Prescribed fire affects female white-tailed deer habitat use during summer lactation

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ABSTRACT

Prescribed fire commonly is used to manage habitat for white-tailed deer (Odocoileus virginianus). Although the effects of fire on forage availability for deer have been studied, how female deer use burned areas is not well known, particularly as it relates to fire season and the years-since-fire. We used GPS tracking data from 16 adult female white-tailed deer to assess the effects of fire season and years-since-fire on habitat use during summer lactation. Females selected unburned drainages and older (>1 yr-since-fire) burned areas, and avoided recently burned areas. Individuals with a greater percentage of their summer core area burned expanded the size of their summer home range but did not change summer core area size. Furthermore, summer core area site fidelity (i.e., % overlap between 2011 and 2012 core areas) decreased as the percentage of the 2011 summer core area burned in 2012 increased. Female deer increased selection of burned areas as years-since-fire increased, likely because there was a temporary loss of cover immediately following fire with plants slowly regenerating the subsequent growing seasons. Likewise, to avoid areas depleted of cover, females shifted their core areas away from recent burns when possible but increased their core area size when burned areas were unavoidable (i.e., a large portion of their home range was burned). Burning large contiguous areas may initially have a negative effect on female deer during lactation because of the depletion of cover.

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1. Introduction

Prescribed fire commonly is used in the longleaf pine (*Pinus palustris*) ecosystem (LLPE) for restoration and maintenance of plant communities and fire-dependent fauna (Aschenbach et al., 2010; Beckage et al., 2005; Fill et al., 2012; Van Lear et al., 2005). Fire-related research often has focused on the appropriate season, application techniques, and frequency of fire (Aschenbach et al., 2010; Beckage et al., 2005; Fill et al., 2012; Lashley et al., 2014a; Stambaugh et al., 2011; Van Lear et al., 2005). However, few studies have reported adaptations of fauna following fire and little is known about the effects of fire season and frequency on some fauna.

Growing-season fire (i.e., May and June) in the LLPE overlaps the lactation period of white-tailed deer (*Odocoileus virginianus*;

hereafter deer). Thus, reproductive females may be sensitive to growing-season fires because the lactation period is the most nutritionally stressful period for white-tailed deer (Hewitt, 2011). Additionally, female deer may be negatively affected by growing-season fires during lactation if available cover declines (McCord et al., 2014), because lactating females require dense cover for protection from predators (Kie and Bowyer, 1999; Naugle et al., 1997). Alternatively, female deer may be positively affected by growing-season fire because young, regenerating plant growth stimulated by fire is more palatable and higher in nutrients than older plant tissue (Jones and Case, 1990; Leigh et al., 1991; Lewis et al., 1982; Wood, 1988). Furthermore, fire can increase forage availability for several growing seasons after the fire (Edwards et al., 2004; Lashley et al., 2011; Masters et al., 1993, 1996).

Few studies have directly evaluated the effects of prescribed fire on deer habitat use. Ivey and Causey (1984) reported deer avoided recently burned areas in the same year as the fire in favor of unburned drainages, unless fire spread through the area in a mosaic configuration and retained some cover. However, they

had a small sample size (2 individuals). Meek et al. (2008) reported no selection for burned areas in Texas, but concluded drought conditions during their study hindered regeneration of high-quality forbs, and thus negated the expected benefit of the burn to deer. Hence, because of small sample sizes and confounding weather conditions, little information exists on how deer respond to fire. Moreover, to our knowledge, no information exists on the influence of season of fire and years-since-fire on deer selection of burned areas, which is important because season and timing can be manipulated within a prescribed fire management plan.

Given the importance of fire in many ecosystems (Bowman et al., 2009) and the ecological and economic importance of white-tailed deer (Waller and Alverson, 1997), we measured the movement of female deer following fire in the LLPE. We hypothesized that female deer would select more recently burned areas to take advantage of the high-quality forages expected to regenerate following fire. To test this hypothesis, we evaluated the effects of fire season and years-since-fire on burned area selection, space use (i.e., 95% home range and 50% core area sizes), and core area site fidelity (i.e., area of overlap in core area between years). Furthermore, we evaluated the effects of percent summer home range and core area burned on the amount of space used by female deer and site fidelity of core areas across years.

2. Materials and methods

2.1. Study area

We conducted our study at Fort Bragg Military Installation, a 73,469-ha property owned by the U.S. Department of Defense and located in the Sandhills physiographic region in the LLPE of central North Carolina. Uplands were dominated by longleaf pine forests and managed with growing-season prescribed fire on a 3-yr fire-return interval (Lashley et al., 2014a). Some areas are missed during the targeted burn year and burned in the following dormant season (December–March). Treating missed areas in this manner results in a small area of the study site (i.e., ~15% during the study period) burned greater than 3 years prior and burned during the dormant season. Densely vegetated (primarily *Lyonia* spp. and *Ilex* spp.) drainages were interspersed throughout the landscape and infrequently burned because of moisture. Deer population density was low (3–5 deer/km^2), and harvest records corrected for hunter effort indicated the deer population declined from 1989 to present (Lashley et al., 2015), commensurate with the initiation of the current growing-season dominated fire regime at Fort Bragg (Cantrell et al., 1995).

2.2. Deer capture

We captured 16 female deer $\geqslant$1.5-year-old using tranquilizer guns, January–May, 2011. We used Telazol (5 mg/kg; Midwest Veterinary Supply, Burnsville, MN), xylazine hydrochloride (2.5 mg/kg; Congaree Veterinary Pharmacy, Cayce, SC), and ketamine hydrochloride (5 mg/kg; Midwest Veterinary Supply, Burnsville, MN) in 2-cc transmitter darts. We fit 200-g tracking collars (Wildcell, Lotek Wireless Inc., Newmarket, Ontario, Canada) and ear tags on each individual. At 80-min post-injection, we reversed the xylazine hydrochloride with tolazoline hydrochloride (10 mg/kg; Midwest Veterinary Supply, Burnsville, MN) and visually monitored the deer from a distance until full recovery. The tracking collars transmitted global positioning system relocations to a remote site via the short messaging service network. All data were uploaded to Movebank (www.movebank.org) (Wikelski and Kays, 2014). In Movebank, we censored data that were obvious collar error (e.g., positions outside the continental United States) as

well as data from first 2 weeks of deployment (~3% of locations) because of potential capture bias to movements (Quinn et al., 2012). Deer capture and handling protocols were approved by the North Carolina Wildlife Resources Commission and the North Carolina State University Institutional Animal Care and Use Committee (10-143-O).

2.3. Fire data

We categorized all portions of the study area based on fire history using a Geographic Information System and data provided by Fort Bragg. We designated 10 categories based on the last fire occurrence: (1) same year as a growing-season fire (April–June; 0yrG); (2) same year as a dormant-season fire (December–March; 0yrD); (3) 1 year post growing-season fire (hereafter 1yrG); (4) 1 year post dormant-season fire (1yrD); (5) 2 years post growing-season fire (2yrG); (6) 2 years post dormant-season fire (2yrD); (7) 3 years post growing-season fire (3yrG); (8) 3 years post dormant-season fire (3yrD); (9) 4 or more years post growing-season fire (4yrG); and (10) the drainages that were rarely or never burned and generally contained relatively dense cover (Fig. 1). We distinguished each season and year-since-fire as its own category because managers set fire prescriptions on a yearly and seasonal scale. Fort Bragg has an extensive manmade firebreak network, which parcels burned areas into individual units about 43 ha in size (Lashley et al., 2014a).

2.4. Summer home range and core area calculation

We used the adehabitat package (Calenge, 2006) of R statistical software version 3.0.1 (R Foundation for Statistical Computing, Vienna, Austria) to calculate a summer 95% home range (hereafter home range) and summer 50% core area (hereafter core area) using the classical kernel method for each individual for each 3-month summer season (Worton, 1989). We imported each home range and core area into ArcMAP 10.0 (ESRI, Redlands, California) and overlaid each with the 10 delineated burn categories. We used the Geographical Information System to calculate the area of the 2011 and 2012 home ranges and core areas, the percentage of core areas overlapping between years (i.e., site fidelity), the change in size of home ranges and core areas from 2011 to 2012, the percentage of the 2011 home ranges and core areas that were burned in 2012, and the percentage of each burn classification (i.e., 0yrG–4yrG and 0yrD–3yrD) in the home range by individual each year (Fig. 1). Also, we calculated the percentage of relocations occurring in each burn classification each year.

2.5. Data analysis

To determine selection of burn category by female deer, we calculated use (percentage of relocations in each burn category) versus availability (percentage of the 95% home range in each burn category) and performed a compositional analysis in the R statistical software (Aebischer and Robertson, 1992; Aebischer et al., 1993). We assumed the diel period did not influence deer selection of burned areas (Meek et al., 2008) or general use of some areas for cover or foraging (Coulombe et al., 2011) and did not stratify relocations by time of day. Additionally, we wanted to determine how individuals responded to newly burned areas in their core area and home ranges. Therefore, we fit standard least squares regression models to determine if newly burned areas affected site fidelity of core areas and change in size of the home range and core area from 2011 to 2012, using the percentage of the 2011 home range and core area burned in 2012, and the percentage of the 2012 home range and core area burned in 2012 as predictor variables. Also, we fit standard least squares regression models to determine
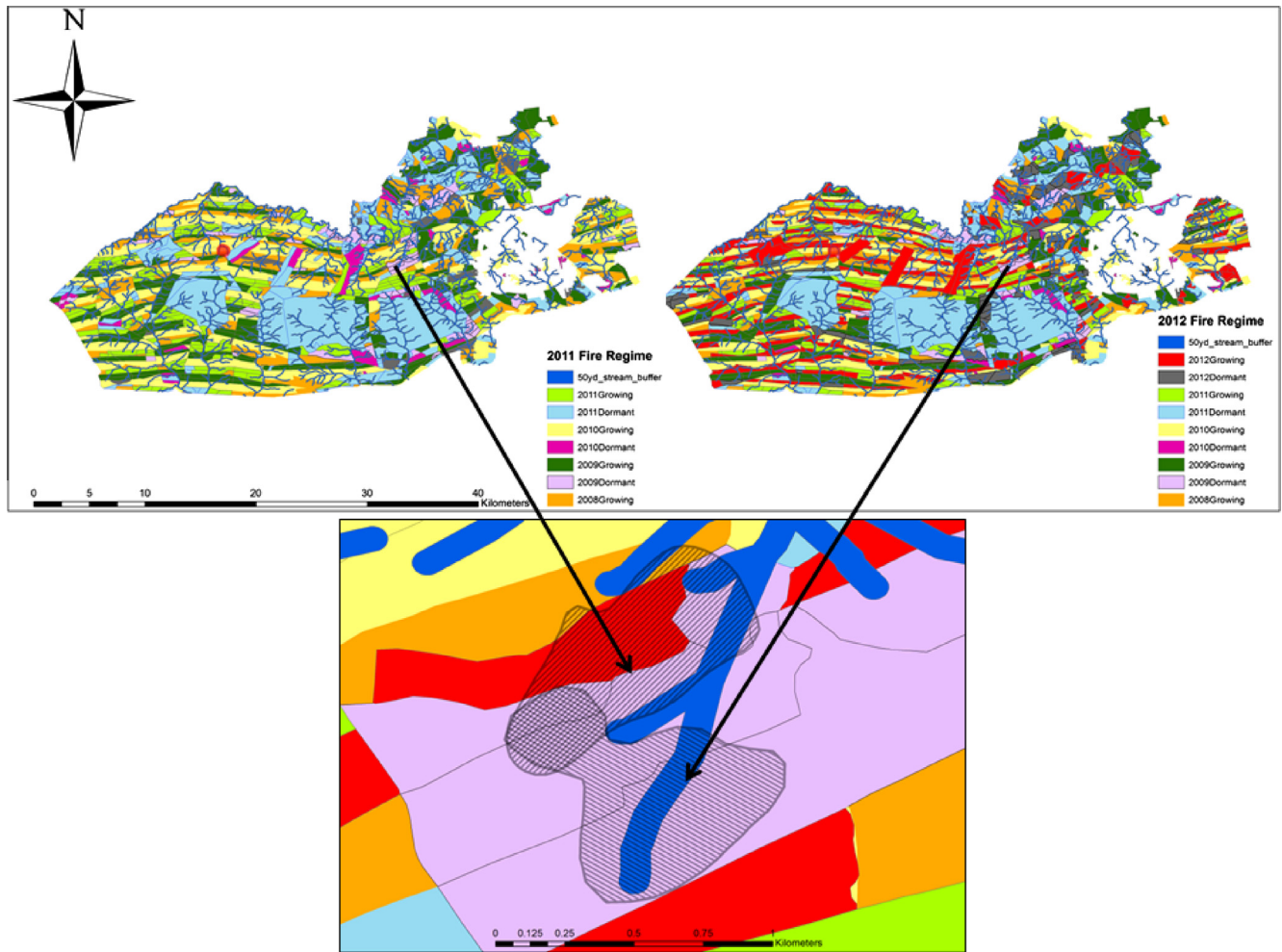
Fig. 1. Years-since-fire during summer 2011 (top left) and 2012 (top right) and an example of a female white-tailed deer core area in 2011 (cross hatch left) and 2012 (cross hatch right). Site fidelity was defined as the area where the 2011 and 2012 core areas overlap. Notice that the female moved her core area in 2011 to avoid the recently burned areas (red) in 2012. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

if the amount of burned area could explain the variation in core area and home range sizes across individuals, using the percentage of the respective year's core area and home range burned.

3. Results

3.1. Burned area selection

Female deer showed strong positive selectivity for burned areas that had at least 1-year-since-fire (Lambda = 0.41, $P < 0.01$, DF = 9; Table 1). Also, drainages were selected more than all of the growing-season fire categories, but were selected similarly to the dormant-season categories $\geqslant$1-year-since-fire (Table 1).

3.2. Fire effects on space use

The average summer core area and home range sizes across years were 43.5 ± 10 and 204 ± 54 ha, respectively. On average, females displayed $64 \pm 6\%$ core area site fidelity. Individuals increased their home range size when a greater proportion of their core area was burned (Table 2). Also, individuals decreased core area site fidelity as a greater proportion of their 2011 core area was burned in 2012. The proportion of home range burned had a positive relationship with the core area size (Table 2).

4. Discussion

Because cover is sparse in the same year as fire (e.g., 0yrD and 0yrG, McCord et al., 2014), female white-tailed deer likely avoided newly burned areas because of the lack of cover, despite the nutritious new plant growth expected to be present (Leigh et al., 1991; Lewis et al., 1982; Wood, 1988). Our result is counter to the prevailing hypothesis that deer benefit immediately from fresh plant parts after fires, but is consistent with several other studies reporting deer avoided areas when cover was removed (Ivey and Causey, 1984; Vercauteren and Hygnstrom, 1998; Meek et al., 2008; Walter et al., 2009). Female deer may have avoided areas with little cover because of the apparently high risk of coyote (*Canis latrans*) predation on adult females and neonates during the lactation period at Fort Bragg (Chitwood et al., 2014, 2015a, 2015b). Ungulates often avoid areas with poor understory structure (i.e., 0yrD and 0yrG in our study) when predation risk is driven by canids and humans (Root et al., 1988; Thaker et al., 2011). During lactation, when females are more vigilant (Lashley et al., 2014b) and require more high-quality forage (Hewitt, 2011), the application of fire may negatively affect females through the depletion of cover in large portions of their home range despite the potential nutritional benefits of regenerating forages. Because we did not measure the nutritional quality of plants following prescribed fires, we suggest

Table 1
Pair-wise comparison of summer burned area selection of GPS-tagged female white-tailed deer in longleaf pine ecosystem in relation to the years since the most recent fire and season of fire on Fort Bragg Military Installation, North Carolina, 2011 and 2012. A + indicates that the burned area in the row was relatively selected over the burned area in the column, while a − indicates that the burned area in the row was relatively selected less than the burned area in the column (a single sign indicates the relationship is non-significant and triple sign indicates the relationship is significant at alpha = 0.05).

Burn category[a]	0yrD[b]	0yrG[b]	1yrD	1yrG	2yrD	2yrG	3yrD	3yrG	4yrG	Drainage
0 yr Dormant	0	+	–	– – –	–	– – –	– – –	–	– – –	– – –
0 yr Growing	–	0	– – –	– – –	–	– – –	– – –	– – –	– – –	– – –
1 yr Dormant	+	+++	0	+	+	+	–	+	+	–
1 yr Growing	+++	+++	–	0	–	–	– – –	–	–	– – –
2 yr Dormant	+	+	–	+	0	–	–	+	–	–
2 yr Growing	+++	+++	–	+	+	0	–	+	+	– – –
3 yr Dormant	+++	+++	+	+++	+	+	0	+	+	–
3 yr Growing	+	+++	–	+	–	–	–	0	–	– – –
4 yr+ Growing	+++	+++	–	+	+	–	–	+	0	– – –
Drainage	+++	+++	+	+++	+	+++	+	+++	+++	0

[a] Lambda = 0.41, $P < 0.001$, DF = 9.
[b] D = dormant-season fire and G = growing-season fire.

Table 2
The effects of percent of summer home range (HR) and core areas (CA) burned on the change in size, site fidelity, and total area used by female white-tailed deer at Fort Bragg Military Installation, North Carolina, USA, 2011 and 2012. An asterisk indicates significance at alpha = 0.05.

Response	Term	Estimate	SE	T-ratio	P-value
Change in size of 50% core area	%2011CAburned2012	0.1	0.9	0.1	0.91
	%overlapburned2012	−0.7	1.2	−0.6	0.58
	%11HRBurned2012	−0.4	1.1	−0.4	0.70
Site fidelity of core area	%2011CAburned2012	−0.9	0.4	−2.4	0.04*
	%overlapburned2012	0.5	0.5	1.0	0.36
	%11HRBurned2012	−0.6	0.4	−1.3	0.22
Change in size of 95% home range	%2011CAburned2012	0.7	0.7	1.0	0.32
	%2012CAburned2012	2.1	0.9	2.5	0.03*
	%overlapburned2012	−1.7	0.9	−1.9	0.08
	%11HRBurned2012	0.0	0.8	−0.1	0.96
50% core area Size	%CABurn	0.1	0.6	0.2	0.83
	%HRBurn	1.8	0.8	2.3	0.03*
95% home range size	%CABurn	3.7	3.3	1.1	0.27
	%HRBurn	6.9	4.4	1.6	0.13

future research evaluate the nutritional value of forage as a function of years-since-fire.

In response to increased percentage of their core area burned, individuals increased home range sizes likely to find appropriate cover. Similarly, previous studies reported ungulates had larger home ranges when resource availability (in our case cover) was low (Relyea et al., 2000; Tufto et al., 1996). Thus, our study indicates changes in space use were consistent with the expected response in terms of cover availability. Moreover, other studies have documented ungulates increased movement rates and space use, and used larger core areas to avoid increased predation risk (Kilpatrick and Lima, 1999; Naugle et al., 1997; Root et al., 1988; Vercauteren and Hygnstrom, 1998; Williams et al., 2008), particularly in response to non-ambush style predators such as coyotes (Thaker et al., 2011).

Individuals decreased core area site fidelity as the percent of their 2011 core area was burned in 2012, indicating deer were moving their core areas year to year to avoid recently burned areas. When deer could not avoid burned areas because a large portion of their home range was burned, they increased the size of their core area likely to compensate for depleted cover in burned areas. Our results contradict Campbell et al. (2004) who noted site fidelity of female white-tailed deer was not influenced by disturbance,

though they studied timber harvest, not fire. However, they reported female deer were found outside their pre-harvest ranges more routinely than in non-harvested areas, which is similar to the increases in core area sizes we observed.

Traditionally, it was believed that fire benefits deer immediately because of increased forage quality in the same year as fire (Wood, 1988). However, our study supports previous evidence that female white-tailed deer avoid areas burned in the same year (Ivey and Causey, 1984; Meek et al., 2008), which likely is reflective of the increase in available cover each year for 5–10 years following fire as plants regenerate in the understory. In the long term, deer benefit from burning because it resets understory succession, increasing cover in the understory for several years after the year of fire (McCord et al., 2014). Without fire, plants providing cover would succeed into the midstory, resulting in an overall loss of cover in long-term fire-suppressed areas (Brockway et al., 1998; Moser and Yu, 2003). Thus, managers must consider a balance between the short-term reductions in cover following prescribed fire and the longer-term benefits of fire-maintained understory structure.

Deer density declined at Fort Bragg commensurate with the initiation of the growing-season fire regime (Cantrell et al., 1995) and the establishment of coyotes as a novel predator (Chitwood et al., 2015a, 2015b). Other studies in the southeastern U.S. have demonstrated deer density declines following the establishment of coyotes largely attributable to coyote predation on fawns (Chitwood et al., 2015a; Kilgo et al., 2010, 2012), and recruitment at Fort Bragg was the lowest reported in the region (Chitwood et al., 2015b). Hence, it is possible that the application of fire on Fort Bragg could indirectly contribute to the population-level effects of coyotes on deer. For example, the large-scale and frequent application of prescribed burning at Fort Bragg may restrict cover to the narrow linear strips of moist drainages, in turn predisposing females to bed fawns in this dense cover while simultaneously limiting the amount of cover for coyotes to search (Chitwood, 2014). This is a plausible explanation for the low fawn survival given females in our study selected drainages and fawns that used more cover at Fort Bragg were more likely to be depredated (Chitwood, 2014).

The relationships we documented between female white-tailed deer habitat use and prescribed fire may not apply to male deer or during other seasons of the year. Males are likely less dependent on cover than females during the summer (Kie and Bowyer, 1999; Naugle et al., 1997). Further, males were less fearful than females as indicated by their overall lower vigilance levels at Fort Bragg (Lashley et al., 2014b), and therefore, male deer may be more

willing to take advantage of the nutritious vegetation and more risky understory conditions (i.e., the predation hypothesis; Bowyer, 2004) associated with recent fire. During fall and winter, we suspect that females and males would avoid the more open understory conditions associated with recent burns because both sexes seek dense cover during hunting season (Root et al., 1988). Moreover, the primary food consumed by both sexes in fall and winter are acorns (Quercus spp.; Hewitt, 2011), which were not affected by fire season or years-since-fire at Fort Bragg (Lashley et al., 2014a).

5. Conclusions

Because deer avoid newly burned areas, efforts should be taken to minimize burning large contiguous areas. For example, at Fort Bragg the average burn block size (43 ha) is similar to the average core area of females during the lactation period, and additional adjacent areas often are burned in the same year (Lashley et al., 2014a). To minimize the depletion of cover during the lactation period, managers concerned with deer populations should avoid burning adjacent burn blocks during the same year and allow variability in fire-return interval to maintain denser cover in areas with longer years-since-fire.

Acknowledgements

References

Aebischer, N.J., Robertson, P.A., 1992. Practical aspects of compositional analysis as applied to pheasant habitat utilisation. In: Priede, G., Swift, S.M. (Eds.), Wildlife Telemetry, Remote Monitoring and Tracking of Animals. Ellis Horword, New York, USA, pp. 285–293.
Aebischer, N.J., Robertson, P.A., Kenward, R.E., 1993. Compositional analysis of habitat use from animal radiotracking data. Ecology 74, 1313–1325.
Aschenbach, T.A., Foster, B.L., Imm, D.W., 2010. The initial phase of a longleaf pine-wiregrass savanna restoration: species establishment and community responses. Restor. Ecol. 18, 762–771.
Beckage, B., Platt, W.J., Panko, B., 2005. A climate-based approach to the restoration of fire-dependent ecosystems. Restor. Ecol. 13, 429–431.
Bowman, D.M., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M.A., D'Antonio, C.M., DeFries, R.S., Doyle, J.C., Harrison, S.P., Johnston, F.H., Keeley, J.E., Krawchuk, M.A., Kull, C.A., Marston, J.B., Moritz, M.A., Prentice, I.C., Roos, C.I., Scott, A.C., Swetnam, T.W., van der Werf, G.R., Pyne, S.J., 2009. Fire in the earth system. Science 324, 481–484.
Bowyer, R.T., 2004. Sexual segregation in ruminants: definitions, hypotheses and implications for conservation and management. J. Mammal. 85, 1039–1052.
Brockway, D.G., Outcalt, K.W., Wilkins, R.N., 1998. Restoring longleaf pine wiregrass ecosystems: plant cover, diversity and biomass following low-rate hexazinone application on Florida sandhills. Forest Ecol. Manage. 103, 159–175.
Calenge, C., 2006. The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. Ecol. Model. 197, 516–519.
Campbell, T.A., Laseter, B.R., Ford, W.M., Miller, K.V., 2004. Movements of female white-tailed deer (Odocoileus virginianus) in relation to timber harvests in the central Appalachians. Forest Ecol. Manage. 199, 371–378.
Cantrell, M.A., Brithcher, J.J., Hoffman, E.L., 1995. Red-cockaded woodpecker management initiatives at Fort Bragg Military Installation. In: Kulhavy, D., Hooper, R., Costa, R. (Eds). Red-cockaded Woodpecker: Recovery, Ecology and Management. Center for Applied Studies in Forestry, College of Forestry, Stephen F. Austin State University, Nacodoches, TX.
Chitwood, M.C., 2014. White-tailed Deer in the Presence of a Novel Predator. Ph.D. Dissertation. North Carolina State University, Raleigh.
Chitwood, M.C., Lashley, M.A., Kilgo, J.C., Moorman, C.E., DePerno, C.S., 2015a. White-tailed deer population dynamics and adult female survival in the presence of a novel predator. J. Wildl. Manage. 79, 211–219.
Chitwood, M.C., Lashley, M.A., Kilgo, J.C., Pollock, K.H., Moorman, C.E., DePerno, C.S., 2015b. Do biological and bedsite characteristics influence survival of neonatal white-tailed deer? PLoS ONE. http://dx.doi.org/10.1371/journal.pone.0119070.

Chitwood, M.C., Lashley, M.A., Moorman, C.E., DePerno, C.S., 2014. Confirmation of coyote predation on adult female white-tailed deer in the Southeastern U.S. Southeast. Nat. 13, N30–N32.
Coulombe, M.L., Huot, J., Massé, A., Côté, S.D., 2011. Influence of forage biomass and cover on deer space use at a fine scale: a controlled-density experiment. Ecoscience 18, 262–272.
Edwards, S.L., Demarais, S., Watkins, B., Strickland, B.K., 2004. White-tailed deer forage production in managed and unmanaged pine stands and summer food plots in Mississippi. Wildl. Soc. Bull. 32, 739–745.
Fill, J.M., Welch, S.M., Waldron, J.L., Mousseau, T.A., 2012. The reproductive response of an endemic bunchgrass indicates historical timing of a keystone process. Ecosphere 3, 1–12.
Hewitt, D.G., 2011. Nutrition. In: Hewitt, D.G. (Ed.), Biology and Management of White-tailed Deer. CRC Press, Boca Raton, Florida, USA, pp. 75–106.
Ivey, T.L., Causey, M.K., 1984. Response of white-tailed deer to prescribed fire. Wildl. Soc. Bull. 12, 138–141.
Jones Jr., J.B., Case, V.W., 1990. Sampling, handling, and analyzing plant tissue samples. In: Westerman, R.L. (Ed.), Soil Testing and Plant Analysis, third ed., Soil Science Society of America Inc., Madison, Wisconsin, USA, pp. 389–427.
Kie, J.G., Bowyer, R.T., 1999. Sexual segregation in white-tailed deer: density-dependent changes in use of space, habitat selection, and dietary niche. J. Mammal. 80, 1004–1020.
Kilgo, J.C., Ray, H.S., Ruth, C., Miller, K.V., 2010. Can coyotes affect deer populations in Southeastern North America? J. Wildl. Manage. 74, 929–933.
Kilgo, J.C., Ray, H.S., Vukovich, M., Goode, M.J., Ruth, C., 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. J. Wildl. Manage. 76, 1420–1430.
Kilpatrick, H.J., Lima, K.K., 1999. Effects of archery hunting on movement and activity of female white-tailed deer in an urban landscape. Wildl. Soc. Bull. 27, 433–440.
Lashley, M.A., Chitwood, M.C., Harper, C.A., Moorman, C.E., DePerno, C.S., 2015. Poor soils and density-mediated body weight in deer: forage quality or quantity? Wildl. Biol. http://dx.doi.org/10.2981/wlb.00073.
Lashley, M.A., Chitwood, M.C., Prince, A., Elfelt, M.B., Kilburg, E.L., DePerno, C.S., Moorman, C.E., 2014a. Subtle effects of a managed fire regime: a case study in the longleaf pine ecosystem. Ecol. Indic. 38, 212–217.
Lashley, M.A., Chitwood, M.C., Biggerstaff, M.T., Morina, D.L., Moorman, C.E., DePerno, C.S., 2014b. White-tailed deer vigilance: the influence of social and environmental factors. PLoS ONE 9, e90652.
Lashley, M.A., Harper, C.A., Bates, G.E., Keyser, P.D., 2011. Forage availability for white-tailed deer following silvicultural treatments in hardwood forests. J. Wildl. Manage. 75, 1467–1476.
Leigh, J.H., Wood, D.H., Slee, A.V., Holgate, M.D., 1991. The effects of burning and simulated grazing on productivity, forage quality, mortality and flowering of eight subalpine herbs in Kosciusko National Park. Aust. J. Bot. 39, 97–118.
Lewis, C.E., Grelen, H.E., Probasco, G.E., 1982. Prescribed burning in southern forest and rangeland improves forage and its use. South. J. Appl. For. 6, 19–25.
Masters, R.E., Lochmiller, R.L., Engle, D.M., 1993. Effects of timber harvest and prescribed fire on white-tailed deer forage production. Wildl. Soc. Bull. 21, 401–411.
Masters, R.E., Wilson, C.W., Bukenhofer, G.A., Payton, M.E., 1996. Effects of pine-grassland restoration for red-cockaded woodpeckers on white-tailed deer forage production. Wildl. Soc. Bull., 77–84.
McCord, J.M., Harper, C.A., Greenberg, C.H., 2014. Brood cover and food resources for wild turkeys following silvicultural treatments in mature upland hardwoods. Wildl. Soc. Bull. http://dx.doi.org/10.1002/wsb.403.
Meek, M.G., Cooper, S.M., Owens, M.K., Cooper, R.M., Wappel, A.L., 2008. White-tailed deer distribution in response to patch burning on rangeland. J. Arid Environ. 72, 2026–2033.
Moser, W.K., Yu, C.K., 2003. Effects of overstory structure and fire regime upon diversity and abundance of selected understory species in longleaf pine (Pinus palustris Mill.) forests in southeastern Georgia. J. Forest Sci. 49, 395–402.
Naugle, D.E., Jenks, J.A., Kernohan, B.J., Johnson, R.R., 1997. Effects of hunting and loss of escape cover on movements and activity of female white-tailed deer, Odocoileus virginianus. Can. Field Nat. 114, 595–600.
Quinn, A.C.D., Williams, D.M., Porter, W.F., 2012. Postcapture movement rates can inform data-censoring protocols for GPS-collared animals. J. Mammal. 93, 456–463.
Relyea, R.A., Lawrence, R.K., Demarais, S., 2000. Home range of desert mule deer: testing the body-size and habitat-productivity hypotheses. J. Wildl. Manage., 146–153.
Root, B.G., Fritzell, E.K., Giessman, N.F., 1988. Effects of intensive hunting on white-tailed deer movement. Wildl. Soc. Bull. 16, 145–151.
Stambaugh, M.C., Guyette, R.P., Marschall, J.M., 2011. Longleaf pine (Pinus palustris Mill.) fire scars reveal new details of a frequent fire regime. J. Veg. Sci. 22, 1094–1104.
Thaker, M., Vanak, A.T., Owen, C.R., Ogden, M.B., Niemann, S.M., Slotow, R., 2011. Minimizing predation risk in a landscape of multiple predators: effects on the spatial distribution of African ungulates. Ecology 92, 398–407.
Tufto, J., Andersen, R., Linnell, J., 1996. Habitat use and ecological correlates of home range size in a small cervid: the roe deer. J. Anim. Ecol., 715–724.
Van Lear, D.H., Carroll, W.D., Kapeluck, P.R., Johnson, R., 2005. History and restoration of the longleaf pine-grassland ecosystem: implications for species at risk. Forest Ecol. Manage. 211, 150–165.
Vercauteren, K.C., Hygnstrom, S.E., 1998. Effects of agricultural activities and hunting on home ranges of female white-tailed deer. J. Wildl. Manage., 280–285.
Waller, D.M., Alverson, W.S., 1997. The white-tailed deer: a keystone herbivore. Wildl. Soc. Bull., 217–226.

Walter, W.D., VerCauteren, K.C., Campa III, H., Clark, W.R., Fischer, J.W., Hygnstrom, S.E., Winterstein, S.R., 2009. Regional assessment on influence of landscape configuration and connectivity on range size of white-tailed deer. Landscape Ecol. 24, 1405–1420.

Wikelski, M., Kays, R., 2014. Movebank: archive, analysis and sharing of animal movement data. World Wide Web electronic publication, <http://www.movebank.org>.

Williams, S.C., DeNicola, A.J., Ortega, I.M., 2008. Behavioral responses of white-tailed deer subjected to lethal management. Can. J. Zool. 86, 1358–1366.

Wood, G.W., 1988. Effects of prescribed fire on deer forage and nutrients. Wildl. Soc. Bull. 16, 180–186.

Worton, B.J., 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70, 164–168.