistulosa*
wild comfrey	*Cynoglossum virginianum*
wild garlic	*Allium vineale*
wild potato	*Ipomoea pandurata*
wild quinine	*Parthenium integrifolium*
wild senna	*Senna marilandica*
wild strawberry	*Fragaria virginiana*
wild yam	*Dioscorea virginiana*
wingstem	*Verbesina alternifolia*
woodland sunflower	*Helianthus divaricatus*
wrinkleleaf goldenrod	*Solidago rugosa*
yellow passionflower	*Passiflora lutea*
yellowroot	*Xanthorhiza simplicissima*

Table 3.3. Continued.

Common Name	Scientific Name
Graminoids Continued	
beaked panicgrass	*Panicum anceps*
big bluestem	*Andropogon gerardii*
broomsedge bluestem	*Andropogon virginicus*
caric sedge	*Carex* spp.
corn	*Zea mays*
crabgrass	*Digitaria* spp.
deer tongue	*Dichanthelium clandestinum*
Dicantheilum	*Dichanthelium* spp.
downy brome	*Bromus tectorum*
flatsedge	*Cyperus* spp.
Johnsongrass	*Sorghum halepense*
little bluestem	*Schizachyrium scoparium*
low panicgrass	*Panicum* spp.
needle grass	*Piptochaetium avenaceum*
Nepalese browntop	*Microstegium vimineum*
nimblewill	*Muhlenbergia schreberi*
orchard grass	*Dactylis glomerata*
panicgrass	*Dichanthelium* spp.
poverty grass	*Danthonia* spp.
rush	*Juncus* spp.
silver plumegrass	*Saccharum alopecuroides*
slender wood oats	*Chasmanthium laxum*
tall fescue	*Schedonorus arundinaceus*
timothy	*Phleum pratense*
Virginia rye	*Elymus virginicus*
whip nutrush	*Scleria triglomerata*
yellow foxtail	*Setaria pumila*
Shrubs	
Amur honeysuckle	*Lonicera maackii*
autumn olive	*Elaeagnus umbellata*
blueberry	*Vaccinium* spp.
deerberry	*Vaccinium stamineum*
devil's walking stick	*Aralia spinosa*
elderberry	*Sambucus canadensis*
farkleberry	*Vaccinium arboreum*
huckleberry	*Vaccinium* spp.
lowbush blueberry	*Vaccinium angustifolium*

Table 3.3. Continued.

Common Name	Scientific Name
Shrubs Continued	
mapleleaf viburnum	*Viburnum acerifolium*
mountain camellia	*Stewartia ovata*
smooth sumac	*Rhus glabra*
southern arrowwood	*Viburnum dentatum*
spicebush	*Lindera benzoin*
strawberry bush	*Euonymus americanus*
viburnum	*Viburnum* spp.
wild azalea	*Rhododendron canescens*
wild hydrangea	*Hydrangea arborescens*
winged sumac	*Rhus copallinum*
Trees	
American beech	*Fagus grandifolia*
American elm	*Ulmus americana*
American holly	*Ilex opaca*
American hornbeam	*Carpinus caroliniana*
American sycamore	*Platanus occidentalis*
black cherry	*Prunus serotina*
black locust	*Robinia pseudoacacia*
black oak	*Quercus velutina*
black walnut	*Juglans nigra*
blackgum	*Nyssa sylvatica*
boxelder	*Acer negundo*
butternut	*Juglans cinerea*
chestnut oak	*Quercus montana*
chinquapin	*Castanea pumila*
cucumbertree	*Magnolia acuminata*
downy serviceberry	*Amelanchier arborea*
eastern redbud	*Cercis canadensis*
eastern redcedar	*Juniperus virginiana*
eastern white pine	*Pinus strobus*
flowering dogwood	*Cornus florida*
green ash	*Fraxinus pennsylvania*
hophornbeam	*Ostrya virginiana*
mockernut hickory	*Carya tomentosa*
northern red oak	*Quercus rubra*
oak	*Quercus* spp.
pawpaw	*Asimina triloba*

Table 3.3. Continued.

Common Name	Scientific Name
Trees Continued	
persimmon	*Diospyros virginiana*
pignut hickory	*Carya glabra*
post oak	*Quercus stellata*
princess tree	*Paulownia tomentosa*
red maple	*Acer rubrum*
sassafras	*Sassafras albidum*
scarlet oak	*Quercus coccinea*
shagbark hickory	*Carya ovata*
shortleaf pine	*Pinus echinata*
silky dogwood	*Cornus amomum*
slippery elm	*Ulmus rubra*
sourwood	*Oxydendrum arboreum*
southern red oak	*Quercus falcata*
tree of heaven	*Ailanthus altissima*
tuliptree	*Liriodendron tulipifera*
umbrella-tree	*Magnolia tripetala*
Virginia pine	*Pinus virginiana*
white oak	*Quercus alba*
winged elm	*Ulmus alata*
yellow buckeye	*Aesculus flava*
Woody Vines	
grape	*Vitis* spp.
Japanese honeysuckle	*Lonicera japonica*
muscadine	*Vitis rotundifolia*
oriental bittersweet	*Celastrus orbiculatus*
poison ivy	*Toxicodendron radicans*
trumpet creeper	*Campsis radicans*
Virginia creeper	*Parthenocissus quinquefolia*

APPENDIX 4: HOME RANGES AND MORPHOMETRICS

Table 4.1. Minimum convex polygon (MCP), kernel density estimates (KDE), average daily movement, and morphometrics of eastern box turtles used in step-selection analysis, Tennessee, USA, 2016–18.

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
1	Kyker	female	5.4	0.5	3.1	9.5	132	458
2	Kyker	female	4.7	0.4	2.6	5.6	119	350
3	Kyker	male	1.1	0.2	1.1	6.2	118	257
4	Kyker	male	5.0	0.5	2.4	6.9	129	458
5	Kyker	female	2.7	0.1	1.0	7.4	131	512
6	Kyker	female	38.5	1.2	13.6	16.2	116	363
7	Kyker	male	1.0	0.3	1.2	9.4	130	413
8	Tanasi	male	1.9	0.4	1.9	8.3	128	407
9	Tanasi	female	5.8	0.2	1.2	7.4	129	483
10	Tanasi	female	2.3	0.2	0.9	4.6	133	457
11	Tanasi	female	5.9	0.3	2.1	11.5	122	358
12	Tanasi	male	6.2	0.6	2.6	8.6	135	357

Table 4.1. Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
13	Tanasi	female	4.2	0.9	4.6	10.1	116	370
14	Tanasi	female	15.5	1.4	8.9	18.8	123	440
15	Tanasi	female	9.1	1.0	6.0	19.8	128	433
16	Tanasi	male	4.6	0.4	2.5	8.6	118	400
17	Tanasi	female	7.1	0.7	4.8	11.0	136	515
18	Tanasi	female	2.2	0.6	2.6	10.3	121	342
19	Tanasi	female	2.5	0.4	2.0	8.9	118	378
20	Tanasi	male	1.0	0.2	1.2	10.1	130	348
21	Tanasi	female	3.5	0.3	1.7	10.7	126	408
22	Tanasi	male	0.9	0.3	1.0	7.3	136	468
23	Tanasi	female	0.5	0.2	0.7	5.4	121	358
24	Tanasi	female	1.9	0.2	1.1	7.9	122	442
25	Kyker	female	1.2	0.2	1.1	8.3	116	325

Table 4.1. Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
26	Kyker	female	3.5	0.7	3.7	9.1	110	332
27	Kyker	male	4.3	1.1	4.9	9.0	124	358
28	Kyker	male	0.9	0.2	1.0	5.6	113	285
29	Kyker	female	2.9	1.5	5.5	7.8	117	350
30	Kyker	male	2.0	0.2	1.2	8.1	109	283
31	Kyker	female	2.8	0.5	2.5	8.5	124	427
32	Catoosa	female	1.1	0.3	1.0	8.3	128	408
33	Catoosa	male	8.7	1.5	6.4	10.9	119	322
34	Catoosa	male	6.1	1.9	8.2	8.3	124	390
35	Catoosa	male	2.9	0.5	3.1	13.2	128	383
36	Catoosa	male	3.4	1.2	4.6	13.6	132	402
37	Tanasi	female	2.8	0.3	2.0	10.9	131	468

Table 4.1 Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
38	Tanasi	male	1.4	0.3	1.5	13.1	138	442
39	Tanasi	male	1.1	0.2	1.0	8.3	132	358
40	Tanasi	male	1.5	0.3	1.7	10.4	130	448
41	Tanasi	male	2.6	0.6	2.5	9.5	135	382
42	Tanasi	male	3.2	0.3	2.6	9.6	123	418
43	Kyker	male	2.0	0.3	1.9	4.9	124	362
44	Kyker	male	9.7	0.8	3.8	16.0	134	490
45	Kyker	female	5.8	1.8	7.4	10.9	120	320
46	Kyker	female	1.9	0.3	1.8	8.8	119	400
47	Kyker	female	5.0	0.6	3.8	12.1	111	358
48	Tanasi	female	1.7	0.3	1.2	6.2	120	420
49	Tanasi	female	5.4	0.3	2.4	14.8	120	393
50	Kyker	male	1.3	0.2	1.4	5.0	126	332

Table 4.1. Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
51	Catoosa	male	0.9	0.2	1.0	5.2	124	400
52	Catoosa	male	4.6	1.9	6.6	19.2	138	500
53	Catoosa	male	282.2	54.1	270.8	22.6	124	388
54	Catoosa	male	52.3	2.9	22.5	18.4	126	478
55	Catoosa	male	46.3	7.2	34.0	14.6	124	383
56	Tanasi	male	1.4	0.3	1.5	5.2	117	290
57	Tanasi	female	14.6	2.2	11.6	14.4	136	445
58	Tanasi	female	3.7	1.4	5.5	14.2	127	495
59	Catoosa	male	1.0	0.2	1.0	6.1	144	495
60	Tanasi	female	2.3	0.2	1.3	9.5	121	398
61	Tanasi	male	4.8	0.3	3.1	10.4	123	405
62	Kyker	male	0.4	0.1	0.6	7.2	105	360
63	Kyker	male	7.9	1.5	7.5	9.0	120	353

Table 4.1. Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
64	Catoosa	male	2.2	0.3	2.2	11.2	132	408
65	Tanasi	male	4.5	0.9	5.0	12.0	129	422
66	Kyker	male	2.0	0.4	1.7	11.5	124	373
67	Kyker	female	3.5	0.5	3.6	8.9	131	450
68	Tanasi	female	7.0	1.0	6.8	10.4	126	417
69	Catoosa	male	6.6	1.6	6.9	12.8	118	393
70	Catoosa	female	2.7	0.5	2.8	8.6	124	342
71	Catoosa	male	1.6	0.3	1.8	11.4	131	505
72	Tanasi	male	10.1	1.3	9.2	16.4	122	325
73	Catoosa	female	5.8	0.5	3.6	11.9	124	458
74	Kyker	male	7.8	0.4	3.3	20.5	120	352
75	Kyker	male	1.2	0.3	1.5	8.4	121	328
76	Kyker	male	4.3	0.8	3.9	5.8	120	352

Table 4.1. Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
77	Kyker	female	1.4	0.5	1.9	7.6	136	483
78	Kyker	female	1.6	0.3	1.7	6.4	114	330
79	Catoosa	female	67.7	9.3	69.3	25.8	131	538
80	Kyker	female	8.8	1.3	7.7	12.9	120	430
81	Catoosa	female	4.8	0.7	4.8	9.7	128	387
82	Catoosa	female	8.2	1.6	9.0	15.1	130	495
83	Catoosa	female	1.2	0.4	1.6	7.2	126	388
84	Kyker	male	2.0	0.2	2.0	7.2	118	367
85	Kyker	female	3.4	1.4	5.4	11.2	119	402
86	Kyker	male	1.5	0.4	1.7	7.4	128	372
87	Catoosa	male	1.1	0.1	1.0	8.6	116	318
88	Catoosa	female	7.4	0.8	5.5	10.2	126	503
89	Catoosa	male	67.8	13.6	81.9	20.9	130	398

Table 4.1. Continued

Turtle ID	Site	Gender	MCP (ha)	50% KDE (ha)	95% KDE (ha)	Average daily movement (m/day)	Carapace length (mm)	Mass (g)
90	Catoosa	female	8.6	0.9	6.1	21.7	136	530
91	Catoosa	male	1.3	0.4	2.0	7.7	121	345
92	Catoosa	female	21.0	4.5	29.3	21.3	128	495
93	Catoosa	female	2.0	0.4	1.8	9.4	124	483
94	Catoosa	male	2.8	0.7	3.2	13.4	131	420
95	Catoosa	female	4.4	0.8	3.7	18.7	126	420
96	Kyker	male	4.1	1.1	5.0	9.1	126	415
97	Catoosa	male	5.7	1.5	7.5	18.8	124	380
98	Catoosa	female	0.6	0.1	0.7	6.9	123	340
99	Catoosa	male	1.8	0.3	2.2	7.3	127	373
100	Tanasi	male	1.8	0.3	1.9	7.7	130	452

CONCLUSION

Fire is required to restore and maintain fire-dependent ecosystems and to maintain and improve habitat quality for many wildlife species. However, nontarget species often experience direct and indirect effects of prescribed fire events. Box turtles commonly occur in areas that are managed with prescribed fire but seldom are a management priority. Recent population stressors coupled with life-history traits have increased conservation concerns of box turtles. Although prescribed fire may be necessary to meet certain management goals, fire regimes can be altered to reduce negative impacts on box turtles when box turtles are of concern but not top priority. Our results indicate mortalities are possible during fire events and that fire seasonality can influence mortality.

Our data suggest dormant-season prescribed fire poses little or no threat to box turtle survival. However, fire during the growing season, and especially during the early portion of the growing season (late Mar–May), increases mortality potential. Our data indicate box turtles can avoid direct contact of fire by moving to refuge. However, lethargy following emergence reduce opportunities for individuals to retreat to refuge during early growing-season burns. Early growing-season burns pose the greatest risk of mortality and should be avoided where box turtles are of concern. Managers should use low-intensity fire and avoid ring fires to reduce mortality if burning occurs during the late growing season. High-intensity fires and ring fires reduce opportunities for box turtles to retreat to refuge. Our study did not assess fire effects on recruitment or juvenile survival, which are crucial components to understand population-level effects. However, prescribed fire can increase the availability of nesting sites and potentially offset adult mortality if fire-mediated effects increase reproductive output and recruitment.

Nevertheless, further study on population-level effects of prescribed fire on box turtles is warranted.

Our discrete-choice analysis revealed total vegetation cover was the most significant resource-selection variable, followed by bramble cover, and visual obstruction at the 0–0.25-m level, respectively. Areas with increased bramble cover and visual obstruction provide important cover resources that offer thermoregulatory opportunities and foraging opportunities for box turtles. Prescribed fire coupled with canopy removal is an effective method to increase total vegetation cover, visual obstruction, and bramble cover. It should be recognized that low-intensity prescribed fire may elicit little change on understory vegetation composition under closed-canopy conditions. Intense fire or other forest management techniques may be precursory to allow ≥20% light penetration to encourage an understory response. Management efforts for box turtles should concentrate on increasing groundcover within vegetation types, opposed to managing for a single vegetation type on the macrohabitat scale.

Low-intensity dormant-season fire on a 3–8-yr fire-return interval should increase important structural and composition components for box turtles, assuming canopy closure is ≤80%. However, fire-return intervals should be site specific and adjusted to reflect and meet desired vegetation response. Fire-return intervals should be mediated to allow leaf litter and downed woody debris to accumulate while also retaining vegetation cover ≥35% with a bramble component of ≥22% and visual obstruction at the 0–0.25-m level ≥31%. Low-intensity fire also will retain coarse woody debris, which was an important predictor of resource selection and aided survival during prescribed fires. Infrequent fire also allows leaf litter to accumulate to favor resource selection. Odds of selection increased with increased litter depths; however, probability of selection reached 100% and remained constant when litter depths were ≥4 cm.

Similarly, box turtles that survived prescribed fires were in shallower litter depths than box turtles that experienced mortality during prescribed fires. It should be realized that though litter depth was an important indicator of resource selection, total vegetation cover, bramble cover, and visual obstruction were more important predictors of resource selection. Increased litter depths are less important if vegetation cover is ≥35% and visual obstruction at the 0–0.25-m level is ≥31%. Increased litter depths become important if vegetation cover is limited.

Our results can be used to minimize negative effects of prescribed fire and aid in conservation efforts of box turtles. The information presented in these chapters should serve as a foundation to build upon previously scant data regarding habitat use and response to prescribed fires. Resource selection data in conjunction with survival models should offer insight towards management practices that can reduce fire-related mortality of box turtles while also increasing habitat quality. Additional research should be conducted to determine long-term population models and habitat use that we were unable to document within a 2-yr study period.

VITA

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