5-2013

Rutting behavior and factors influencing vehicle collisions of white-tailed deer in Middle Tennessee

Peyton Seth Basinger
pbasinge@utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Peyton Seth Basinger entitled "Rutting behavior and factors influencing vehicle collisions of white-tailed deer in Middle Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

Craig A. Harper, Major Professor

We have read this thesis and recommend its acceptance:

Lisa I. Muller, Joseph D. Clark, John B. Wilkerson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Rutting behavior and factors influencing vehicle collisions of white-tailed deer in Middle Tennessee

A Thesis Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Peyton Seth Basinger
May 2013

DEDICATION

I dedicate this work to my dad, Rufus Glenn Basinger, and the late Rufus George Basinger "Pop," who sacrificed to ensure a passion for the outdoors to future generations. The time spent and memories together were priceless. One of these days, I hope to be able to do the same.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God for the endless blessings bestowed upon me in my life. He gave me an opportunity to extend my education and to pursue my aspirations in life. My relationship with Him also allowed me to endure through the many nights spent afterhours at the office without losing my sanity.

I would like to thank the funding sources that made this project possible including the University of Tennessee, Department of Forestry, Wildlife and Fisheries, the US Department of Defense, Arnold Air Force Base (AAFB), Arnold Engineering Development Center (AEDC), and the US Fish and Wildlife Service. A special thanks to the AAFB and Tennessee Wildlife Resources Agency personnel, in particular, retired AAFB Natural Resource Manager Rick McWhite and AEDC WMA manager Wes Winton. Without your help and support, this project could not have been successful. Thanks also to Stephen Farrington who provided thorough GIS support.

Thanks to my advisor, Dr. Craig Harper, who gave me an opportunity to take on this project as well as showing me the “ropes-and-reins” of applied wildlife management. Little did I know what ALL I was getting into! The knowledge and experience I have gained under your direction is invaluable. Thanks for your expertise, motivation, and friendship. The Harper family showed me the utmost kindness imaginable in which I can’t express my gratitude enough.

Thanks to my committee, Dr. Lisa Muller, Dr. Joe Clark, and Dr. John Wilkerson, who provided gratuitous amounts of insight. It has been a pleasure to have your expertise and direction on this project. Your doors were always open to me and I can’t express how meaningful that is to a graduate student. Thanks for the friendship and kindness, and I hope I get more opportunities to work with you all again.

To my counterparts, Jared Beaver, Jessie Birckhead, Jarred Brooke, Matt Goode, Michael McCord, and Ashley Unger, that I worked closely with on various side projects, thanks for your assistance and fellowship along the way. To the technicians involved on this project, Cody Fulk, Austin Keene, Michael Nunnery, I am in debt to you for the time and determination you gave in field work. I couldn't ask for better assistance. Thanks also to the technicians I've had on other projects, Derek Brawner, Ronnie Cowan, and Justin Droke, who have provided hard work and friendship.

I'd also like to express my appreciation to others in the department including Mirian Wright, Jared Laufenberg, and Dr. Arnold Saxton for various contributions to this project. Also, to Billy Minser who gave me a lifelong imprint on the way I perceive wildlife management.

Finally, a special thanks to all of my family and friends that have supported and encouraged me along the way. To my parents, Glenn and Katy Basinger, thanks for the constant love and commitment towards me, in which I am forever grateful for. To my two brothers, Cole and Ryan Basinger, and their families, thanks for the companionship, support, and memories growing up. Ryan, I know you didn't always have to let me tag along on hunting and other outdoor adventures, but you did and because of that, I reckon I "owe you one" for directing me towards this profession. Thanks also to my friends "back home" who I have shared many great hunting and fishing experiences with. Last but not least, I want to thank the lovely Janie Colvin who endured a long-distance, 3-year relationship while showing me nothing but indescribable love, compassion, trust, and encouragement. A simple "thanks" does not hold a candle to what you deserve.

ABSTRACT

White-tailed deer (*Odocoileus virginianus*; deer) and human populations have expanded, and as a result, deer-vehicle collisions (DVCs) have become a primary concern. In particular, Arnold Air Force Base (AAFB) in Tullahoma, Tennessee, USA has had extensive problems with DVCs and has struggled to incorporate effective mitigation strategies. To address this issue, I initiated a study on AAFB to investigate deer behavior and factors increasing the likelihood of DVCs.

DVCs typically increase with peaks in deer activity during the breeding season (rut). I deployed GPS-ARGOS satellite collars on 10 adult males and 10 females during the summer of 2010. I investigated movement rates, excursions, home ranges, and interactions throughout the fall-winter seasons of 2010, which included the rut. I partitioned the rut into 3 periods (pre-, peak-, and post-rut) based on estimation from fetal measurements from 16 females collected during the spring of 2011. Males increased movement rates, used core areas less, and took excursions as the rut peaked. Females showed constant use of core areas with no deviations in movement rates, but took excursions outside of home ranges during the rut. I documented a female that excursed during the peak-rut to interact with a male. I believe this was associated with breeding and was influenced by a lack of male presence when the female entered estrus or a result of participation in mate selection.

I used 8 years (2002 – 2009) of documented DVC locations at AAFB on major roads outside the Security Area to investigate temporal and spatial patterns. I tallied DVCs by month of occurrence to gain a better understanding of high-risk periods. I also measured and modeled land cover and transportation variables for DVC and random locations to identify important factors affecting DVC spatial distributions. I found DVCs were greatest during fall-winter, which coincides with increased deer activity during the rut at AAFB. My model results suggested pine plantations, drainages, road intersections, and traffic volume were important determinants in DVCs. I believe the most pertinent mitigation strategy is to focus future implementation and management of pine plantations away from roads, especially in predominately hardwood forests.

PREFACE

This study was initiated to address concerns regarding white-tailed deer-vehicle collisions. Data presented here were obtained in cooperation with Arnold Air Force Base, The University of Tennessee, and Tennessee Wildlife Resources Agency.

My research focused on deer behavior during the breeding season in addition to evaluating factors affecting the spatial distribution of deer-vehicle collisions. I have broken these data into 2 chapters and followed format specified by the Journal of Wildlife Management. Chapters will be individually submitted to peer-reviewed journals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*; deer) are socially and economically important in the United States (Miller et al. 2003). However, increases in deer and human populations have led to interactions that are dangerous for both species, particularly concerning deer-vehicle collisions (DVCs). Each year in the United States, it is estimated that DVCs result in >$1 billion in property damage and personal injury, including >200 human fatalities (Hansen 1983, Conover et al. 1995, Biggs et al. 2004, Ng et al. 2008). DVCs have also been shown to result in deer fatality in >90% of collisions (Allen and McCullough 1976). Conflicts at the road interface between humans and deer will likely increase with the continuing expansion of urban areas nationwide (Ramp et al. 2005).

Studies have shown DVCs are temporally and spatially correlated, meaning they are aggregated in time and space (Finder et al. 1999, Ng et al. 2008). Peaks in deer activity help explain temporal DVC aggregations, which are typically amplified during the fall-winter breeding season (Allen and McCullough 1976, Finder et al. 1999). Studies on spatial aggregations of road-kills have primarily shown that in addition to population density, two major factors influence road-kill rates: (1) proximity of cover and wildlife movement corridors, and (2) traffic volume and speed (Forman et al. 2003).

Arnold Air Force Base (AAFB) has had a substantial DVC problem with >250 reported (2002 – 2009) on major roads outside of the Security Area. Information regarding deer behavior and factors enhancing DVCs is needed to accurately implement mitigation strategies. To address this concern, The University of Tennessee initiated a study to investigate deer activity during the breeding season in addition to land cover and transportation variables involved in spatial DVC aggregations.

I used these data to formulate 2 manuscript chapters. Chapter 1 evaluates deer behavior during the breeding season, which includes male and female excursions, movement rates, home ranges, and interactions. Chapter 2 investigates the influence of surrounding land cover and transportation variables, such as adjacent cover types, drainages, road intersections, traffic volumes, and speed limits, on the probability of DVC occurrences.

CHAPTER I. BREEDING MOVEMENTS, HOME RANGE, AND INTERACTIONS OF MALE AND FEMALE WHITE-TAILED DEER

ABSTRACT

To better understand white-tailed deer (*Odocoileus virginianus*; deer) reproductive biology, we looked at simultaneous movements and interactions of both males and females during the breeding season (rut). We evaluated excursions, interactions, movement rates, and core area use of 7 adult (≥2.5-yr-old) males and 9 females (1 1.5-yr-old and 8 ≥2.5-yr-olds) during the rut on Arnold Air Force Base in Tennessee, USA from September 2010 to March 2011 using GPS-ARGOS satellite collars with locations taken every 3 h. We partitioned the rut into 3 periods (pre-, peak-, and post-rut) using fetal measurements taken from 16 females collected 1 – 11 March 2011. We determined fall-winter (seasonal) 90% fixed kernel home ranges and 50% core areas. We defined an excursion as ≥2 consecutive locations outside the 90% home range extending beyond a mean distance traveled between 3-h locations for that individual during the fall-winter season. Males had the greatest movement rates and used core areas less during the peak-rut. Four of 7 males took 7 excursions during the rut. Females showed constant use of core areas through all rut periods with no change in movement rates. However, 6 females took 11 excursions during the rut. One collared female left her home range and interacted with a collared male at the periphery of his home range for ≥9 h during the peak-rut. We believe this excursion was associated with breeding. This excursion may have been due to lack of males in her area or a result of direct participation in mate selection.

KEY WORDS excursions, Global Positioning System (GPS), interactions, mate choice, movements, *Odocoileus virginianus*, rut, sexual selection, white-tailed deer

INTRODUCTION

Male and female deer segregate into groups except during the breeding season (rut). Males will typically become solitary during the rut, but interactions between genders increase (Hirth 1977, Nelson and Mech 1984, Ozoga and Verme 1985). Deer rely on chemical communication to convey information on identity, dominance status, physical condition, and reproductive status (Miller et al. 2003). Males use olfactory signposts, such as “rubbing” and “scraping”, during the rut which is believed to advertise these cues (Hirth 1977, Miller et al. 1987). Antler rubs on saplings serve as visual marks and chemical signposts from male forehead glands that likely convey territory and dominance (Atkeson and Marchinton 1982, de Vos 1967, Moore and Marchinton 1974). Antler rubbing typically starts with velvet removal from ossified antlers, peaks prior to rut, and gradually declines with the onset of increased scraping activity (Kile and Marchinton 1977, Nielson et al. 1982). Scrapes are pawed depressions to bare soil beneath overhanging tree branches that are marked with secretions from forehead glands, preorbital glands, or saliva (Alexy et al. 2001, Miller et. al 1987). Males will usually urinate or rub-urinate (urinating over tarsal glands while rubbing together) in association with scraping (Haugen 1959, Moore and Marchinton 1974). Scraping activity is typically greatest before or during the peak-rut (Alexy et al. 2001, Kile and Marchinton 1977). Females have been documented urinating in scrapes which was thought to advertise their location to males (Moore and Marchinton 1974). However, Alexy et al. (2001) used remote video monitoring and found females visited scrapes more frequently than males, but were less likely to deposit scent from branch-marking or urinating suggesting mate evaluation rather than presence advertisement.

Males typically increase movement rates and expand or shift home ranges during the rut (Kammermeyer and Marchinton 1976, Marchinton and Hirth 1984, Tierson et al. 1985). Recent

GPS-telemetry studies showed males made excursions outside of their home ranges (Karns et al. 2011) and can increase daily movements (Webb et al. 2010) during the rut, which may be indicative of searching for receptive females.

Two primary strategies for females have been proposed for ensuring timely breeding: “sit-and-wait” (Hölzenbein and Schwede 1989) and “active” (Labisky and Fritzen 1998). The sit-and-wait strategy is characterized by reduced movements by females and confinement within core areas of their home ranges during the rut, presumably to make locations more predictable for searching males (Hölzenbein and Schwede 1989, Ivey and Causey 1981).

Contrary to a sit-and-wait strategy, females have used active searching and taken excursive movements relative to estrus (Hölzenbein and Schwede 1989, Sawyer 1989). Ozoga and Verme (1975) documented increased pacing activity among females during estrus. Labisky and Fritzen (1998) observed increases in mobility for females in a low-density population with a female-biased adult sex ratio during the peak- and post-rut, implying females were adopting a search strategy to ensure successful breeding with few males. Even with an equal adult sex ratio, D’Angelo et al. (2004) reported females made exaggerated movements related to estrus in a low-density population. Kolodzinski et al. (2010) also found excursive movements of females during peak rut in a moderate-high population density with a nearly equal adult sex ratio. These females did not have to increase movements to find a mate, but may have been searching for preferred mates.

Excursive movements for both males and females could be associated with disturbances. Root et al. (1988) found increased female movements with high levels of human disturbance from hunting. Vercauteren and Hygnstrom (1998) documented that 53% of resident female deer were flushed from home ranges by hunters, but usually returned within the next morning.

Sweeney et al. (1971) concluded deer could easily be chased outside their normal home ranges when exposed to dog hunting but returned within 1 day. Hood and Inglis (1974) studied the effects of cattle roundup disturbances and found males may temporarily leave home ranges but females showed site fidelity and usually took circuitous flight paths within their home range. In contrast, Karns et al. (2008) determined that males did not venture outside of home ranges in response to hunter-related disturbances. Abundance of dense cover is likely the primary factor causing deer to remain in home ranges during disturbance (Sweeney et al. 1971, Vercauteren and Hygnstrom 1998).

We are not aware of any GPS-collar studies addressing behavior of both males and females simultaneously. Furthermore, most tracking studies have been conducted with conventional VHF-telemetry and an in-depth analysis of male and female behavior was not possible because of the limited number and accuracy of radio locations during the relatively short estrous period (Kolodzinski et al. 2010). Also, monitoring is often limited to daytime hours and favorable weather conditions (Rodgers et al. 1996). Therefore, our objectives were to evaluate behavior of males and females during the rut, characterize excursions, and evaluate the potential for mate selection through deer interactions. We predicted males would increase movement rates and use core areas less as rut peaked, as well as take excursions, to maximize breeding opportunities. We hypothesized females would conform to an active search strategy during the rut, in which we expected increased movement rates, lessened use of core areas, and excursive movements.

STUDY AREA

Arnold Air Force Base (AAFB) encompassed 15,815 ha located between Manchester, Tullahoma, and Winchester in Coffee and Franklin counties, Tennessee. Cultivated loblolly pine

(*Pinus taeda*) plantations and oak- (*Quercus* spp.) dominated hardwood forests covered 11,553 ha at AAFB. The mid- and understories were comprised mostly of dogwoods (*Cornus* spp.), maples (*Acer* spp.), sassafras (*Sassafras albidum*), sourwood (*Oxydendrum arboretum)*, blueberries (*Vaccinium* spp.), hickories (*Carya* spp.), and blackgum (*Nyssa sylvatica*). Grasslands and early-successional vegetation, primarily in utility rights-of-way, comprised 898 ha. The remaining land cover (1,895 ha) was buildings, structures, roads, wildlife food plots, and open, mowed areas surrounding these features (United States Department of Defense 2006).

AAFB was divided into 6 Wildlife Management Area (WMA) units and a 1,489-ha high-fenced Security Area. Although the 2.13-m tall fence surrounding the Security Area could influence deer movements, it did not exclude deer from crossing inside and out. Units were jointly managed by the Department of Defense and Tennessee Wildlife Resources Agency (TWRA) and open to public hunting. Deer hunting dates were weekend-oriented as either 2- or 3-day hunts. In 2010, there were 1 young sportsman, 4 archery, and 5 shotgun/muzzleloader hunts. Beaver (2011) reported deer densities of 6.7 deer/km^2 in unit 1 and 8.7 deer/km^2 in unit 2. Adult sex ratio was about 2 females to 1 male in the 2 units.

METHODS

Deer capture

All capture procedures were approved by The University of Tennessee Institutional Animal Care and Use Committee (UT-IACUC #1887) and followed American Society of Mammalogists guidelines (Sikes et al. 2011). We used pneumatic dart rifles (Dan-Inject, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA) with 2-ml telemetry darts (Pneu-dart, Inc., Williamsport, Pennsylvania, USA) to inject deer with chemical immobilization drugs. We used 2 drug combinations: medetomidine-ketamine-telazol (MKT; Muller et al. 2012) and xylazine-telazol (XT; Murray et al. 2000). The MKT consisted of 150 ug/kg medetomidine (40 mg/ml; ZooPharm, Fort Collins, Colorado, USA), 1.5 mg/kg ketamine (100 mg/ml Ketaset ®, Fort Dodge Animal Health, Ford Dodge, Iowa), and 1.0 mg/kg Telazol® (50 mg/ml tiletamine and 50 mg/ml zolazaepam; 100 mg/ml total of Telazol®; Ford Dodge Animal Health). The XT was comprised of 2.3 mg/kg xylazine (300 mg/ml; Zoo Pharm) and 5 mg/kg Telazol®. We assumed an average mass of 70.0 kg for males and 50.8 kg for females.

We targeted deer along roadsides throughout AAFB via spotlight as well as within WMA units 1 and 2 using tree stands and bait. We placed immobilized deer in a sternal position and monitored physiological parameters (heart rate, respiratory rate, oxygen saturation, and temperature) during handling (Muller et al. 2012). We weighed each deer and determined age according to tooth replacement and wear, and body characteristics when possible. Cattle and metal ear tags, and Lotek GPS-ARGOS satellite collars (GPS 7000SA Collars, ARGOS PTT, Lotek Wireless, Inc., New Market, Ontaria, Canada), were attached. Each collar weighed approximately 450 g. After handling, we injected each deer intramuscularly with antagonists for medetomidine consisting of atipamezole (0.35 mg/kg; 5.0 mg/ml Antisedan®, Pfizer Animal Health, Exton, Pennsylvania, USA) or with a combination of atipamezole (0.35 mg/kg) with Tolazoline (200 mg/ml; 4.0 mg/kg) mixture and monitored recovery.

GPS collars and data import

We programmed GPS-ARGOS collars to acquire locations every 3 h. All acquired GPS locations were stored on-board the collar and up to 90 ARGOS locations were stored in temporary memory and transmitted via ARGOS satellites every 7 days. Each collar had a unique VHF frequency (148 □ 150 MHz) that could be tracked using a receiver (Biotracker scanning receiver, Lotek Wireless, Inc.). Collars were also programmed to record and transmit a mortality signal to ARGOS satellites after remaining stationary for 4 h and could be tracked from the ground via increased pulse rates.

We used store-on-board GPS locations for collars that were recovered through hunter harvest. We downloaded these locations via a link unit and software (GPS Host, Lotek Engineering, Ontario, Canada). We used ARGOS locations for collars that were not retrieved from deer. ARGOS locations were emailed to us every 6-7 days and converted (ARGOS-GPS Data Processor Version 3.4, Lotek software) into a format compatible with ArcGIS® (Environmental Systems Research Institute (ESRI), Inc., Redlands, California, USA). We imported all locations into ArcGIS 9.2 (ESRI) and projected in Universal Transverse Mercator (UTM) North American Datum 1983 Zone 16 North (m). We removed any erroneous locations involving impossible dates, times, or coordinates from the analyses.

GPS collar testing

We placed GPS-ARGOS collars in the 4 major vegetation types of AAFB to test accuracy and performance. One collar was tested 1 – 11 March 2011 in an immature pine plantation. From 11 March to 1 April 2011, 3 collars were tested in an open field, mature pine, and mature hardwood setting.

We placed collars at approximately 1-m height aboveground, in an upright position to simulate the height and orientation of the collar on a deer. After testing, we used a Trimble Pathfinder® ProXT™ receiver (Trimble Navigation Limited, California, USA) with sub-meter accuracy and Bluetooth connection with ArcPad Version 8.0 (Environmental Systems Research Institute, Inc., Redlands, CA) to take multiple points for the locations in which collars were placed. We averaged these points to represent the true location of the collars.

We used ArcGIS 9.2 to determine accuracy of store-on-board GPS locations in each vegetation type by calculating Euclidean distances to the true location. We did not analyze accuracy of ARGOS locations because they were analogous to the store-on-board GPS locations but rounded up to conserve memory for temporary storage and transmission. We analyzed collar transmission success for store-on-board GPS and ARGOS locations separately to evaluate differences in performance relative to vegetation type. We also evaluated transmission success of collars deployed on deer by computing the number of locations that should have been acquired for each deer until the collar battery life failed or the deer was harvested. We compared these estimates to the number actually acquired.

Female conception

A special collection of female deer was conducted by the TRWA during March 2011 to estimate conception for females during the 2010 rut at AAFB. We determined female age (at time of conception) up to 6.5 yrs according to tooth replacement and wear, and body characteristics. We also measured the fetuses to determine the date of conception using a fetal scale (Hamilton et el. 1985). We used a 95% CI to determine peak-rut based on conception dates.

Rut excursions and core area use

We used Home Range Tools (Rodgers et al. 2007) in ArcGIS 9.2 to generate fall-winter (seasonal) 90% fixed kernel home ranges and 50% core areas for each deer. We used seasonal equinox dates from the United States Naval Observatory website (www.usno.navy.mil/USNO) to define fall-winter as 23 September 2010 – 19 March 2011. We defined an excursion as ≥2 consecutive locations outside the 90% home range extending beyond a mean distance traveled between 3-h locations for that individual during the fall-winter season (Fig. 1). We documented the number of excursions, time spent on excursions, maximum distance traveled outside of 90%

home ranges, and any interactions with other collared deer. We calculated the percentage of points within the 50% seasonal core areas using a minimum of 30 locations. We evaluated core area use during pre-, peak-, and post-rut, as well as “before” and “after” periods, which preceded and followed rut periods.

Movements

We used Hawth’s Tools (Beyer 2004) in ArcGIS 9.2 to calculate Euclidean distances between consecutive locations. We divided the distance by the time interval between locations to standardize movements into rates (m/h). We only used consecutive locations ≤6 h apart. We compared movement rates for males and females during pre-, peak-, and post-rut, as well as “before” and “after” periods. We used a 2-way, repeated measures analysis of variance (ANOVA) with Kenward-Roger adjustment for degrees of freedom to test if movement rates for males and females differed within periods.

We also compared movement rates during peak-hunting and days when hunters were not present to evaluate the potential effects of hunting pressure on deer movements. We chose 2 periods for peak-hunting (26 □ 28 November 2010 and 3 □ 5 December 2010), which were shotgun/muzzleloader hunts (Friday □ Sunday) with the highest hunter turnout. For comparison, we chose 2 periods (23 □ 25 November and 30 November 2010 □ 2 December 2010) preceding the peak-hunting days (Tuesday □ Thursday). We only included deer that inhabited WMA units 2-6 because unit 1 was not open for hunting during these dates. We used 2-way ANOVA to test for hunting effects on movement rates for males and females.

In all statistical analyses, we used SAS 9.3 (PROC MIXED; SAS Institute, Cary, NC) and least squares mean separation (adjusted for unbalanced data) using Tukey-Kramer adjusted P values ($\alpha = 0.05$ for significance).

RESULTS

GPS collar performance

Eight-six percent (*n* = 539) of store-on-board GPS locations were within 10 m of the true testing location across all vegetation types. However, overall transmission success was much higher for store on-board GPS (92%) than ARGOS (63%) locations. Open field had the least location error ($\bar{x}$ = 2.81 m, SE = 0.17 m, *n* = 132). Location error distance increased with canopy cover, yet collar accuracy still performed well: young pine ($\bar{x}$ = 8.23 m, SE = 0.97 m, *n* = 69), mature hardwood ($\bar{x}$ = 8.28 m, SE = 0.55 m, *n* = 169), mature pine ($\bar{x}$ = 10.12 m, SE = 0.63 m, *n* = 169). The relatively flat terrain at AAFB could have contributed to low location error. Open field transmission success was lowest for both GPS (78%) and ARGOS (59%) locations. These results suggest the ability to successfully acquire and transmit a location may have been dependent more on the functionality of each individual collar rather than vegetation type during our tests.

We equipped 10 females (1 1-yr-old and 9 ≥2-yr-olds) and 10 adult (≥2-yr-olds) males (30 March – 20 July 2010) with GPS-ARGOS collars. However, because of collar malfunctions, only 9 females and 7 males were used in the analyses. GPS-ARGOS collars acquired 5,406 female and 5,353 male locations during the fall-winter seasons. Transmission success for store-on-board GPS (81%; range: 43% – 98%) was higher than ARGOS locations (59%; range: 33% – 80%) for collars deployed on deer, excluding 1 female with long, unexplained periods of missing store-on-board GPS and ARGOS locations.

Similar studies have applied screenings to remove locations with high associated dilution of precision (DOP) values (Kolodzinski 2010, Karns 2011). However, our collar tests showed only 14% of GPS locations had DOP values ≥ 5 with a resulting mean location error of 12.68 m (SE = 1.31 m). GPS locations with DOP values < 5 (86%) averaged 6.68 m (SE = 0.28 m) from the true testing location. Therefore, given high accuracy of the GPS locations, we did not apply screening. Also, screening could only be applied to store-on-board GPS locations because DOP information was not available for ARGOS satellite-downloaded data.

Timing of Conception

The TWRA collected 16 females from 1 to 11 March 2011. Ages of deer (at time of conception) were 1.5 (n = 1) and 3.5 – 6.5+ yrs (n = 15; $\bar{x}$ = 5.0 yrs). Conception dates ranged from 11 November 2010 – 8 January 2011 ($\bar{x}$ = 24 November 2010). Six females were bred 22 – 25 November 2010. We used a 95% CI to identify a 19-day period (18 November – 6 December 2010) as peak-rut. Nineteen days were partitioned before and after peak-rut to represent pre- (30 October – 17 November 2010) and post-rut (7 – 25 December 2010) periods.

Rut excursions and Core Area Use

Three adult males and 2 females that were collared were harvested during peak-rut of the 2010-2011 hunting season. Four adult males made a total of 7 excursions during pre- (1), peak- (4), and post-rut (2) periods, and 6 females made a total of 11 excursions during pre-(2), peak- (5), and post-rut (4) periods (Table 1). One male and female interacted ≥ 9 h during the peak-rut at a site beyond their home ranges (Fig. 2). Mean excursion time was 7.3 h (*SE* = 2.4 h) for males and 10.4 h (*SE* = 1.2 h) for females. Mean maximum excursion distance before returning to home ranges was 838 m (*SE* = 187 m) for males and 676 m (*SE* = 90 m) for females. Male use of core areas averaged 73% (n = 7) before the rut, 51% (n = 7) during the pre-rut, 32% (n = 6) during the peak-rut, 59% (n = 4) during the post-rut, and 56% (n = 4) after the rut. Female use of core areas remained relatively constant throughout fall-winter season: "before" (71%; n = 8), pre-rut (62%; n = 8), peak-rut (64%; n = 8), post-rut (63%; n = 6), and "after" (63%; n = 6).

Movements

Overall movement rates were greater for males than females ($P \leq 0.001$) throughout the fall-winter season. Movement rates among males increased during peak- and post-rut periods, but female movement rates did not differ (Table 2). Hunting pressure did not affect male ($n = 5$) movement rates ($P = 0.314$; hunting pressure: $\bar{x} = 168.7$ m/h, $SE = 32.7$; no pressure: $\bar{x} = 186.6$ m/h, $SE = 32.8$). Female ($n = 4$) movement rates were also not affected by hunting pressure ($P = 0.221$; hunting pressure: $\bar{x} = 90.3$ m/h, $SE = 13.8$; no pressure: $\bar{x} = 75.8$ m/h, $SE = 13.3$).

DISCUSSION

Male reproductive success among mammals has been linked to fighting ability and is dependent on superior body and weapon development (Clutton-Brock et al. 1979, 1982, Cowlishaw and Dunbar 1991) which may allow access to specific females. Among white-tailed deer, dominance is typically associated with older-aged males because of increased antler and body development. However, DeYoung et al. (2009) found breeding was distributed among males in all age classes across 3 wild deer populations with no evidence of breeding skewed toward any dominant individuals. Successful breeding in subordinates suggest male white-tailed deer strategies may differ from that of other highly polygynous cervids in which lekking, territoriality, or harem defense is vital to mating success (Clutton-Brock 1989, DeYoung et al. 2009). Instead, mate-searching or alternate strategies not concerning dominance may enhance breeding opportunities (DeYoung et al. 2009). Our data showed males exhibited greater movement rates and used core areas less during peak rut, and took excursions which corresponded with our expectations and previous GPS telemetry studies (Karns et al. 2011, Webb et al. 2010) implying a mate-searching or “roaming” strategy to facilitate maximal breeding opportunities.

Females showed consistent use of core areas throughout the fall-winter season with no deviations in movement rates, which does not coincide with neither sit-and-wait or active strategies. However, 6 of 7 females took excursions during pre-, peak-, and post-rut periods which may imply active mate-searching. We documented 1 female that left her home range and closely interacted with a male at the periphery of his home range ≥9 h. We do not know if this interaction resulted in copulation, but given the timing of the female excursion (compared to conception of other deer in the area) and the time spent together, we believe the interaction was associated with breeding. Females enter estrus for approximately 24 h (Verme 1965, Warren et al. 1978) but can extend estrous behavior if not bred (White et al. 1995).

Excursive movements by female deer during the rut could be a result of: (1) hunting pressure, (2) males chasing or harassing females outside of home range areas, (3) forced mate-searching after females were not successfully located by a searching male, or (4) active mate-searching demonstrating sexual selection for specific males. Increases in deer movements have been reported with high hunting pressure (Root et al. 1988), but we found no significant differences in male or female movement rates related to hunting. Additionally, only 3 of 18 excursions were documented during the 2 peak-hunting weekends. Therefore, we do not believe hunting pressure was a primary cause of excursions outside home range areas.

Male harassment or chasing of females can occur prior to copulation (Marchinton and Hirth 1984). Cox and Boeuf (1977) theorized female avoidance behavior may be a form of sexual selection by allowing females to evaluate male fitness during pursuit. Three of 6 does in our study completed multiple excursions during the rut, which could be indicative of male pursuits. Whether females would leave their home ranges during male harassment and expose themselves to unknown predation risks in unfamiliar areas is not known. Rosenberry et al. (1999)

demonstrated the potential risk of hunting mortality when they found 22 of 38 dispersing yearling males were harvested. Vulnerability in unfamiliar terrain may increase predation of deer (Nelson and Mech 1991). Studies have shown varying flight responses to disturbance (Hood and Inglis 1974, Karns et al. 2008, Root et al. 1988, Sweeney et al. 1971, Vercauteren and Hygnstrom 1998); however, female flight response from male harassment has not been extensively studied.

The preceding locations (0600 h) of the male and female relative to their initial interaction locations (0900 h) during the peak-rut in our study do not suggest harassment or pursuit from that male (Fig. 2). The female inhabited a wooded-anthropogenic transition area on the edge of AAFB's boundary and the outskirts of the city of Tullahoma. The small, fragmented woodlots likely did not support many males. The male involved in the interaction was not near the female before she excursed although their home ranges overlapped. It is possible that no males were present when she entered estrus and she had to excurse to ensure successful reproduction.

It is also possible that males were in close proximity when the female entered estrus, yet she chose to excurse to find a more suitable breeding partner. Female mate selection is not well documented in white-tailed deer. Among the cervids, male antlers are not only used in intraspecific combat (Clutton-Brock 1982), but may be indicators of good genes, parasite resistance (Ditchkoff et al. 2001), and sperm production and quality (Malo et al. 2005). However, whether female deer perceive superior body or antler development as honest signs of quality or status to choose a mate is still unknown. Geist (1998) proposed that females choose male mates with superior characteristics, but this has not been proven in deer. Theoretically, females should select for specific males with superior genes considering the high parental investment of gestation and lactation compared with minimal energetic costs for male fertilization (Clutton-Brock et al. 1982).

Female mating preferences in mammals should be highly developed, but may be confounded with male competition or attempted constraint of female choice by breeding males (Clutton-Brock and McAuliffe 2009). Additionally, individual female deer cannot be readily identified and therefore field observations of behavior may have overlooked female movements indicative of selection. Observers have been able to monitor individual males throughout the rut and make inferences on reproductive strategies based on individual behaviors. However, GPS telemetry allows for improved tracking of individual females during estrous periods. Our results and other GPS studies (D'Angelo et al. 2004, Kolodzinski et al. 2010) suggest females may exert more energy to ensure reproductive success than originally thought by demonstrating excursions within varying population densities and sex ratios during the rut. However, whether excursions are attributed to male harassment, lack of male presence during estrus, or female mate selection is still not proven.

LITERATURE CITED

Alexy, K. J., J. W. Gassett, D. A. Osborn, and K. V. Miller. 2001. Remote monitoring of scraping behaviors of a wild population of white-tailed deer. Wildlife Society Bulletin 29:873–878.

Atkeson, T. D., and R. L. Marchinton. 1982. Forehead glands in white-tailed deer. Journal of Mammology 63:613–617.

Beaver, J. T. 2011. An evaluation of population estimators and forage availability and quality for white-tailed deer in Tennessee. M.S. Thesis, University of Tennessee, Knoxville, Tennessee, USA.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. http://www.spatialecology.com/htools/. Accessed 1 June 2012.

Clutton-Brock, T. H. 1982. The functions of antlers. Behaviour 79:108–124.

Clutton-Brock, T. H. 1989. Mammalian mating systems. Proceedings of the Royal Society of London, B. Biological Sciences 326:339–372.

Clutton-Brock, T. H., S. D. Albon, R. M. Gibson, and F. E. Guinness. 1979. The logical stag: Adaptive aspects of fighting in red deer (*Cervus elaphus* L.). Animal Behaviour 27:211–225.

Clutton-Brock, T. H, F. E. Guinness, and S. D. Albon. 1982. Red deer: behavior and ecology of two sexes. University of Chicago Press, Chicago, Illinois, USA.

Clutton-Brock, and K. McAuliffe. 2009. Female mate choice in mammals. Quarterly Review of Biology 84:3–27.

Cox, C. R., and B. J. Le Boeuf. 1977. Female incitation of male competition: a mechanism in sexual selection. American Naturalist 111:317–335.

Cowlishaw, G., and R. I. M. Dunbar. 1991. Dominance rank and mating success in male primates. Animal Behaviour 41:1045–1056.

D'Angelo, G. J., C. E. Comer, J. C. Kilgo, C. D. Drennan, D. A. Osborn, and K. V. Miller. 2004. Daily movements of female white-tailed deer relative to parturition and breeding. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 58:292–301.

de Vos, A. 1967. Rubbing of conifers by white-tailed deer in successive years. Journal of Mammalogy 48:146–147.

DeYoung, R. W., S. Demarais, K. L. Gee, R. L. Honeycutt, M. W. Hellickson, and R. A. Gonzales. 2009. Molecular evaluation of the white-tailed deer (Odocoileus virginianus) mating system. Journal of Mammalogy 90:946–953.

Ditchkoff, S. S., R. L. Lochmiller, R. E. Masters, S. R. Hoofer, and R. A. Van Den Bussche. 2001. Major-histocompatibility-complex-associated variation in secondary sexual traits of white-tailed deer (*Odocoileus virginianus*): evidence for good-genes advertisement. Evolution 55:616–625.

Geist, V. 1998. Deer of the world: their evolution, behavior, and ecology. Stackpole Books, Mechanicsburg, Pennsylvania, USA.

Hamilton, R. J., M. L. Tobin, and W. G. Moore. 1985. Aging Fetal White-tailed Deer. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 39:389–395.

Haugen, A. O. 1959. Breeding records of captive white-tailed deer in Alabama. Journal of Mammalogy 40:108–113.

Hirth, D. H. 1977. Social behavior of white-tailed deer in relation to habitat. Wildlife Monographs 57:1–55.

H□lzenbein, S., and G. Schwede. 1989. Activity and movements of female white-tailed deer during the rut. Journal of Wildlife Management 53:219–223.

Hood, R. E., and J. M. Inglis. 1974. Behavioral responses of white-tailed deer to intensive ranching operations. Journal of Wildlife Management 38:488–498.

Ivey, T. L., and M. K. Causey. 1981. Movements and activity patterns of female white-tailed deer during rut. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 35:149–166.

Kammermeyer, K. E. and R. L. Marchinton. 1976. Notes on dispersal of white-tailed deer. Journal of Mammalogy 57:776–778.

Karns, G. R. 2008. Impact of hunting pressure on adult male white-tailed deer behavior. M.S. Thesis, North Carolina State University, Raleigh, North Carolina, USA.

Karns, G. R., R. A. Lancia, C. S. DePerno, and M. C. Conner. 2011. Investigation of adult male white-tailed deer excursions outside their home range. Southeastern Naturalist 10:39–52.

Kile, T. L. and R. L. Marchinton. 1977. White-tailed deer rubs and scrapes: spatial, temporal and physical characteristics and social role. American Midland Naturalist 97:257–266.

Kolodzinski, J. J., L. V. Tannenbaum, L. I. Muller, D. A. Osborn, K. A. Adams, M. C. Conner, W. M. Ford, and K. V. Miller. 2010. Excursive behaviors by female white-tailed deer during estrus at two Mid-Atlantic sites. The American Midland Naturalist 163:366–373.

Labisky, R. F., and D. E. Fritzen. 1998. Spatial mobility of breeding female white-tailed deer in a low-density population. Journal of Wildlife Management 62:1329–1334.

Malo, A. F., E. R. S. Roldan, J. Garde, A. J. Soler, and M. Gomendio. 2005. Antlers honestly advertise sperm production and quality. Proceedings of the Royal Society of London, B. Biological Sciences 272:149–157.

Marchinton, R. L., and D. H. Hirth. 1984. Behavior. Pp. 129–168 *in* White-tailed deer ecology and management (L. K. Halls, ed.). Stackpole Books, Harrisburg, Pennsylvania, USA.

Miller, K. V., L. I. Muller, and S. Demarais. 2003. White-tailed deer. Pp. 906–930 *in* Wild mammals of North America: Biology, management, and conservation. Second edition (G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, eds.). John Hopkins University Press, Baltimore, Maryland, USA.

Miller, K. V., R. L. Marchinton, K. J. Forand, and K. L. Johansen. 1987. Dominance, testosterone levels, and scraping activity in a captive herd of white-tailed deer. Journal of Mammalogy 68:812–817.

Moore, W. G., and R. L. Marchinton. 1974. Marking behavior and its social function in white-tailed deer. Pp. 447–456 *in* The behavior of ungulates and its relation to management (V. Geist and F. Walther, eds.). IUCN Publ. 24. Morges, Switzerland.

Muller, L. I., D.A. Osborn, T. Doherty, M. K. Keel, B. F. Miller, R. J. Warren, and K. V. Miller. 2012. Optimal medetomidine dose when combined with ketamine and tiletamine-zolazepam to immobilize white-tailed deer. Journal of Wildlife Diseases 48:477–482.

Murray, S., S. L. Monfort, L. Ware, W. J. McShea, and M. Bush. 2000. Anesthesia in female white-tailed deer using telazol and xylazine. Journal of Wildlife Diseases 36:670–675.

Nelson, M. E., and L. D. Mech. 1984. Home-range formation and dispersal of deer in northeastern Minnesota. Journal of Mammalogy 65:567–575.

Nelson, M. E., and L. D. Mech. 1991. Wolf predation risk associated with white-tailed deer movements. Canadian Journal of Zoology 69:2696–2699.

Nielson, D. G., M. J. Dunlap, and K. V. Miller. 1982. Pre-rut rubbing by white-tailed bucks: nursery damage, social role, and management options. Wildlife Society Bulletin 10:341–348.

Ozoga, J. J., and L. J. Verme. 1975. Activity patterns of white-tailed deer during estrus. Journal of Wildlife Management 39:679–683.

Ozoga, J. J., and L. J. Verme. 1985. Comparing breeding behavior and performance of yearling vs. prime-age white-tailed bucks. Journal of Wildlife Management 19:364–372.

Rodgers, A.R., A.P. Carr, H.L. Beyer, L. Smith, and J.G. Kie. 2007. HRT: Home Range Tools for ArcGIS. Version 1.1. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.

Rodgers, A. R., R. S. Rempel, and K. F. Abraham. 1996. A GPS-based telemetry system. Wildlife Society Bulletin 24:559–566.

Root, B. G., E. K. Fritzell, and N. F. Giessman. 1988. Effects of intensive hunting on white-tailed deer movement. Wildlife Society Bulletin 16:145–151.

Rosenberry, C. S., R. A. Lancia, and M. C. Conner. 1999. Population effects of white-tailed deer dispersal. Wildlife Society Bulletin 27:858–864.

Sawyer, T. G., R. L. Marchinton, and K. V. Miller. 1989. Response of female white-tailed deer to scrapes and antler rubs. Journal of Mammalogy 70:431–433.

Sikes, R. S., W. L. Gannon, and the Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. Journal of Mammalogy 92:235–253.

Sweeney, J. R., R. L. Marchinton, and J. M. Sweeney.1971. Responses of radio-monitored white-tailed deer chased by hunting dogs. Journal of Wildlife Management 35:707–716.

Tierson, W. C., G. F. Mattfeld, R. W. Sage, and D. F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management 49:760–769.

U.S. Department of Defense. Arnold Engineering Development Center. 2006. Integrated Natural Resources Management Plan. Arnold Air Force Base, Tennessee, USA.

Vercauteren, K. C., and S. E. Hygnstrom. 1998. Effects of agricultural activities and hunting on home ranges of female white-tailed deer. Journal of Wildlife Management 62:280–285.

Verme, L. J. 1965. Reproduction studies on penned white-tailed deer. Journal of Wildlife Management 29:74–79.

Warren, R. J., R. W. Vogelsang, R. L. Kirkpatrick, and P. F. Scanlon. 1978. Reproductive behaviour of captive white-tailed deer. Animal Behaviour 26:179–183.

Webb, S. L., K. L. Gee, B. K. Strickland, S. Demarais, and R. W. DeYoung. 2010. Measuring fine-scale white-tailed deer movements and environmental influences using GPS collars. International Journal of Ecology 2010:1–12.

White, L. M., D. A. Hosack, R. J. Warren, and R. A. Fayrer-Hosken. 1995. Influence of mating on duration of estrus in captive white-tailed deer. Journal of Mammalogy 76:1159–1163.

APPENDIX

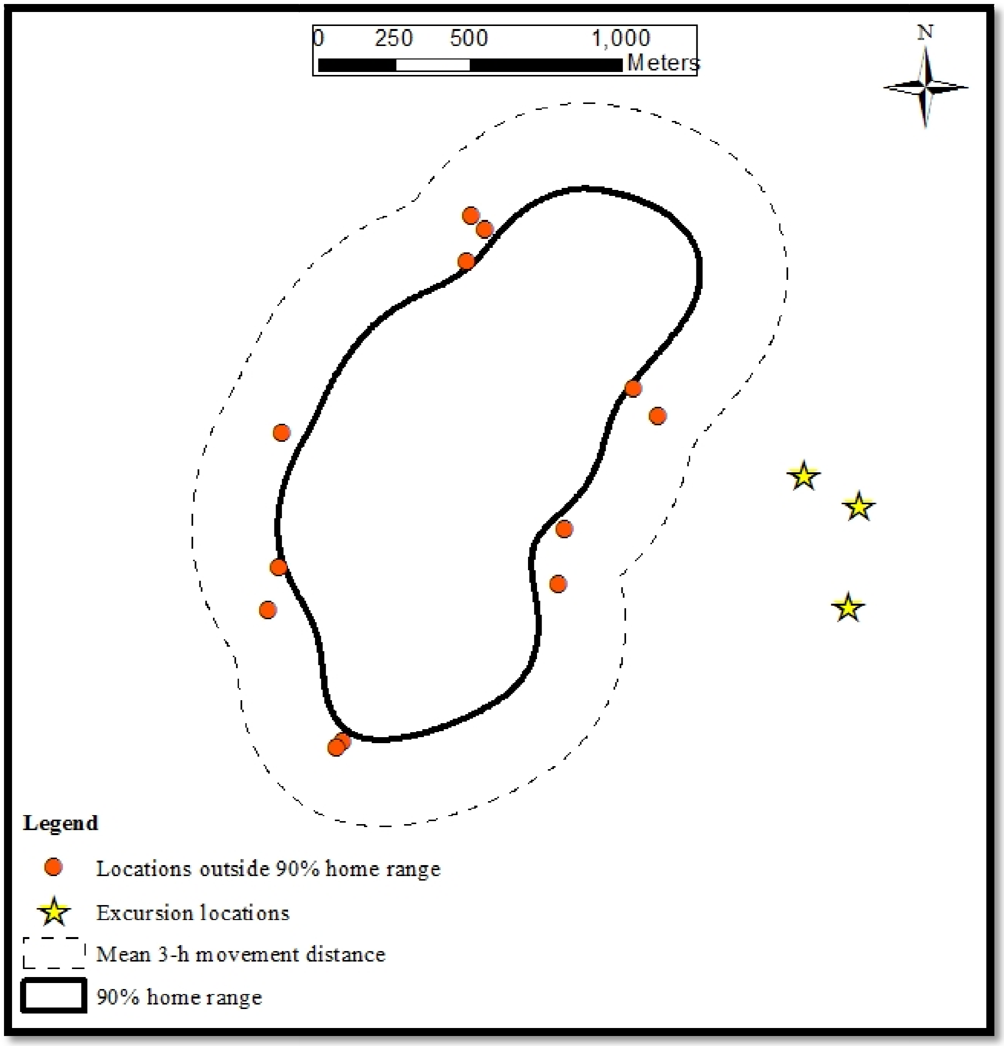

Figure 1. Example of an excursion for a GPS-collared female during the rut at Arnold Air Force Base, Tullahoma, Tennessee, USA. An excursion was characterized as ≥2 consecutive locations outside the 90% home range extending beyond a mean distance traveled between 3-h locations for that individual during the fall-winter season.

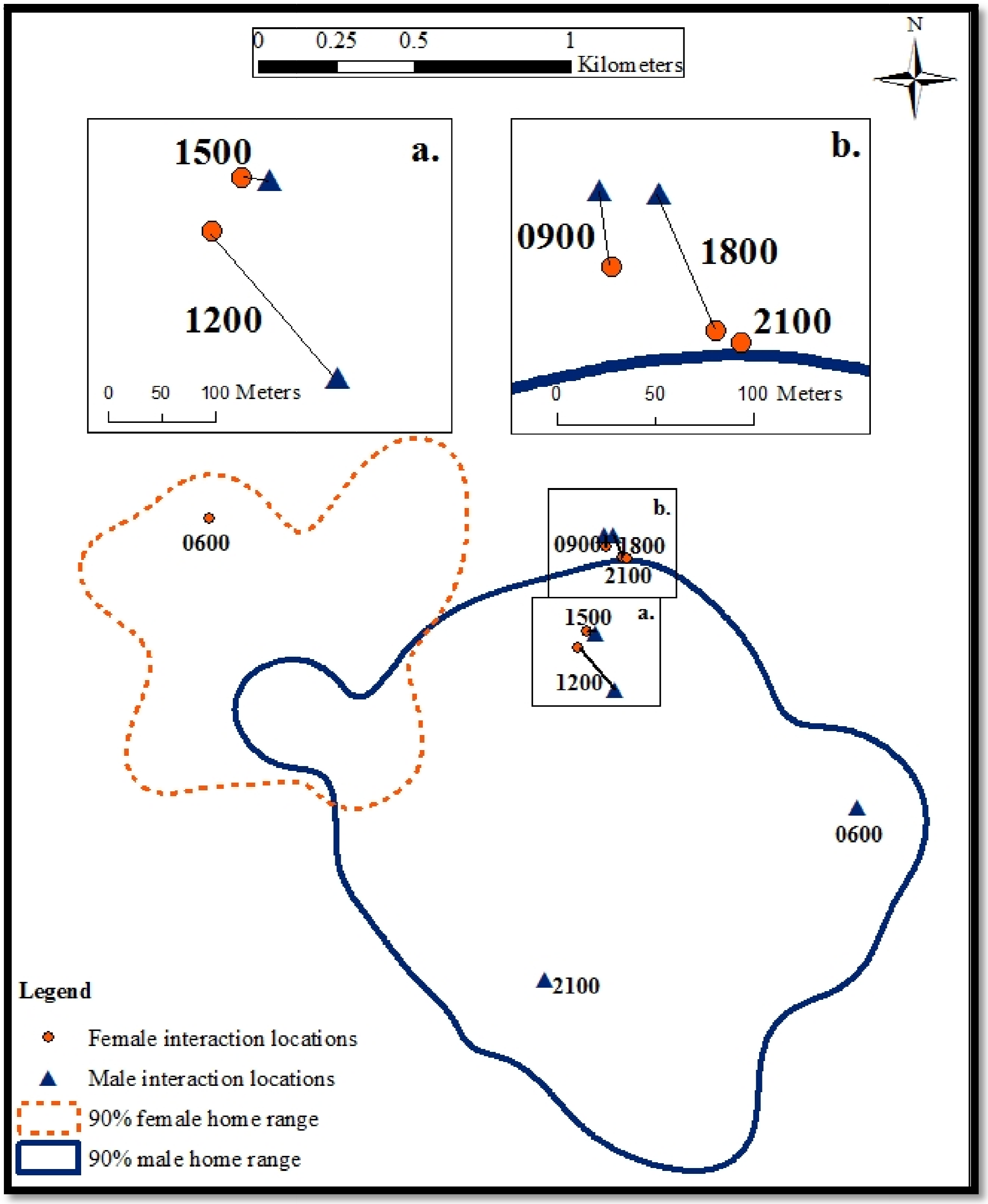

Figure 2. Interaction of a GPS-collared male and female on 19 November 2010 during the peak-rut at Arnold Air Force Base, Tullahoma, Tennessee, USA. The connecting lines represent their interactive locations at the given time. The female excursed outside of her seasonal 90% home range after 0600 h and joined with the male on the periphery of his home range. They stayed in close proximity for ≥9 h (0900 – 1800 h) before the male separated between 1800 and 2100 h.

Table 1. Male and female excursion records during 3 rut periods at Arnold Air Force Base, Tullahoma, Tennessee, USA. We partitioned dates based on conception using fetal scale measurements of 16 collected females (1 – 11 March 2011).

ID[a]	Gender	Date	Rut period[b]	Time[c]	Excursion distance[d]
80673	F	Nov. 19	Peak-rut	18	520
		Dec. 15	Post-rut	9	682
		Dec. 17	Post-rut	9	557
80674	F	Nov. 27	Peak-rut	6	521
80675	F	Nov. 7	Pre-rut	6	584
		Nov. 20	Peak-rut	9	603
80676	F	Nov. 27	Peak-rut	9	946
81789	F	Nov. 13	Pre-rut	18	475
		Dec. 2	Peak-rut	12	1475
		Dec. 15	Post-rut	9	454
85133	F	Dec. 13	Post-rut	9	621
83864	M	Dec. 10	Post-rut	6	1951
84168	M	Nov. 15	Pre-rut	6	647
		Dec. 6	Post-rut	6	696
84172	M	Nov. 24	Peak-rut	6	564
		Dec. 2	Peak-rut	12	754
		Dec. 3	Peak-rut	9	637
84182	M	Nov. 22	Peak-rut	6	616

Table 1 continued.

[a] Identification no. unique to individual deer

[b] Periods partitioned into pre-rut (30 October – 17 November 2010), peak-rut (18 November – 6 December 2010), and post-rut (7 – 25 December 2010)

[c] Minimum excursion time (h) using consecutive 3-h locations

[d] Distance (m) measured from furthest excursion locations to closest edges of 90% seasonal home range

Table 2. Male and female least squares mean movement rates (m/h) for 5 periods during the fall-winter seasons at Arnold Air Force Base, Tullahoma, Tennessee, USA. We partitioned dates based on conception using fetal scale measurements of 16 collected females (1 – 11 March 2011).

Period[a]	**Males**[b] m/h (SE)	**Females**[b] m/h (SE)
Before	81.8 (13.1) B	74.3 (11.6) A
Pre-rut	140.4 (13.1) AB	84.2 (11.6) A
Peak-rut	173.4 (13.1) A	78.2 (11.6) A
Post-rut	154.0 (16.8) A	87.5 (13.0) A
After	116.6 (17.3) AB	77.3 (13.2) A

Standard errors for least square means in parenthesis

[a] Periods partitioned into before (23 September – 29 October 2010), pre-rut (30 October – 17 November 2010), peak-rut (18 November – 6 December 2010), post-rut (7 – 25 December 2010), and after (26 December 2010 – 19 March 2011)

[b] Different letter groupings indicate differences among periods ($P < 0.05$)

CHAPTER II. FACTORS INFLUENCING WHITE-TAILED DEER-VEHICLE COLLISIONS

ABSTRACT

White-tailed deer-vehicle collisions (*Odocoileus virginianus*; DVCs) are a concern for the public. Previous studies have shown that DVCs are spatially or temporally correlated. However, factors affecting spatial aggregations of DVCs have primarily focused on a landscape scale. Understanding fine-scale spatial relationships of DVCs should help facilitate mitigation efforts to reduce DVCs. We evaluated 8 years of DVC locations (2002 – 2009) to random locations along major roads at Arnold Air Force Base in Middle Tennessee. We measured land cover (percentage of adjacent cover types within 125 m, distance to nearest drainages) and transportation (traffic volume, speed limits, and distance to nearest road intersections) variables for DVC and random locations to evaluate possible factors increasing the likelihood of DVCs. We used logistic regression to model variables for DVC and random locations and conducted model selection using Akaike's second-order information criterion (AICc) scores. We confirmed variable importance using model-averaged beta (β) estimates. The presence of pine plantations surrounding DVCs along with intersecting drainages were important land cover variables. Road intersections, traffic volume, and speed limits were all important transportation variables in DVC occurrence. We believe the most effective mitigation strategy is to focus future implementation and management of pine plantations away from roads, especially in predominately hardwood forests. Our results can be used throughout much of the Southeast where pine plantations and hardwood forests are juxtaposed alongside roadways.

KEY WORDS deer-vehicle collision, highway mortality, logistic regression, modeling, *Odocoileus virginianus*, white-tailed deer

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*; deer) are the most economically beneficial game species in North America (Miller et al. 2003). However, deer can cause problems including deer-vehicle collisions (DVCs), property damage, and decreased agricultural productivity (Conover et al. 1995). Deer abundance and their geographic range have increased over the past century (McShea et al. 1997, Finder et al. 1999) from an estimated 500,000 in the early 1900s to current estimates exceeding 20 million individuals (Cook and Daggett 1995, Hubbard et al. 2000, Grovenburg et al 2008). Both human population and development are also on the rise, resulting in increased deer-human interactions (Finder et al. 1999, Squires 2002, Grovenburg et al. 2008).

Deer-human interactions have resulted in escalating annual DVCs (Conover et al. 1995, Romin and Bissonette 1996). More than1 million DVCs occur every year in the United States, resulting in >$1 billion in property damage and personal injury (Conover et al. 1995, Ng et al. 2008). It is also estimated that 4–5% of DVCs result in human injury, including >200 human fatalities annually (Hansen 1983, Conover et al. 1995, Biggs et al. 2004). Nationwide, estimates of damage resulting from DVCs from 1981 to 1991 averaged approximately $2,000 per accident (Romin and Bissonette 1996, Biggs et al. 2004).

Roads impact wildlife populations by forming barriers to movements, which can fragment populations and cause isolation from resources and mates (Richardson et al. 1997, Dyer et al. 2002, Ramp et al. 2005). However, the most apparent impact of roads is the increasing number of fatalities of animals because of vehicle collisions (Ramp et al. 2005, Langen 2009). In particular, Allen and McCullough (1976) found DVCs result in deer fatalities in >90% of collisions. Conflict between humans and wildlife, especially deer, at the road interface will likely increase with the continuing expansion of urban areas nationwide (Ramp et al. 2005).

DVCs are not temporally or spatially random, but may be aggregated in time and space (Finder et al. 1999, Ng et al. 2008). DVCs are typically amplified around dawn and dusk, which coincides with deer crepuscular activity patterns, or after dark when driver visibility is lessened (Allen McCullough 1976, Finder et al. 1999). DVCs also tend to peak during the fall-winter breeding season, when movement activity tends to escalate (Allen and McCullough 1976, Finder et al. 1999). There also may be a lesser peak during spring, which is attributed to dispersal of young (Reilly and Green 1974, Finder et al. 1999, Etter et al. 2002). Although the predominant sex involved in vehicle collisions is female, shifts in favor of males can result from seasonal peaks, which are stimulated primarily by breeding (Allen and McCullough 1976).

Peaks in human and deer activity may help explain temporal aggregations, but more information is needed on factors influencing the spatial aggregation of DVCs. Areas with aggregated DVCs must be influenced by surrounding landscape patterns or features (Finder 1999). Studies have shown that in addition to population density, two major factors influence road-kill rates: (1) proximity of cover and wildlife movement corridors, and (2) traffic volume and speed (Forman et al. 2003). Adjacent land-cover distributions and topography may facilitate deer movements or reduce driver visibility and increase DVC likelihoods (Finder et al. 1999, Clevenger et al. 2003). Transportation factors, such as high traffic volumes and speed, can increase collision probability on particular road segments by reducing the time and space for crossing opportunities (Case 1978, Langevelde and Jaarsma 2004). Site and landscape variables at appropriate spatial scales associated with DVC locations should be evaluated for applying effective mitigation measures. Both local and landscape scales may be correlated with collisions (Ng et al. 2008).

Road designers need to know where an animal will likely cross when designing new roads or managing existing roads to mitigate DVCs (Langen et al. 2009, McCollister and van Manen 2010). Road designers have tried incorporating features to reduce DVCs, such as deer-crossing signs and lighting systems to aid drivers and warning reflectors to deter deer from crossing roads; however, their effectiveness has been questionable (Pojar et. al 1975, Reed and Woodard 1981, D'Angelo et al. 2006, McCollister and van Manen 2010). Exclusion fencing also has been used to reduce DVCs (Ward 1982, Bashore et al. 1985), but may amplify DVCs toward fence ends (Clevenger et al. 2001, Gulsby et al. 2011). We need to understand key linkages that should be managed to reduce DVCs while maintaining population connectivity (Langen et al. 2009, McCollister and van Manen 2010).

Most of the previous work on DVCs have used field evaluation of areas immediately adjacent to DVCs (Finder et al. 1999). Only recently have researchers used detailed geographic information system (GIS) databases to identify potential factors influencing the probability of DVCs, which has primarily been studied at broad scales. Additionally, previous DVC studies have not differentiated the types of forested cover (Finder et al. 1999, Hubbard et al. 2000, Hussain et al. 2007) that deer may use differently.

Personnel at Arnold Air Force Base have emphasized DVC reduction. A large number of DVCs (272 outside the Security Area) occurred from 2002 to 2009. Previous mitigation efforts (2005 – 2006) resulted in the removal of approximately 25 m of adjacent forested cover along most of the right-of-way (ROW) on Watterndorf Memorial Hwy, a 19.7-km stretch where nearly 70% of collisions occurred, but did not effectively reduce DVC numbers (2002 – 2004, $n = 91$; 2007 – 2009, $n = 95$). Therefore, we used ArcGIS (Environmental Systems Research Institute, Redlands, CA) to investigate how different cover types close to roads and other potentially important variables affect the spatial distribution of DVCs to provide additional mitigation measures. We hypothesized DVCs would be affected by surrounding cover types. We also expected DVCs to be concentrated near road intersections and drainage crossings, as well as on roads or road segments with higher traffic volumes and speed limits.

STUDY AREA

Arnold Air Force Base (AAFB) encompassed 15,815 ha and was located between Manchester, Tullahoma, and Winchester in Coffee and Franklin counties, Tennessee. AAFB was divided into 6 wildlife management units and a 1,489-ha high-fenced Security Area. The land cover was primarily loblolly pine (*Pinus taeda*) plantations (2,223 ha) and oak- (*Quercus* spp.) dominated hardwood forests (9,329 ha) at AAFB. The mid- and understories were comprised mostly of dogwoods (*Cornus* spp.), maples (*Acer* spp.), sassafras (*Sassafras albidum*), sourwood (*Oxydendrum arboretum)*, blueberries (*Vaccinium* spp.), hickories (*Carya* spp.), and blackgum (*Nyssa sylvatica*). Grasslands and early-successional vegetation, primarily in utility rights-of-way, comprised 898 ha. The remaining land cover (1,895 ha) was buildings, structures, roads, wildlife food plots, and open, mowed areas surrounding these features (United States Department of Defense 2006).

We investigated DVCs on 8 main roads outside the Security Area and within AAFB. These roads were 2-laned and totaled 40.0 km in length. Speed limits varied between 40 □ 89 kph (25 – 55 mph), with 75% of road length at 89 kph (55 mph).

Deer density was regulated by public hunting on the wildlife management units. Beaver (2011) reported deer densities of 6.7 deer/km^2 in Unit 1 and 8.7 deer/km^2 in Unit 2. Adult sex ratio was about 2 females to 1 male in the 2 units.

METHODS

DVC data

We used a GIS database provided by AAFB personnel of reported DVC locations recorded from 2002 to 2009 (*n* = 272) on major roads outside the Security Area. Location coordinates of deer carcasses within AAFB boundaries and the year of occurrence were recorded by TWRA personnel with GPS units. We imported these locations into ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, CA) and joined locations to the nearest major road using the Hawths Tools extension (Beyer 2004) to represent the road location where the DVC occurred (Fig. 3).

We generated an equal number of randomly distributed locations in ArcGIS 10.0 (Environmental Systems Research Institute, Redlands, CA) on the major roads within AAFB. We rationed equal numbers of random locations to match the DVCs within each year. We analyzed DVC locations and random locations by year to address vegetation changes that occurred, primarily through loblolly pine harvest.

We also used DVC data from 2005 to 2009, when month and day of occurrence was recorded, to identify periods of high-risk. We included DVCs both inside and outside of the Security Area to gain a better understanding of temporal trends. We tallied DVCs by month.

Land cover variables and extraction

We used ArcGIS to extract land cover characteristics associated with DVC and random locations. Previous studies created circular buffer zones, which were based on the ecology and behavior of the species and the scale of prediction, to characterize DVC locations (Ramp et al. 2005). We were interested in cover types in close proximity to roads so we created a 125-m buffer to extract cover types in ArcGIS. Previous DVC studies have dealt with county and statewide data and analyzed adjacent roadside characteristics on a large scale (Finder et al. 1999, Hubbard et al. 2000).

We used an ArcGIS shapefile of land cover provided by AAFB along with historical aerial imagery from Google Earth (http://www.google.com/earth) and ground-truthing to delineate cover types along roads. We categorized land cover types (10- x 10-m cell resolution) into 6 primary categories of biological relevance to deer. We updated land cover type layers for each year from 2002 to 2009 that included the following:

1) Agriculture – farmed fields maintained in row crops or wildlife food plots,
2) Anthropogenic disturbed – buildings, residents, roads, and associated open, continuously mowed areas,
3) Early succession – early succession areas maintained by periodic prescribed burning or mowing; pine plantations 1 □ 5 years old,
4) Hardwood – deciduous closed-canopy forest,
5) Pine – pine plantations >5 years old, and
6) Water – ponds, lakes, and reservoirs.

We extracted the cell occurrence frequency for cover types surrounding DVC and random locations using Hawths Tools extension (Beyer 2004) in ArcGIS 9.2. We calculated cover type percentages within the 125-m buffers. To compensate for the road ROW extension along Wattendorf Memorial Hwy from 2005 to 2006, we treated DVC and random locations from 2002 to 2005 as being prior and locations from 2006 to 2009 as subsequent to the ROW extension because timely aerial imagery or information was not available to accurately assess the progress of the removal.

We used ArcGIS 10.0 to measure the distance to the nearest drainage structure or culvert along the roads from DVC and random locations. We used data provided by AAFB and the Street View feature in Google Earth to mark intersecting locations of drainages that could potentially serve as deer movement corridors or hinder driver visibility.

Transportation variables

We used annual average daily traffic (AADT) estimates acquired from Tennessee Department of Transportation (http://www.tdot.state.tn.us) as well as personal observation to categorize the roads into three traffic volume categories (low, medium, and high). We also delineated road segments by speed limits using a handheld GPS in the field and the Street View feature in Google Earth. Speed limits included 40, 56, 64, 72, and 88 kph (25, 35, 40, 45, and 55 mph, respectively) on road segments within AAFB. We used ArcGIS 10.0 to measure the distance from DVC and random locations to the nearest intersection of a public, paved road.

Statistical Analysis

Attributes for adjacent cover types, distance to nearest drainage, and distance to nearest road intersection in addition to the traffic volume and speed limit on the road or road segment of occurrence were assigned to each DVC and random location. We did not include agriculture or water in the analysis because there was little coverage along roads.

We used logistic regression in R software version 2.15.2 (R Development Core Team 2008) to evaluate the relationship of DVCs to land cover and transportation variables. We treated traffic volume as a categorical variable and all other variables as continuous. We generated a global model of all independent and additive combinations. We modeled harvested stands adjacent to DVC and random locations as both pine and anthropogenic disturbed because we knew the year of harvest from AAFB records, but not the exact date. We used an informationtheoretic approach to model selection based on Akaike's second-order information criterion (AICc; Burnham and Anderson 2002). We examined relative importance of models according to Δ_iAICc (Δ_iAICc = AICc$_i$ – AICc$_{min}$) and AICc weights (w_i). We also used model-averaged beta (β) estimates across the entire set of models to evaluate variable importance (whether the variable beta estimate included 0 within the associated 95% CI) and relationships (positive or negative sign of the variable beta estimate). We evaluated goodness-of-fit for our models using the Hosmer-Lemeshow test (Hosmer and Lemeshow 1989).

RESULTS

Temporal trends of DVCs

There were temporal trends in DVCs from 2005 to 2009 at AAFB (Fig. 4). The high-risk period was October – January when nearly half (n = 95) of DVCs (n = 196) occurred. A lesser peak was apparent in April, followed by a sharp decline in May.

Factors affecting spatial patterns of DVCs

Modeling harvested pine stands as both pine and anthropogenic disturbed showed similar results. Thus, we reported results for these stands as anthropogenic disturbed. The Hosmer-Lemeshow test of goodness-of-fit was not significant (*P* = 0.66), indicating adequate fit for our models. The best model included all the additive variable combinations except for percentages of early succession and hardwood cover types within 125 m (Table 3). This model accounted for 25% of the relative global model weight (w_i). Five variables (distance to drainage, distance to road intersection, percentage of pine, speed, traffic volume) were consistently present in the top models (Table 3). Model-averaged beta estimates (β; Table 4) further supported these variables importance considering they did not contain 0 within their associated 95% CI, suggesting a definite relationship with DVC likelihood. Based on model averaging, distance to drainage (β =

0.0010, 95% CI = 0.0003 to 0.0018) and percentage of pine (β = 0.0232, 95% CI = 0.0080 to 0.0385) had positive relationships suggesting as distance (m) or percentages were increased, DVCs were more likely. Contrary, distance (m) to road intersections (β = -0.0007, 95% CI = -0.0010 to -0.0003) and speeds (β = -0.0528, 95% CI = -0.0942 to -0.0114) had negative relationships suggesting DVCs are more likely closer to road intersections and on road segments with decreased speed limits. Also, roads with high traffic volumes increased the odds of DVC likelihood by 1.7497 (95% CI = 0.4939 to 3.0055) compared to low traffic volume.

DISCUSSION

We accepted our hypothesis that certain cover types affected the likelihood of DVCs. The best model included both anthropogenic disturbed and pine cover types within 125 m (Table 3). However, beta estimates (β) for anthropogenic disturbed contained 0 within the 95% CI (Table 4). Pine was in our best model and increased the likelihood of DVCs. Managed pine plantations can provide deer a superior resource for forage and cover compared with closed-canopy hardwoods. At AAFB, Beaver (2011) found greater forage availability in young, middle-aged, and mature pine plantations than closed-canopy hardwoods for forages important to deer during the growing season. In addition to forage availability, deer also may use cover types that provide optimal cover for predator-avoidance and seasonal thermoregulation (DePerno et al. 2003). The thick vegetation in managed pine plantations, especially in young stands, provides an increase in cover compared to surrounding closed-canopy hardwoods that lack understory development. Therefore, pine plantations abundant in escape and fawning cover may serve as a refuge for deer when subjected to increased hunting pressure or predation risks. Additionally, dense pine stands are important to deer during winter by minimizing energy expenditures for thermoregulation (Moen 1968, Moen 1976, DePerno et al. 2002).

At AAFB, deer likely used pine plantations throughout much of the year with the exception of fall/early winter when hard mast was abundant in closed-canopy hardwoods. GPS data acquired in 2010 – 2011 (see Chapter 1) provided two examples of a female (Fig. 5) and male (Fig. 6) that inhabited areas close to road systems and suggested they frequently used pine plantations when available, especially in the younger stages of development. Thus, areas with greater proportions of pine plantations near roads at AAFB are likely attracting deer and consequently contributing to increased DVCs.

The likelihood of DVCs increased with distance from drainages. In contrast, we expected DVCs to be closer to streams and drainages based on previous studies because deer use these features as movement corridors and because of decreased driver visibility (Finder et al. 1999, Clevenger et al. 2003). Our findings may be a result of heightened road embankments where drainages intersect the roads at AAFB, which may deter deer crossings at these elevated areas.

Transportation variables important in increasing likelihoods of DVCs included closer proximity to road intersections, high traffic volumes, and decreased speed limits. Traffic is more congested at road intersections, which could amplify DVCs. Additionally, driver awareness may be focused more on proximity of other vehicles than deer on roadsides at intersections. We also theorized deer crossing attempts could be concentrated at road intersections. For example, particular roads or road segments may be less attractive or serve as barriers for deer to cross. Therefore, deer movements could be diverted parallel to the road until ultimately becoming funneled into an intersecting road.

High traffic volumes and speeds are typically correlated with increased risk of DVCs (Allen and McCullough 1976, Case 1978, Marcoux et al. 2005, Sudharsan et al. 2009). Therefore, we expected high traffic volumes to be important in DVCs. Model-averaged beta (β) estimates showed high traffic volume did not contain 0 within the 95% CI in addition to being well supported in our top models. Thus, high traffic volumes were likely contributing to increased DVCs. These results were not surprising given the majority of DVCs occurred on the road with the most traffic (Wattendorf Memorial Hwy). We also expected DVCs to be more abundant on road segments with higher speed limits. However, at AAFB, our results showed decreases in speed limits increased the likelihood of DVCs. We attribute this primarily to a lower speed limit road segment (64 kph or 40 mph) near the Security Area on Wattendorf Memorial Hwy. The DVCs in this area were probably more greatly influenced by traffic volume and congestion entering and exiting the Security Area along with the increased number of road intersections. Additionally, roads such as UTSI Rd and S Hap Arnold Dr (Fig. 3) share the same speed limit as Wattendorf Memorial Hwy (mostly 88 kph or 55 mph), yet did not have the abundance of DVCs. Therefore, we do not believe speed limit is a primary contributing factor at AAFB.

Seasonal deer behavior is a good indicator for changes in DVC occurrences. Deer activity increased during the breeding season, which peaked in mid-late November (see Chapter 1), and likely explained increased DVCs from October to January. This period also corresponds with the fall-winter hunting season, which theoretically may increase deer movements and DVCs from hunter disturbance. However, we found no differences in deer movement rates in addition to relatively few deer excursions when hunting pressure was greatest at AAFB (see Chapter 1). Also, Sudharsan et al. (2006) found rapid declines in DVCs past opening day of hunting season. Therefore, DVCs during these months were probably influenced by increased deer activity from the breeding season rather than hunting. The lesser peak in April may be linked to dispersal (Reilly and Green 1974, Etter et al. 2002), exaggerated female movements during pre-parturition

(D'Angelo et al. 2004), and/or increased female foraging time during spring on road ROWs to meet high metabolic demands of gestation and lactation (DeYoung and Miller 2011). We also speculate the decrease in DVCs during May is likely influenced by fawning when females reduce movements and home ranges (Ozoga et al. 1982, D'Angelo et al. 2004). Public awareness could aid in reducing the high numbers of DVCs, particularly during the fall-winter months. Although these temporal trends can be useful for identifying periods of high-risk, mitigation efforts concentrated around spatial patterns of DVCs will likely be most effective.

Additional measures should be taken regarding road ROWs at AAFB. Forage availability is the prime reason deer enter road ROWs (Feldhamer et al. 1986). Deer at AAFB were often observed foraging on road ROWs, especially along Wattendorf Memorial Hwy that had the widest ROW. Continuous mowing to adjacent wood lines along roads should be maintained throughout the growing season. This mowing would eliminate browse and cover and reduce deer incentives to enter road ROWs. Additionally, supplementary preferred food away from road ROWs has been shown to manipulate deer movements away from roads, resulting in reduced DVCs (Wood and Wolfe 1988). This method of "intercept feeding" could be beneficial at AAFB, especially during mid-late winter when DVCs are greatest and forage and hard mast availability in wooded areas have declined. During this period, deer may be induced to forage in open, road ROWs that are typically abundant in cool-season grasses and forbs thereby enhancing the possibility of DVC occurrences. Therefore, using existing utility ROWs or creating areas away from roads at AAFB to implement preferred forages may keep deer off of roadsides, especially during high-risk periods.

MANAGEMENT IMPLICATIONS

We believe management should focus on adjacent roadside vegetation. Traffic volume, drainages, and road intersections, which also contribute to DVCs at AAFB, are much more difficult to control. We found increases in pine plantations adjacent to roads were important in DVC occurrences. Pine plantations near roads in these systems could draw and hold deer close to roadsides, thus likely increasing deer densities and DVCs in these areas. In predominately hardwood forests, the location of pine plantations should be planned cautiously, especially if deer often use road ROWs to forage.

LITERATURE CITED

Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. Journal of Wildlife Management 40:317–325.

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769–774.

Beaver, J. T. 2011. An evaluation of population estimators and forage availability and quality for white-tailed deer in Tennessee. M.S. Thesis, University of Tennessee, Knoxville, Tennessee, USA.

Beyer, H. L. 2004. Hawth's analysis tools for ArcGIS. http://www.spatialecology.com/htools. Accessed 1 June 2012.

Biggs, J., S. Sherwood, S. Michalak, L. Hansen, and C. Bare. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. The Southwestern Naturalist 49:384–394.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and multimodel inference. Second edition. Springer-Verlag, New York, New York, USA.

Case, R. M. 1978. Interstate highway road-killed animals: a data source for biologists. Wildlife Society Bulletin 6:8–13.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29:646–653.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biological Conservation 109:15–26.

Cook, K. E., and P. M. Daggett. 1995. Highway roadkill, associated issues of safety and impacts on highway ecotones. Task Force on Natural Resources, Transportation Research Board. National Research Council, Washington D. C., USA.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407–414.

D'Angelo, G. J., C. E. Comer, J. C. Kilgo, C. D. Drennan, D. A. Osborn, and K. V. Miller. 2004. Daily movements of female white-tailed deer relative to parturition and breeding. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 58:292–301.

D'Angelo, G. J., J. G. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2006. Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. Wildlife Society Bulletin 34:1175–1183.

DePerno, C. S., J. A. Jenks, and S. L. Griffin. 2003. Multidimensional cover characteristics: is variation in habitat selection related to white-tailed deer sexual segregation? Journal of Mammalogy 84:1316–1329.

DePerno, C. S., J. A. Jenks, S. L. Griffin, L. A. Rice, and K. F. Huggins. 2002. White-tailed deer habitats in the central Black Hills. Journal of Range Management 55:242–252.

DeYoung, R. W., and K. V. Miller. 2011. White-tailed deer behavior. Pages 311–351 *in* D. G. Hewitt, editor. Biology and management of white-tailed deer. CRC Press, Boca Raton, Florida, USA.

Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology 80:839–845.

Etter, D. R., K. M. Hollis, T. R. Van Deelen, D. R. Ludwig, J. E. Chelsvig, C. L. Anchor, and R. E. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500–510.

Feldhamer, G. A., J. E. Gates, D. M. Harman, A. J. Loranger, and K. R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management 50:497–503.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. Landscape and Urban Planning 44:77–85.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. Road ecology: science and solutions. Island Press, Washington, D.C., USA.

Grovenberg, T. W., J. A. Jenks, R. W. Klaver, K. L. Monteith, D. H. Galster, R. J. Schauer, W. W. Morlock, and J. A. Delger. 2008. Factors affecting road mortality of white-tailed deer in eastern South Dakota. Human-Wildlife Conflicts 2:48–59.

Gulsby, W. D., D. W. Stull, G. R. Gallagher, D. A. Osborn, R. J. Warren, K. V. Miller, and L. V. Tannenbaum. 2011. Movements and home ranges of white-tailed deer in response to roadside fences. Wildlife Society Bulletin 35:282–290.

Hansen, C. S. 1983. Cost of deer-vehicle accidents in Michigan. Wildlife Society Bulletin 11:161–164.

Hosmer, D. W., and S. Lemeshow. 1989. Applied Logistic Regression. John Wiley and Sons, New York, USA.

Hubbard, M. W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer-vehicle accidents in Iowa. Journal of Wildlife Management 64:707–713.

Hussain, A., J. B. Armstrong, D. B. Brown, and J. Hogland. 2007. Land-use pattern, urbanization, and deer-vehicle collisions in Alabama. Human-Wildlife Conflicts 1:89–96.

Langen, T. A., K. M. Ogden, and L. L. Schwarting. 2009. Predicting hot spots of herptofauna road mortality along highway networks. Journal of Wildlife Management 73:104–114.

Langevelde, F. V., and C. F. Jaarsma. 2004. Using traffic flow theory to model traffic mortality in mammals. Landscape Ecology 19:895–907.

Marcoux, A., G. J. Hickling, S. J. Riley, and S. R. Winterstein. 2005. Situational and driver characteristics associated with deer-vehicle collisions in southeastern Michigan. Pages 363–374 *in* D. L. Nolte and K. A. Fagerstone, editors. Proceedings of the 11th Wildlife Damage Management Conference. University of Nebraska, Lincoln, USA.

McCollister, M. F., and F. T. Van Manen. 2010. Effectiveness of wildlife underpasses and fencing to reduce wildlife-vehicle collisions. Journal of Wildlife Management 74:1722–1731.

McShea, W.J., Underwood, H.B., and J. H. Rappole, editors. 1997. The science of overabundance: deer ecology and population management. Smithsonian Institution Press, Washington, D. C., USA.

Miller, K. V., L. I. Muller, and S. Demarais. 2003. White-tailed deer. Pages 906–930 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild mammals of North America: biology, management, and conservation. Second edition. John Hopkins University Press, Baltimore, Maryland, USA.

Moen, A. N. 1968. Surface temperatures and radiant heat loss from white-tailed deer. Journal of Wildlife Management 32:338–344.

Moen, A. N. 1976. Energy conservation by white-tailed deer in winter. Ecology 57:192–198.

Ng, J. W., C. Nielsen, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer-vehicle collisions in an urban environment. Human-Wildlife Conflicts 2:34–47.

Ozoga, J. J., L. J. Verme, and C. S. Bienz. 1982. Parturition behavior and territoriality in white-tailed deer: impact on neonatal mortality. Journal of Wildlife Management 46:1–11.

Pojar, T. M., R. A. Prosence, D. F Reed, and T. N. Woodard. 1975. Effectiveness of a lighted, animated deer crossing sign. Journal of Wildlife Management 39:87–91.

R Development Core Team. 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ramp, D., J. Caldwell, K. A. Edwards, D. Warton, and D. B. Croft. 2005. Modelling of wildlife fatality hotspots along the Snowy Mountain Highway in New South Wales, Australia. Biological Conservation 126:474–490.

Reed, D. F., and T. N. Woodard. 1981. Effectiveness of highway lighting in reducing deer-vehicle accidents. Journal of Wildlife Management 45:721–726.

Reilly, R. E., and H. E. Green. 1974. Deer mortality on a Michigan interstate highway. Journal of Wildlife Management 38:16–19.

Richardson, J. H., R. F. Shore, J. R. Treweek, S. B. C. Larkin. 1997. Are major roads a barrier to small mammals? Journal of Zoology 243:840–846.

Romin, L. A., and J. A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24:276–283.

Squires, G. D. G. 2002. Urban sprawl: causes, consequences, and policy responses. Urban Institute, Washington, D. C., USA.

Sudharsan, K., S. J. Riley, and S. R. Winterstein. 2006. Relationship of autumn hunting season to the frequency of deer-vehicle collisions in Michigan. Journal of Wildlife Management 70:1161–1164.

Sudharsan, K., S. J. Riley, and H. Campa, III. 2009. Relative risk of deer-vehicle collisions along road types in southeast Michigan. Human Dimensions of Wildlife 14:341–352.

U.S. Department of Defense. Arnold Engineering Development Center. 2006. Integrated Natural Resources Management Plan. Arnold Air Force Base, Tennessee, USA.

Ward, A. L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. Transportation Research Record 859:8–13

Wood, P., and M. L. Wolfe. 1988. Intercept feeding as a means of reducing deer-vehicle collisions. Wildlife Society Bulletin 16:376–380.

APPENDIX

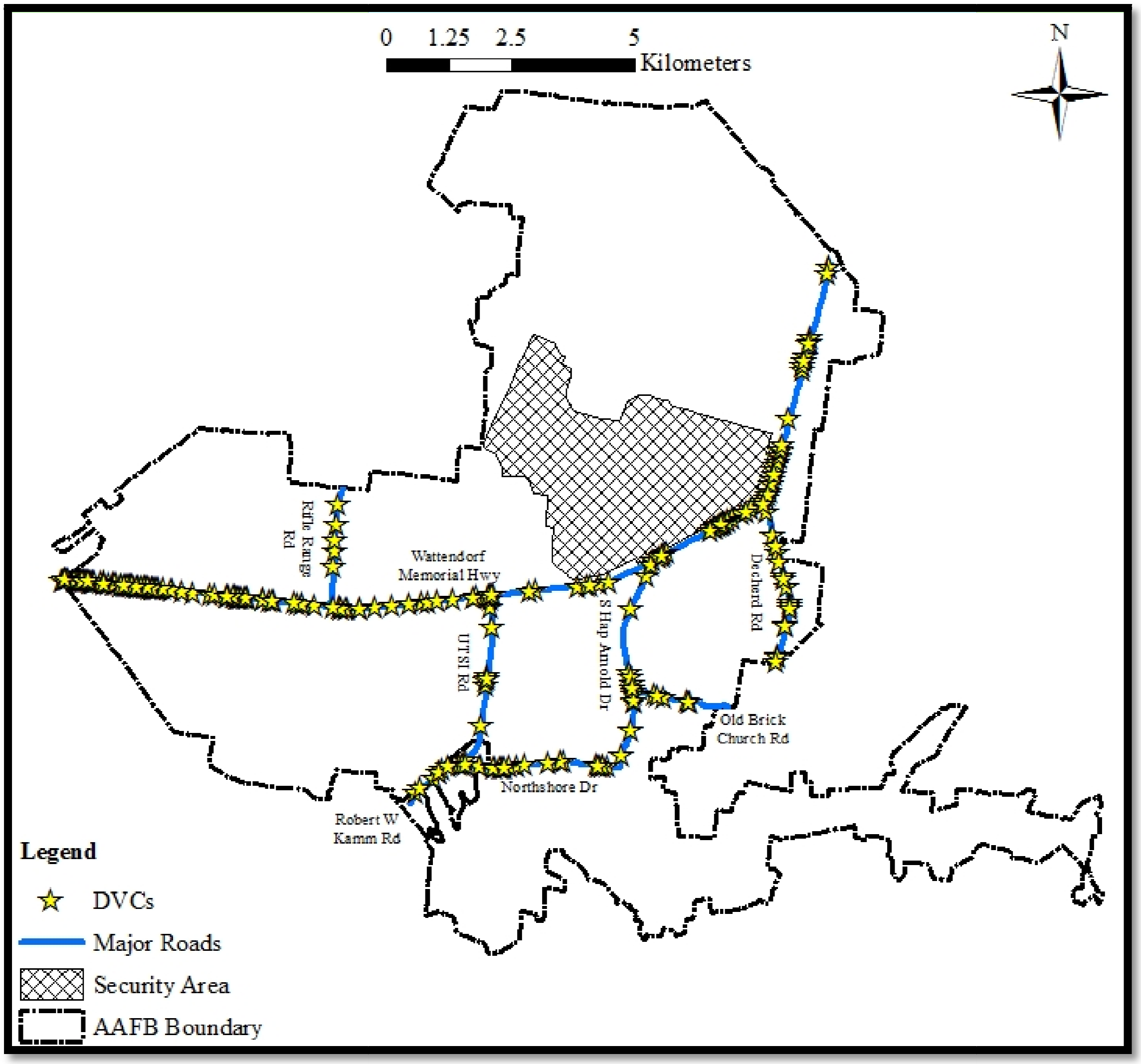

Figure 3. Distribution of deer-vehicle collisions (DVCs) on major roads outside of the Security Area at Arnold Air Force Base, Tullahoma, Tennessee, USA, 2002 – 2009.

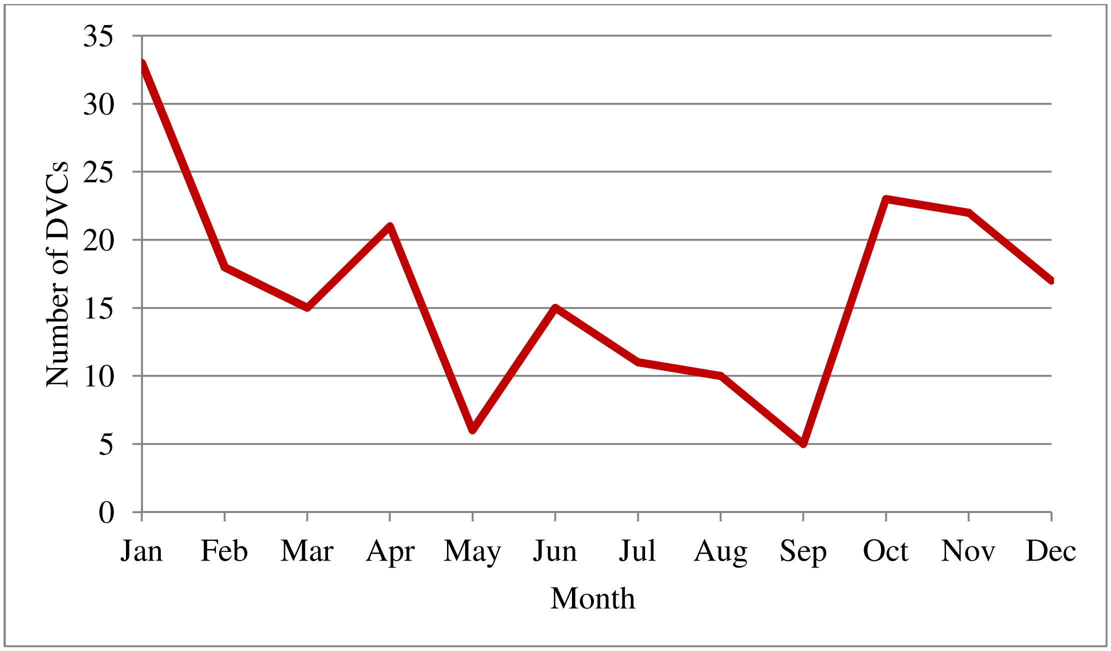

Figure 4. Temporal distribution by monthly occurrence of deer-vehicle collisions (DVCs) at Arnold Air Force Base, Tullahoma, Tennessee, USA, 2005 – 2009.

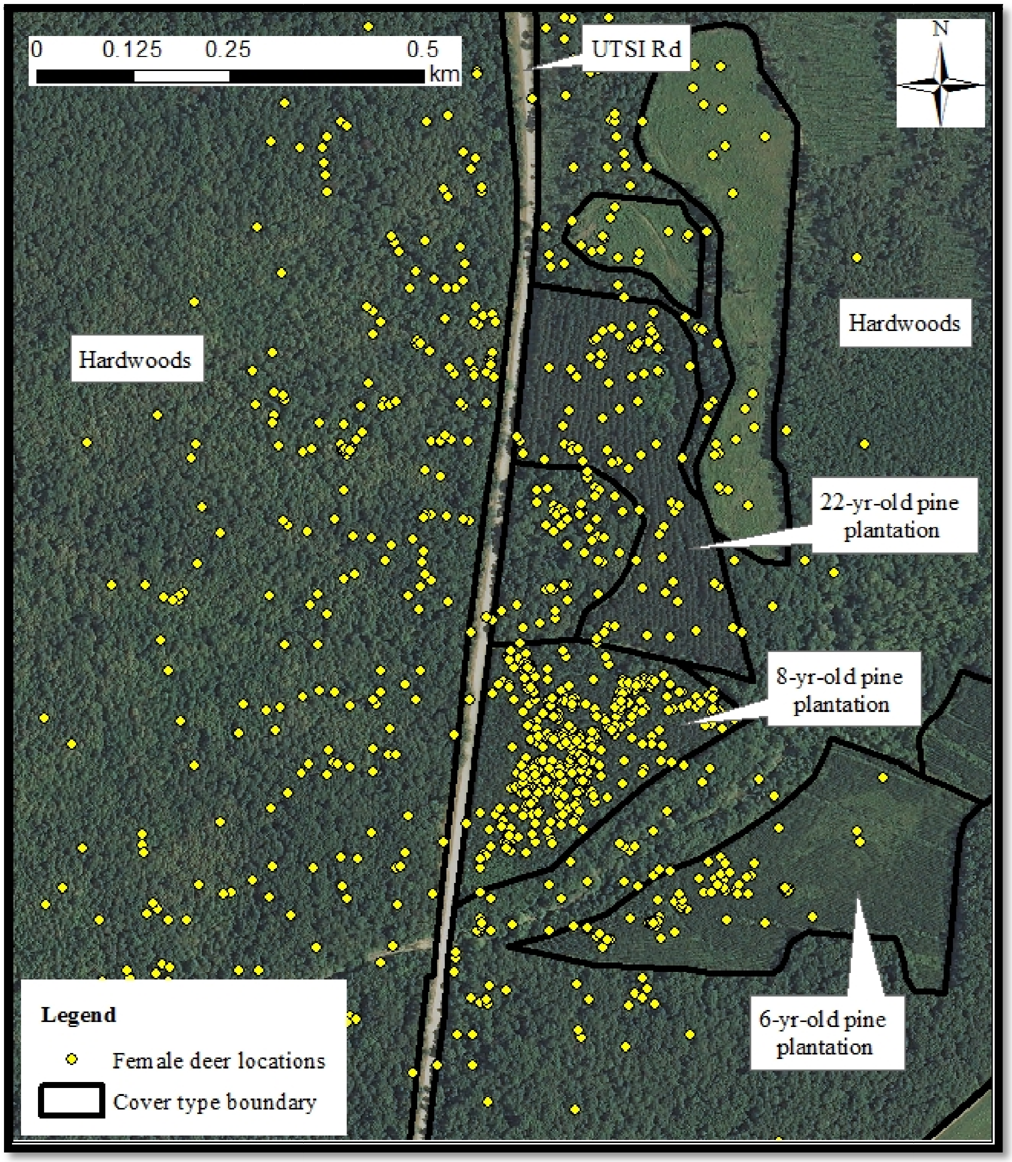

Figure 5. Majority of GPS locations from a collared female deer from June 2010 to January 2011 at Arnold Air Force Base, Tullahoma, TN, USA. She intensively used a young, 8-year-old pine plantation that was directly adjacent to UTSI Rd.

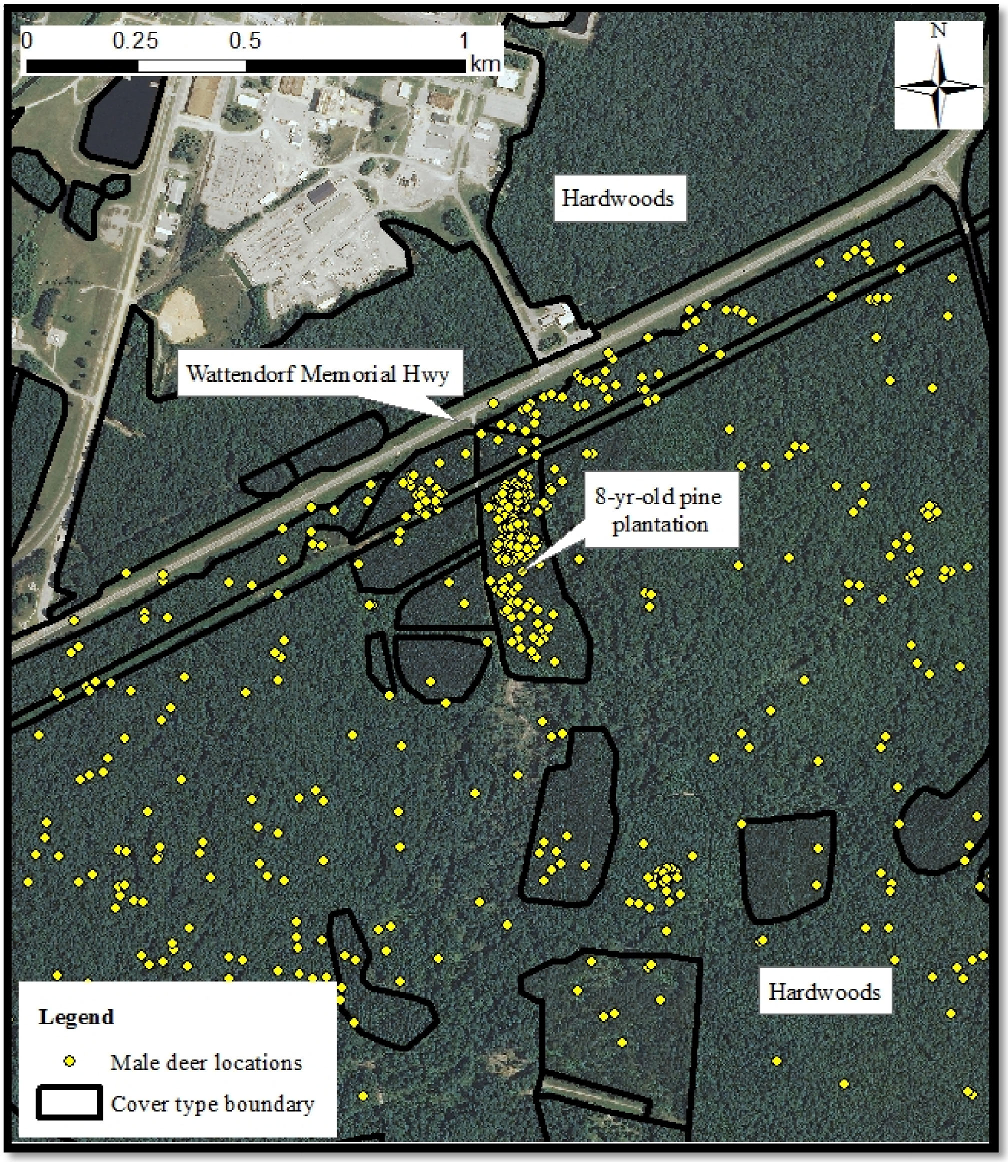

Figure 6. Majority of GPS locations for a collared male from July 2010 to December 2011 at Arnold Air Force Base, Tullahoma, TN, USA. He intensively used a young, 8-year-old pine plantation in close proximity to Wattendorf Memorial Hwy.

Table 3. Logistic regression models predicting white-tailed deer-vehicle collisions (DVCs) along major public roads outside of the Security Area at Arnold Air Force Base in Tullahoma, Tennessee, USA, 2002 – 2009. Models shown are < 4 ΔAICc of top model.

Model[a]	**Log Likelihood**	**K**[b]	**AICc**[c]	**ΔAICc**[d]	w_i[e]
$\gamma = \beta_o$ + drain + intersect + %AD + %PI + speed + volume	-346.25	8	708.77	0.00	0.25
$\gamma = \beta_o$ + drain + intersect + %PI + speed + volume	-348.04	7	710.28	1.51	0.12
$\gamma = \beta_o$ + drain + intersect + %AD + %HW + %PI + speed + volume	-346.22	9	710.78	2.01	0.09
$\gamma = \beta_o$ + drain + intersect + %AD + %ES + %PI + speed + volume	-346.24	9	710.82	2.05	0.09
$\gamma = \beta_o$ + drain + intersect + %ES + %HW + %PI + speed + volume	-346.36	9	711.06	2.29	0.08
$\gamma = \beta_o$ + drain + intersect + %HW + %PI + speed + volume	-347.60	8	711.47	2.70	0.07
$\gamma = \beta_o$ + drain + intersect + %ES + %PI + speed + volume	-347.97	8	712.21	3.44	0.05
$\gamma = \beta_o$ + drain + intersect + %ES + %HW + speed + volume	-348.16	8	712.59	3.82	0.04

[a] drain = distance (m) to nearest intersecting drainage or stream, intersect = distance (m) to nearest public, paved intersection, %AD = percentage of anthropogenic disturbance within 125 m, %ES = percentage of early succession within 125 m, %HW = percentage of hardwood within 125 m, %PI = percentage of pine plantation within 125 m, speed = road segment speed limit (25, 35, 40, 45, 55

Table 3 continued.

mph), volume = road traffic volume (1 = low, 2 = medium, 3 = high).

[b] K = number of parameters including intercept

[c] AICc = Akaike's second-order information criterion

[d] ΔAICc = relative difference in AICc from the model with lowest AICc

[e] w_i = model weight

Table 4. Model-averaged beta estimates (β) for variables included in logistic regression models predicting white-tailed deer-vehicle collisions (DVCs) along major public roads outside of the Security Area at Arnold Air Force Base in Tullahoma, Tennessee, USA, 2002 – 2009.

Variable[a]	**β**	**SE**[b]	**Lower 95% CI**	**Upper 95% CI**
Intercept	1.0166	1.1121	-1.1630	3.1962
Drain	0.0010	0.0004	0.0003	0.0018
Intersection	-0.0007	0.0002	-0.0010	-0.0003
% AD	0.0102	0.0085	-0.0066	0.0269
% ES	-0.0064	0.0095	-0.0251	0.0123
% PI	0.0232	0.0078	0.0080	0.0385
% HW	-0.0080	0.0090	-0.0256	0.0097
Speed	-0.0528	0.0211	-0.0942	-0.0114
Volume (2)	1.1394	0.6171	-0.0701	2.3488
Volume (3)	1.7497	0.6407	0.4939	3.0055

[a] drain = distance (m) to nearest intersecting drainage or stream, intersect = distance (m) to nearest public, paved intersection, %AD = percentage of anthropogenic disturbance within 125 m, %ES = percentage of early succession within 125 m, %HW = percentage of hardwood within 125 m, %PI = percentage of pine plantation within 125 m, speed = road segment speed limit (25, 35, 40, 45, 55 mph), volume = road traffic volume (1 = low, 2 = medium, 3 = high).

[b] Adjusted standard error

VITA

Peyton Seth Basinger was born in Fairhope, Alabama on December 19, 1986. He graduated from Demopolis High School in 2005. Seth then attended Lurleen B. Wallace Community College on a baseball scholarship before earning his Bachelor of Science degree in Biosystems Engineering at Auburn University in 2010. He then earned a Master of Science degree in Wildlife and Fisheries Science at the University of Tennessee−Knoxville.