FINAL PROJECT REPORT

DEVELOPMENT AND EVALUATION OF STRATEGIES TO REDUCE THE INCIDENCE OF DEER-VEHICLE COLLISIONS (PHASE III)
–
OPERATIONAL FIELD TRIAL, PART A

prepared by

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16. Abstract:
To better understand deer movements that might contribute to deer-vehicle collisions (DVC), we conducted preparatory field work necessary for an operational field trial of the efficacy of a 1.2-m woven-wire fence with a top-mounted outrigger. We worked with officials from GDOT and the Federal Highway Administration-Georgia Division to select a 5-mile segment of I-20 near Madison, Georgia. During February-June 2012 and January-April 2013, we captured 32 deer within the 5-mile test roadway and fitted them each with a Global Positioning System collar, programmed to collect 24 locations per day, and monitored surviving deer until April 2014. Each deer was classified as: (1) frequent user, (2) occasional user, or (3) rare user based on highway right-of-way (ROW) utilization. Frequent users (359.5 ± 41.7 m) were closer ($P < 0.01$; $F_{2, 27}=8.46$) to the median of I-20 than occasional (715.3 ± 236.4 m) and rare (766.6 ± 72.3 m) users, but occasional and rare users were the same distance ($P > 0.05$) from the median. Within the frequent user group, the percentage of ROW locations for individuals ranged from 1.7% to 25.8%. Deer ROW use occurred primarily during nighttime hours with about 37% of locations within the ROW occurring between 2200-0300 hours. Increased ROW use by female deer that were frequent users during May and June was likely due to females selecting the ROW for parturition. We also evaluated the annual distribution of DVCs in Georgia based on records of DVCs from 2005-2012 (n = 45,811) to identify peaks in DVCs for each of Georgia's 159 counties, compared to deer breeding data from the Georgia Department of Natural Resources. We observed high concurrence among timing of peak DVCs, peak conception, and peak rut movement. To potentially reduce DVC risk, we recommend: (1) lethal removal of frequent ROW users, (2) warning motorists of the increased risk of encountering deer in the ROW during deer breeding seasons and while driving late at night, and/or (3) modifying ROW habitat to help maintain ROW fences and reduce food and cover resources that can attract deer to roadways.

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EXECUTIVE SUMMARY

In 2004, Drs. Robert J. Warren and Karl V. Miller of the University of Georgia (UGA) and Dr. George R. Gallagher of Berry College initiated Phase I of this collaborative research, which resulted in the Ph. D. dissertation of Gino D'Angelo (2007) and the M.S. thesis of Sharon Valitzski (2007). Phase I research findings were submitted to GDOT on 2 July 2007. In Phase I, we conducted research directed at learning more about deer vision and hearing so we could objectively evaluate sight- and sound-based deterrents to deer-vehicle collisions (DVCs) based on their sensory abilities. We learned white-tailed deer possess ocular features similar to other ungulates including a horizontal slit pupil, reflective tapetum lucidum, typical retinal structure, and medium wavelength sensitive cone photoreceptors concentrated in a horizontal visual streak. The visual system of white-tailed deer is specialized for sensitivity in low-light conditions and for enhanced surveillance of a broad area. In a field-based experiment with free-ranging deer, we evaluated the behavioral responses of white-tailed deer to 4 colors of wildlife warning reflectors (red, white, blue-green, and amber) that are purported to reduce the incidence of deer–vehicle collisions. We observed white-tailed deer behaviors relative to roads before and after installation of wildlife warning reflectors using a forward-looking infrared camera during 90 observation nights. We concluded that wildlife warning reflectors were ineffective in changing deer behavior such that deer–vehicle collisions might be prevented.

Also during Phase I, we used auditory brainstem response testing, to determine that white-tailed deer hear within the range of frequencies we tested, between 0.25–30 kilohertz (kHz), with best sensitivity between 4–8 kHz. The upper limit of human hearing lies at about 20 kHz, whereas we demonstrated that white-tailed deer detected frequencies to at least 30 kHz. In a field-based experiment with free-ranging deer, we evaluated the behavioral responses of white-

tailed deer to pure-tone sounds within their documented range of hearing. Deer behavior within 10 m of roadways was not altered in response to a moving automobile fitted with a sound-producing device that produced 5 sound treatments. Many commercially available, vehicle-mounted auditory deterrents (i.e., deer whistles) are purported to emit continuous pure-tone sounds similar to those we tested. However, our data suggest that deer whistles are likely not effective in altering deer behavior in a manner that would prevent deer–vehicle collisions.

In 2007, Phase II of this collaborative effort began under the direction of Drs. Robert J. Warren and Karl V. Miller of UGA, resulting in the M. S. theses of Daniel W. Stull (2009), William D. Gulsby (2010), Bradley S. Cohen (2011), and Elizabeth A. Miller (2013). Phase II research findings were submitted to GDOT on 2 December 2010. During Phase II, in trials with captive deer, we learned woven-wire fences less than 1.8 m in height are ineffective for excluding deer from roadways. Furthermore, addition of an opaque covering did not improve efficacy. Efficacy of 1.8-m to 2.4-m woven-wire fences might be acceptable depending on the level of exclusion required along a particular roadway. However, 1.8-m to 2.4-m woven-wire fences can potentially trap deer in the roadway, if they circumvent the fence ends. Woven-wire fences 2.1-m tall and a 1.2-m woven-wire fence with a top-mounted outrigger angled toward the deer were most effective at restricting deer movements. During Phase II, we also tested efficacy of a single layer of Type III rip-rap rock (i.e., tactile barrier) for restricting movement of captive deer. The layer of rip-rap did not prevent deer from crossing between 2 adjacent outside paddocks, and likely would be ineffective for excluding deer from roadways. Within weeks of construction, the rip-rap settled, collected debris, and plants became established among the rocks; requiring repeated control by herbicide. We could not recommend this barrier to mitigate DVCs.

In addition to the above trials involving captive deer, we tested efficacy of greater than 2.1-m tall and a 1.2-m woven-wire fence for restricting movement of free-ranging deer; fences were 1-mile long each. Using Global Positioning System (GPS) telemetry we monitored deer movements before (pre-treatment) and after fence construction. We observed seasonal changes in deer home ranges and core areas, but, we found no effect of fencing on home range size. Deer with pre-treatment home ranges that approached or encompassed the end of the fence maintained a high degree of site fidelity by circumventing the fence. However, fence crossings were reduced by 98% and 90% for the 2.4-m and outrigger treatment groups, respectively. Although we recorded fewer crossings of the 2.4-m fence, the prototype outrigger fence was considered to be a viable option for reducing DVCs because of its affordability and potential as a one-way barrier. More importantly, we learned the importance of using localized data on deer home range sizes to determine the minimum length of fencing necessary to prevent circumvention in high-risk areas.

In the final Phase II experiments, we focused on recording behavioral measures of deer vision with the hope that the knowledge gained would be useful for developing more effective vision-related DVC-deterring devices. Few studies have focused on the cognitive perception of deer because of the logistical difficulty in training deer. To facilitate deer training, we developed and validated a automated system that trains white-tailed deer to associate a supra-threshold, white-light stimulus with a food reward through operant conditioning techniques. The ‘‘deer training apparatus’’ (DTA) automatically dispenses food, rings a start buzzer, randomly assigns a stimulus light over 1 of 2 troughs, and registers a deer’s choice. If a deer goes to a trough with the light illuminated, then a correct choice is registered. All 6 deer tested met successful training criteria by Day 19, and a performance of 88.2% correct choices by Day 25. In addition, we trained 2 does to participate in data collection trials when pseudoisochromatic plate tests were presented as stimuli after mounting liquid crystal display monitors on the DTAs. We concluded that the DTA presents an effective and efficient way of training white-tailed deer, and provided an experimental platform for future research on behavior, perception, and preference.

In 2012, Phase III began under the direction of Drs. Robert J. Warren and Karl V. Miller of UGA, resulting in the M. S. theses of James H. Stickles (2014). This phase of the research was designed to serve as a large-scale operational field trial of the 1.2-m woven-wire fence with a top-mounted outrigger. Work and associated funding were split into Phase III, Part A and Phase III, Part B. Part A represented the preparatory field work required before we could construct the experimental fence. Specifically, during Part A we selected the experimental roadway segment, captured deer, and fitted them with Global Positioning System (GPS) collars. Part B began in 2013 and included construction of the experimental fence and monitoring of deer movements before, during and after fence construction. Although Part A and Part B were funded for 2 years, 2013 represented the second year of Part A and the first year of Part B. In this final report, we presented information generated through the completion of Phase III, Part A. The final report for Part B will be submitted after we've completed the analysis of deer movement data after fence construction.

During Part A, we worked with officials from GDOT and the Federal Highway Administration-Georgia Division to identify a 5-mile segment of highway in Georgia for use in the operational field trial. To be selected, the test roadway segment had to be identified as having a high incidence of deer-vehicle collisions and it had to be fenced on both sides with standard 4-foot woven-wire fencing so that we can add the 2-foot outriggers on top of the existing fence. The test roadway that we selected was the 4.8-mile segment of I-20 starting at

Exit 114 near Madison Georgia and proceeding eastward to the underpass at Barrow's Grove Road. This I-20 test roadway segment was ideal for this experiment because it had only 1 major breach along its entire length, which occurs at the overpass at Bethany Road. Of course, potential breaches could occur at both ends of the 4.8-mile segment at Exit 114 and the Barrow's Grove Road underpass; however, the urbanized area surrounding Exit 114 should act as a barrier to deer movement, and the underpass at Barrow's Grove Road should allow deer to pass safely under I-20. This I-20 test roadway segment also was ideal because it contains heavily forested habitat, as well as mixed agriculture and forest habitat on both sides of the road. These associated habitat features represent most of the major habitat types that occur along roadways throughout much of Georgia.

During February-June 2012 and January-April 2013, we captured 32 deer and fitted them each with a GPS collar, programmed to collect 24 locations per day. Each deer was classified as: (1) frequent user, (2) occasional user, or (3) rare user based on highway right-of-way (ROW) utilization. For all deer, mean 95% home range size and 50% core area of use size were 103.6 $\pm$ 11.9 ha ($\bar{x}$ $\pm$ SE; range = 29.9 - 329.8 ha) and 17.0 $\pm$ 1.5 ha (range = 5.7 - 36.0 ha) respectively. Frequent users (359.5 $\pm$ 41.7 m) were closer ($P < 0.01$; $F_{2, 27}=8.46$) to the highway median than occasional (715.3 $\pm$ 236.4 m) and rare (766.6 $\pm$ 72.3 m) users, but occasional and rare users were the same distance ($P > 0.05$) from the median. Within the frequent user group, the percentage of ROW locations for individuals ranged from 1.7% to 25.8%. Deer ROW use occurred primarily during nighttime hours with about 37% of locations within the ROW occurring between 2200-0300 hours. Increased ROW use by female frequent users during May and June was likely due to females selecting the ROW for parturition. To potentially reduce DVC risk, we recommended: (1) lethal removal of frequent ROW users, (2) warning motorists of the increased risk of encountering deer in the ROW during late-night travel, and (3) modifying ROW habitat to help maintain ROW fences and reduce food and cover resources.

Numerous studies have reported that DVCs increased during the breeding season due to increased deer movements associated with breeding behavior. To determine if breeding season-related deer movements affected the annual distribution of DVCs in Georgia we obtained records of DVCs from 2005-2012 (n = 45,811) to identify peaks in DVCs for each of Georgia's 159 counties. The most commonly used method to determine the timing of breeding for deer is to measure fetuses from deceased animals. Therefore, we compared the timing of DVC peaks with (1) fetal data from 3 counties in Georgia, (2) deer movement data from a sample of GPS-collared male and female deer in Harris County, Georgia, and (3) a popularized 'rut map' for the state that was based on Georgia Department of Natural Resources fetal data and hunter observations of deer breeding behavior. We observed high concurrence among timing of peak conception, peak rut movement, and peak DVCs. At the regional level, there were strong similarities between peak DVCs and peak rut. At the county level, peak DVCs were in general concordance with the popular rut map. However, the county-based map of DVCs appeared to provide greater local specificity. For assessing the timing of the breeding season at a county or regional scale, DVC data are cost effective and less susceptible to measurement biases compared to traditional methods employing fetal measurements. In addition, mapping the peak occurrences of DVCs can be used to warn motorists of increased risk associated with deer activity at the local level.

DISSERTATIONS AND THESES RESULTING FROM PHASES I, II AND III PART A: (PHASE III PART A, DOCUMENTS ATTACHED):

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D'Angelo, G. J. 2007. Development and evaluation of strategies designed to minimize deer-vehicle collisions. Ph.D. Dissertation. University of Georgia, Athens, Georgia, USA.

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Valitzski, S. A. 2007. Evaluation of sound as a deterrent for reducing deer-vehicle collisions. M.S. Thesis. University of Georgia, Athens, Georgia, USA.

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PRESENTATIONS RESULTING FROM PHASES I, II AND III PART A

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Miller, K. V. 2005. Evaluation of strategies designed to reduce deer-vehicle collisions. Invited presentation at the Congressional Sportsman's Caucus, Capitol Hill, Washington, D.C.

Stickles, J. H. 2014. Minimizing deer-vehicle collisions along Georgia's Interstates: Progress Report. Oral presentation at Quality Deer Management Association National Convention, Athens, Georgia.

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MOVEMENT PATTERNS OF WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) ALONG AN INTERSTATE HIGHWAY IN GEORGIA, USA

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ABSTRACT: Although many studies have investigated the temporal and spatial distribution of deer-vehicle collisions, movement patterns of white-tailed deer (*Odocoileus virginianus*) as influenced by high-volume roadways have been little studied to assess deer-vehicle collision (DVC) risk. From February-June 2012 and January-April 2013, we captured 32 deer within 0.5-km of a section of Interstate 20 (I-20) in central Georgia and equipped them with GPS collars programmed to collect 24 locations per day. Based on the frequency of individual deer locations within the right-of-way (ROW), we classified animals as either frequent users, occasional users, or rare users of the ROW. The distance from the median to the home range centroid differed among groups ($P < 0.01$; $F_{2, 27}=8.46$). Home range centroids for frequent users (359.5 $\pm$ 41.7 m) were closer ($P < 0.01$) to the I-20 median than rare (766.6 $\pm$ 72.3 m) users, but did not differ between frequent and occasional users ($P > 0.05$, 715.3 $\pm$ 236.4 m) or between occasional and rare users ($P > 0.05$). The percentage of locations within the ROW for those animals classified as frequent users ranged from 1.7% to 25.8%. ROW use occurred primarily at night with 37% of locations within the ROW occurring between 2200-0300 hours. At least 3 of the collared females apparently selected the ROW as parturition sites. Because 34% of the collared animals accounted for about 98% of all animal locations within the highway ROW, targeted removal of deer frequenting ROWs may potentially reduce DVC risk. Modifying ROW habitat or enhanced ROW fence maintenance also may reduce utilization by deer.

KEYWORDS: deer-vehicle collisions, GPS, highway, traffic, white-tailed deer

INTRODUCTION

Each year in the United States, over 1 million deer-vehicle collisions (DVCs) cause an estimated 29,000 injuries, up to 200 deaths (Conover et al. 1995), and losses of $4.6 billion in vehicle damage and medical expenses (Insurance Information Institute 2010). In Georgia, about 50,000 DVCs occur annually, accounting for nearly 14% of reported vehicle collisions (Bowers et. al 2005). Georgia consistently ranks among the top 10 states for numbers of reported DVCs (State Farm Insurance Company 2011).

DVCs in Georgia are spatially clustered. For example, 13% of Georgia's counties accounted for 55% of reported DVCs (Bowers et al. 2005). Other studies have described clustering of DVCs along specified sections of highway or identifiable landscape features (see review by Gunson et al. 2011). The uneven spatial distribution of DVCs suggests mitigation efforts directed at the most problematic sections of roadway may reduce the incidence of DVCs (Hubbard et al. 2000, Gunson et al. 2011).

Based on an analysis of 47 studies investigating the temporal distribution of DVCs among species of deer, Steiner et al. (2014) concluded that deer behavior was the most reliable predictor of DVCs with traffic volume playing only a minor role in their occurrence. DVCs occur most commonly at dawn and dusk, which is consistent with the crepuscular movement patterns of white-tailed deer (Carbaugh et al. 1975, Allen and McCullough 1976, Sudharsan et al. 2006, Webb et al. 2010). Seasonally, most DVCs occur during the spring and fall when breeding (Allen and McCullough 1976, Hubbard et. al 2000, Steiner et al. 2014), dispersal (Nixon et al. 2007; Long et al. 2008, 2009), excursions (Karns 2011, Kolodzinski et al. 2010, Olson et al. 2014), migration (Nixon et al. 2008), and hunting pressure (Sudharsan et al. 2006) may increase deer activity. In addition, when food and salt resources are limited, deer may be attracted to these resources where they exist in highway rights-of-way (ROWs; Bellis and Graves 1971, Feldhamer et al. 1986). Before DVCs can be reduced effectively, factors influencing deer movements relative to roadways must be understood thoroughly (Puglisi et al. 1974).

Although structures such as fences, overpasses, and underpasses are effective at mitigating DVCs, physical and economic constraints often limit implementation. Nonstructural alternatives such as education, signage, intercept feeding, repellants, reflectors, hazing devices, population control, and habitat modification are often less expensive, but the biological consequences and effectiveness of these methods are not well understood (Hedlund et al. 2004, Glista et al. 2009). Nevertheless, an understanding of the effect of deer behavior on the spatial and temporal distribution of DVCs is requisite to the successful implementation of any mitigation technique. Past studies have given some indication of spatial and temporal use of highways by deer, but have done so using indirect measures such as surveys of carcasses, tracks, or deer along roads (Peek and Bellis 1969, Carbaugh et al. 1975, Allen and McCullough 1976, Waring et al. 1991). Feldhamer et al. (1986) studied highway use by deer using very high frequency (VHF) telemetry. However, VHF telemetry lacks the fine-scale data needed to quantify the effects of a highway on deer movements and to assess collision risk based on animal behavior (Gulsby et al. 2011).

Recently, global positioning system (GPS) technology has been used to study animal behavior relative to highways to assess risks to human safety and to implement effective mitigation techniques (Waller and Servheen 2005, Dodd et al. 2007, Gagnon et al. 2007). No studies have used GPS technology to study white-tailed deer movements relative to high traffic volume highways. We used GPS technology to study the spatial and temporal behavior of deer relative to a section of Interstate 20 (I-20) in central Georgia, USA.

STUDY AREA

Our study site included the area 1.6-km north or south of a 7.68-km section of I-20 extending from Exit 113 to the Barrows Grove Road underpass near Madison, Georgia. The plant community within the I-20 ROW was diverse and consisted of grasses (*Schedonorus arundinaceus*, *Cynodon dactylon*, *Andropogon* spp., *Seteria* spp., *Paspalum* spp., and *Digitaria* spp.), forbs (*Trifolium* spp., *Verbena* spp., *Solidago* spp.,), vines (*Rubus* spp. *Vitis* spp., *Smilax* spp., *Toxicodendron radicans, Campsis radicans,* and *Pueraria montana*), shrubs (*Vaccinium* spp. and *Ligustrum sinense*) and trees (*Liquidambar styraciflua*, *Liriodendron tulipifera*, *Pinus taeda*, *Ulmus alata*, *Carya* spp., *Diospyros virginiana*, and *Quercus* spp.). Outside of the ROW, the western portion of the study area was primarily forested on both sides of the highway with planted loblolly pines and mixed pine-hardwoods. The eastern portion of the study area consisted of agricultural fields, planted pines, mixed pine-hardwoods, and pasture on both sides of the highway.

A 1.2 m woven-wire fence, built by Georgia Department of Transportation (GDOT) in 1979, delineated the ROW. Because of little maintenance since construction, sections of the fence were collapsed by fallen trees or overgrown by vegetation. In addition, many of the original wooden posts were rotted or broken.

METHODS

Deer Capture & Monitoring

From February-June 2012 and January-April 2013, we darted deer at tree stand and box blind locations baited with whole kernel shelled corn. Darting sites were located within 0.5-km of I-20. To facilitate capture, we monitored use of bait stations by deer with infrared cameras (Moultrie®, Alabaster, Alabama, USA). Using 3 ml transmitter darts (Pneu-dart Inc., Williamsport, Pennsylvania, USA), we immobilized deer with an intramuscular injection of Telazol® (500mg; tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and AnaSed® (450mg; xylazine hydrochloride; Congaree Veterinary Pharmacy, Cayce, South Carolina, USA). We applied eye ointment (Dechra Veterinary Products, Overland Park, Kansas, USA) and blindfolded immobilized deer. In addition, we monitored heartbeat, temperature, and respiration rate at 10-minute intervals. Because yearling deer were likely to have already dispersed to their adult home ranges prior to our capture season (Long et al. 2008), we assigned deer ages as adults (greater than or equal to 1.5 years-old at time of capture) or juveniles (<1.5 years-old at time of capture) based upon tooth replacement and wear (Severinghaus 1949). Each deer was outfitted with ear tags for individual identification and a FOLLOWiT Tellus Medium GPS collar with remote ultra-high frequency (UHF) download and drop-off capabilities (FOLLOWiT Wildlife, Lindesberg, Sweden) programmed to collect 1 location per hour throughout the study period. The collars were also programmed to emit a VHF beacon from 0900-1700 hours 4 days a week, and to emit a mortality beacon after 6 hours of no movement. After 80 minutes, deer received a 300mg injection (150mg

[IV] + 150mg [IM]) of Tolazine® (tolazoline hydrochloride; Congaree Veterinary Pharmacy, Cayce, South Carolina, USA). All deer were monitored until they were ambulatory. All animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A2011 08-023-R1).

From February 2012 to April 2014 we monitored survival of each deer via VHF telemetry on a weekly basis. We remotely downloaded GPS data from each deer's collar once every 4 to 6 months. We calculated mean collar error ($\bar{x}$ =24.2m) by placing one collar at two surveyed GPS test sites at the University of Georgia, Athens, Georgia (n=252 points).

Traffic

We downloaded traffic volume data recorded by a traffic counter installed within our study area by the Georgia Department of Transportation (GDOT) from the GDOT website. We calculated mean traffic volume by hour, day, and month from 1 January 2012 – 31 December 2013. Using ArcGIS 10.2 (Environmental Research Systems Institute, Inc.), we digitized the I-20 ROW and median.

Spatial and Temporal Analysis

We imported GPS locations into ArcGIS 10.2 and removed impossible locations and locations associated with excursions and dispersals away from the ROW. We also removed improbable locations within the ROW based on prior and subsequent locations. After isolating locations that occurred within the ROW, we classified deer into three groups: (1) frequent users (greater than 1% of all locations within the ROW), (2) occasional users (1.0%-0.1% of all locations within the ROW), and (3) rare users (<0.1% of all locations within the ROW).

We used Program R (R Development Core Team 2010) and a dynamic Brownian bridge movement model to calculate 95% and 50% utilization distributions (UDs) for each deer

(Kranstauber et al. 2012). The distance of the center of the 95% UD geoid to the median was calculated using “Mean Center” and “Near” in ArcToobox. We used a Student’s t-test to test for differences in 95% and 50% UDs between sexes. We used a single factor ANOVA to test for differences in 95% and 50% UDs and distance of mean center from the median among the 3 classified groups of deer. We used Tukey’s HSD test to separate treatment means ($\alpha = 0.05$).

We used “Near” in ArcToolbox to calculate the distance of each GPS location from the median. To avoid bias due to the differences in the number of locations for individual deer, we used the proportion of locations that occurred within the ROW by time interval (hour, day, and month) and compared those proportions against traffic data grouped by deer sex for the frequent user group.

Because greater than 90% of all locations occurred within 1-km of I-20 median, we compared the mean percentage of locations at 40m intervals from 0 to 1,000 m from the I-20 median for males and females to test for gender-related ROW preference or avoidance by the frequent user group of deer. We repeated this analysis with only female frequent users for the months of May-June versus July-April.

Because female deer constrain their home ranges to the general vicinity of their fawns after parturition (D’Angelo et al 2004, Webb et al. 2010, DeYoung and Miller 2011), we reviewed daily clusters of locations for the frequent user group during May and June. When the minimum convex polygon of a daily cluster was $\leq$ 2 ha in size, the geographic center of the cluster was calculated using “Mean Center,” and buffered by a circle with a 300 m radius. The 28 ha area of the circle buffer was approximately 1/3 the size of the average post-parturition diel home range size reported by D’Angelo et al. (2004). We assumed that parturition had occurred if greater than 90% of the diel locations for the initial cluster and 2 days thereafter were contained within the 300 m buffer.

RESULTS

Deer Capture and Monitoring

We captured 32 deer (14 adult males, 11 adult females, 6 juvenile males, 1 juvenile female). Due to collar belting malfunctions, GPS unit malfunctions, and mortalities we obtained partial data sets on most collared animals. Number of collared deer per month ranged from 11 (December) to 30 (June & July; Table 1). Overall, we collected 193,977 total locations, of which 6,107 occurred within the I-20 ROW. Two deer (1 adult, 1 juvenile) were excluded from UD and distance to the median calculation due to data gaps that spanned greater than or equal to12 days. The 95% and 50% UDs did not differ between sexes (95%: $P = 0.18$; 50%: $P = 0.84$) or among groups (95%: $P = 0.85$, $F_{2,\ 27} = 0.16$; 50%: $P = 0.33$, $F_{2,\ 27} = 1.17$), so results were pooled. Average 95% and 50% UDs were 103.6 $\pm$ 11.9 ha ($\bar{x} \pm$ SE; range = 29.9 - 329.8 ha) and 17.0 $\pm$ 1.5 ha (range = 5.7 - 36.0 ha) respectively. No deer had 50% UDs on both sides of I-20. The distance from the median to the home range centroid differed among groups ($P < 0.01$; $F_{2,\ 27}=8.46$). Home range centroids for frequent users (359.5 $\pm$ 41.7 m) were closer ($P < 0.01$) to the I-20 median than rare (766.6 $\pm$ 72.3 m) users, but did not differ between frequent and occasional users ($P > 0.05$, 715.3 $\pm$ 236.4 m) or between occasional and rare users ($P > 0.05$).

Group Descriptions

Sixteen of the collared animals (8 adult males, 5 adult females, 2 juvenile males, 1 juvenile female) were considered rare users of the ROW (Figure 1). The percentage of ROW locations for individuals ranged from 0% to 0.07%. The number of locations within the ROW did not exceed 2 for any month (Table 1). This group had 11 deer with locations that extended to the ROW fence, but rarely, if ever, did they cross into the ROW. Of 90,898 locations recorded for this group, no locations were recorded on the opposite side of the interstate.

Five deer (4 adult males, 1 juvenile male) were occasional users of the ROW (Figure 1). The percentage of ROW locations for individuals ranged from 0.2% to 0.9%. The monthly percentage of locations within the ROW ranged from 0% during January, February, and October to 1.3% during April (Table 1). Although the ROW was not a major component of their home range, these deer often traveled parallel to the ROW, occasionally crossing the ROW fence, but not spending much time there. Of 30,393 locations recorded for this group, only no locations were recorded on the opposite side of the interstate.

The frequent user group was composed of 11 deer (2 adult males, 6 adult females, 3 juvenile males). Adult females accounted for about 85% of all locations within the ROW (Figure 1). The percentage of ROW locations for individuals ranged from 1.7% to 25.8%. The monthly percentage of locations within the ROW ranged from 2.2% during February to 17.1% during May (Table 1). With the exception of one juvenile male and one adult male each deer had locations within the ROW during each full month they were collared. Ten out of 11 of frequent users crossed at least one lane of traffic (n = 123) twice, and four deer crossed at least two lanes of traffic (n = 8) twice accounting for a minimum of 278 lane crossings.

The remainder of our analyses focused on the "frequent users" because their repeated use of the I-20 ROW accounted for 97.7% of all locations within the ROW. Therefore, these deer were most likely to be encountered by motorists. Despite potential risk to motorist safety, no frequent users were killed by vehicles during the study period.

Mean daily traffic volume was greatest during July (30,032 $\pm$ 579 vehicles/day; Figure 2) and lowest during January (22,524 $\pm$ 375 vehicles/day; Figure 2). Seasonal use of the ROW by frequent users peaked in May and June and was reflective of increased ROW use by females (Figure 2). A second, smaller increase in ROW use occurred in September apparently due to increased ROW use by females, although overlapping standard error bars suggested no difference in ROW use between males and females (Figure 2). Traffic volume ranged from 33,243 ± 381 vehicles/day on Fridays to 22,995 ± 276 vehicles/day on Tuesdays, and we did not observe a preference of ROW use by deer of either sex related by weekday. On an hourly scale, traffic volume ranged from 2005 ± 18 vehicles/hour at 1600 hours to 231.4 ± 1.7 vehicles/hour at 0300 hours (Figure 3). Deer ROW usage occurred primarily during nighttime hours (1900-0500), for both sexes with about 37% of locations within the ROW occurring between 2200-0300 hours.

There was a clear truncation of locations adjacent to the ROW, but locations tapered gradually as distance from the ROW increased. There appeared to be a tendency for female locations to occur in tighter proximity to the ROW (Figure 4). When isolated to locations within 80 m of the median, the percent of locations of females was disproportionally higher during May and June when compared to locations recorded from July through April (Figure 5). This increased ROW use was reflective of three adult females. We observed tight clustering of locations during a period of greater than or equal to 3 days during May and June suggesting that they had used the ROW as parturition sites. These females frequently moved to and from the ROW following this tight clustering further suggesting that fawns remained within the ROW for several days or weeks following birth.

DISCUSSION

Although we retrieved data from 32 GPS collared deer that were captured within 0.5-km of the ROW, only some deer made frequent use of the ROW. It is evident from our study that not all deer are equally tolerant of high traffic roadways, and for some deer even a short fence was a sufficient deterrent to prevent ROW access. Many deer had home ranges that touched the ROW, and some occasionally used it, but it appeared that both of these classes of animals avoided entering the ROW. In contrast, there were several deer that apparently habituated to the ROW, and these deer incorporated the ROW into their core area.

The daily, weekly, and annual distribution of traffic volume that we observed was similar to other wildlife-vehicle collision studies where temporal distribution of traffic volume was recorded (Allen and McCullough 1976, Waller and Servheen 2005, Killmaster et al. 2006). Deer we classified as frequent users accessed the ROW primarily at night when traffic was lowest and avoided the ROW when traffic volume was highest, suggesting usage of the ROW was related to traffic patterns. Similarly, grizzly bears (*Ursus arctos*) and elk (*Cervus elaphus*) have been observed crossing or using roads most heavily at night during periods of low traffic (Waller and Servheen 2005, Gagnon 2007). Such observations suggest that motorists traveling late at night, when traffic is lowest and visibility is reduced, may be most at risk of encountering wildlife on or near the road.

The diurnal distribution of DVCs among different deer species reportedly follows a consistent bimodal crepuscular pattern (Steiner et al. 2014). Our data indicates that DVCs would be most likely to occur during the evening – a period of increasing deer ROW usage with relatively high traffic volumes. Relatively high traffic volume during key movement periods likely reduces the probability of deer successfully crossing roads (Allen and McCullough 1976, Hussain et al. 2007, Steiner et al. 2014).

Males appeared to avoid the ROW more than females. Only five of 20 males captured were frequent users of the ROW, whereas six of the 12 females captured were frequent users. Waring et al. (1991) rarely observed males in the ROW and in a Pennsylvania study, only 4.7%

of 1,819 sightings of deer in a highway ROW were recognized as males (Carbaugh et al. 1975). Additionally, many DVCs studies report an overall female bias in sex ratio of road killed deer throughout the year with a more equal ratio between males and females during spring and fall (Jahn 1959, Bellis and Graves, 1971, Puglisi et al. 1974, Allen and McCullough 1976, Feldhamer et al. 1986, Hubbard 2000).

Based on a strong clustering of locations within the ROW during May and June, along with subsequent intensive use of the ROW, it is apparent that three females utilized the ROW as parturition and fawn rearing sites. Jahn (1959) and Hubbard (2000) mentioned that females searching for fawning sites may contribute to increased DVCs during the spring, and high quality forage along roads may be important for females raising young (Scanlon and Vaughan 1985, Romin and Bissonette 1996). Perhaps the females habituated to traffic and knowledge of how to negotiate a ROW fence experience decreased disturbance from human activity, dogs, and predators such as coyotes and bobcats (Ruediger 2004, Fahrig and Rytwinski 2009). As such, highway ROWs may provide excellent fawning habitat.

Deer are frequently observed feeding along highway ROWs (Carbaugh et al. 1975, Waring et al. 1991). In our study area, grasses and forbs were available in the ROW throughout the year. The second, smaller peak of ROW use during September may be related to increased availability of hard and soft mast such as acorns (*Quercus* spp.), persimmons (*Diospyros virginiana*), and Muscadines (*Vitis rotundifolia*). For example, one adult male only used the ROW during September and October, returning nearly every day to an area containing acorn producing oaks.

None of the deer that were frequent users of the ROW were involved in a DVC during our study. Perhaps deer familiar with roads may be less susceptible to vehicle strike than are more naïve deer. Feldhammer et al. (1986) reported that two female deer monitored for 12 months and 17 months respectively made extensive use of the ROW and median strip and had crossed the highway numerous times without being hit by a vehicle. However, in the years immediately after new roads are opened, there is generally a sharp increase in DVC mortality which eventually decreases and then stabilizes (Reilly and Green 1974, Falk et al. 1978) suggesting that deer learn to avoid roads during periods of increased risk or mortality removes individuals that cross roads during periods of high risk. During periods associated with increased deer movement, such as the breeding season, deer that generally avoid roads may encounter and attempt to cross roads more frequently.

MANAGEMENT IMPLICATIONS

Because 85% of all deer locations on the ROW were attributed to 6 adult females, targeted removal of frequent ROW users may aid in reducing encounters between motorists and deer throughout the year. However, removals may not significantly reduce encounters that occur during periods of major deer movement.

Due to DVCs occurring most frequently at dawn and dusk, motorists are often encouraged to reduce vehicle speed and increase vigilance during those times. However, our data suggested that motorists traveling between the hours of 2200-0300 were at greatest risk of encountering deer within the ROW. Substantially decreased highway traffic during late-night hours likely explains why fewer deer are killed during that time frame. We recommend that driver education programs warn motorists of the increased risk of encountering deer in the ROW during late-night travel, with recommendations to reduce vehicle speed and to increase their vigilance.

Habitat modifications may discourage deer from using the ROW. Although the ROW within our study area was regularly mowed, the ROW fence was not maintained allowing mast producing trees and shrubs to grow. Removal of mast producing trees and shrubs may reduce the attractiveness of the ROW. Additionally, dead trees and limbs often fall on boundary fences creating large gaps where deer can access the roadway. Although deer can negotiate a 1.2 m ROW fence, regular maintenance of the fence to repair large gaps may discourage some deer use of the ROW. Vegetation within highway ROWs and along the median often consists of preferred forbs, shrubs, and mast-producing trees, providing food and cover for deer and other animals, and reducing visibility for motorists. Removing these types of vegetation and maintaining highway ROWs and medians in low-preference grasses of low height would be desirable. Furthermore, reducing grass height by mowing immediately prior to fawning season may make the ROW a less desirable place for female deer to birth and raise their fawns.

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Table 1. Monthly total and percent of white-tailed deer GPS locations within the ROW on a 7.68-km section of I-20 in Madison, Georgia. Deer were categorized as frequent users (>1% of all locations within the ROW), occasional users (1.0%-0.1% of all locations within the ROW), and rare users (<0.1% of all locations within the ROW).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Frequent Users												
# of deer	5	6	7	10	11	11	11	9	9	8	5	4
Total # locations	4135	4168	5149	5687	7821	8842	7976	7652	6883	5634	4419	4320
# locations in ROW (%)	209 (5.1)	90 (2.2)	286 (5.6)	336 (5.9)	1337 (17.1)	1115 (12.6)	450 (5.6)	656 (8.6)	794 (11.5)	485 (8.6)	102 (2.3)	108 (2.5)
Occasional Users												
# of deer	3	3	3	3	4	4	4	5	4	3	3	3
Total # locations	2126	2502	2325	2544	3274	3218	3242	2398	2893	1953	1951	1967
# locations in ROW (%)	0 (0)	1 (0.0)	29 (1.3)	34 (1.3)	19 (0.6)	7 (0.2)	10 (0.3)	6 (0.3)	7 (0.2)	0 (0)	1 (0.1)	12 (0.6)
Rare Users												
# of deer	6	7	9	14	14	15	15	13	11	9	9	4
Total # locations	4404	4683	5285	6663	10595	12205	11866	10753	8576	6587	6587	4273
# locations in ROW (%)	1 (0.0)	1 (0.0)	2 (0.0)	2 (0.0)	0 (0)	2 (0.0)	1 (0.0)	1 (0.0)	0 (0)	2 (0.0)	2 (0.0)	0 (0)

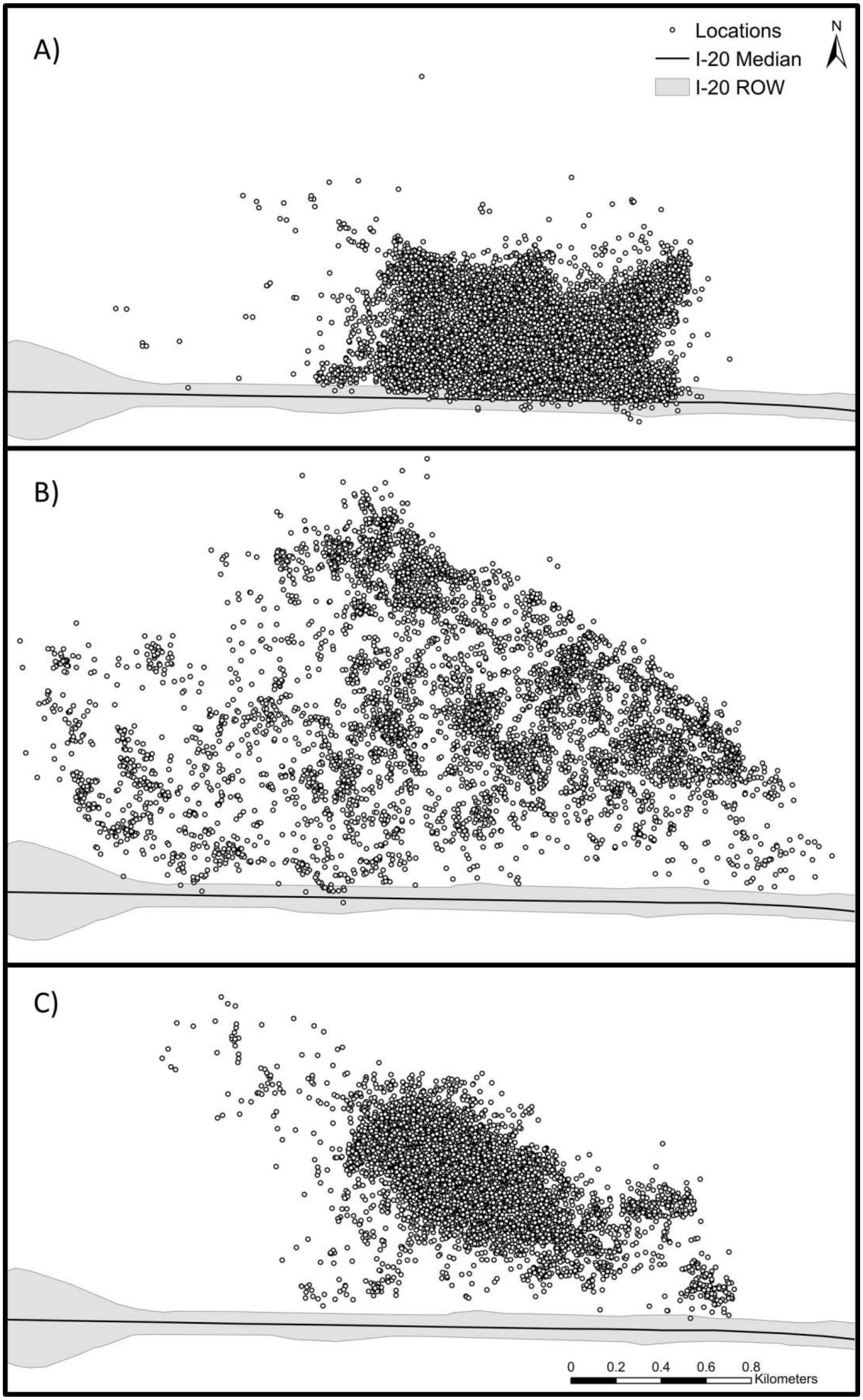
A)
Locations
I-20 Median
I-20 ROW
N
B)
C)
0 0.2 0.4 0.6 0.8
Kilometers

Figure 1. GPS locations demonstrating ROW use for: A) frequent users (adult female; n = total [ROW] 13,525 [1,220]; date range = 30 May 2012 to 28 February 2014), B) occasional users (adult male; n = 6,825 [14]; date range = 2 February 2013 to 29 May 2013; 29 August to 28 February 2014), and C) rare users (adult female; n = 13,795 [5]; date range = 25 May 2012 to 25 January 2014). These three deer occupied the same general area along I-20 in Madison, Georgia.

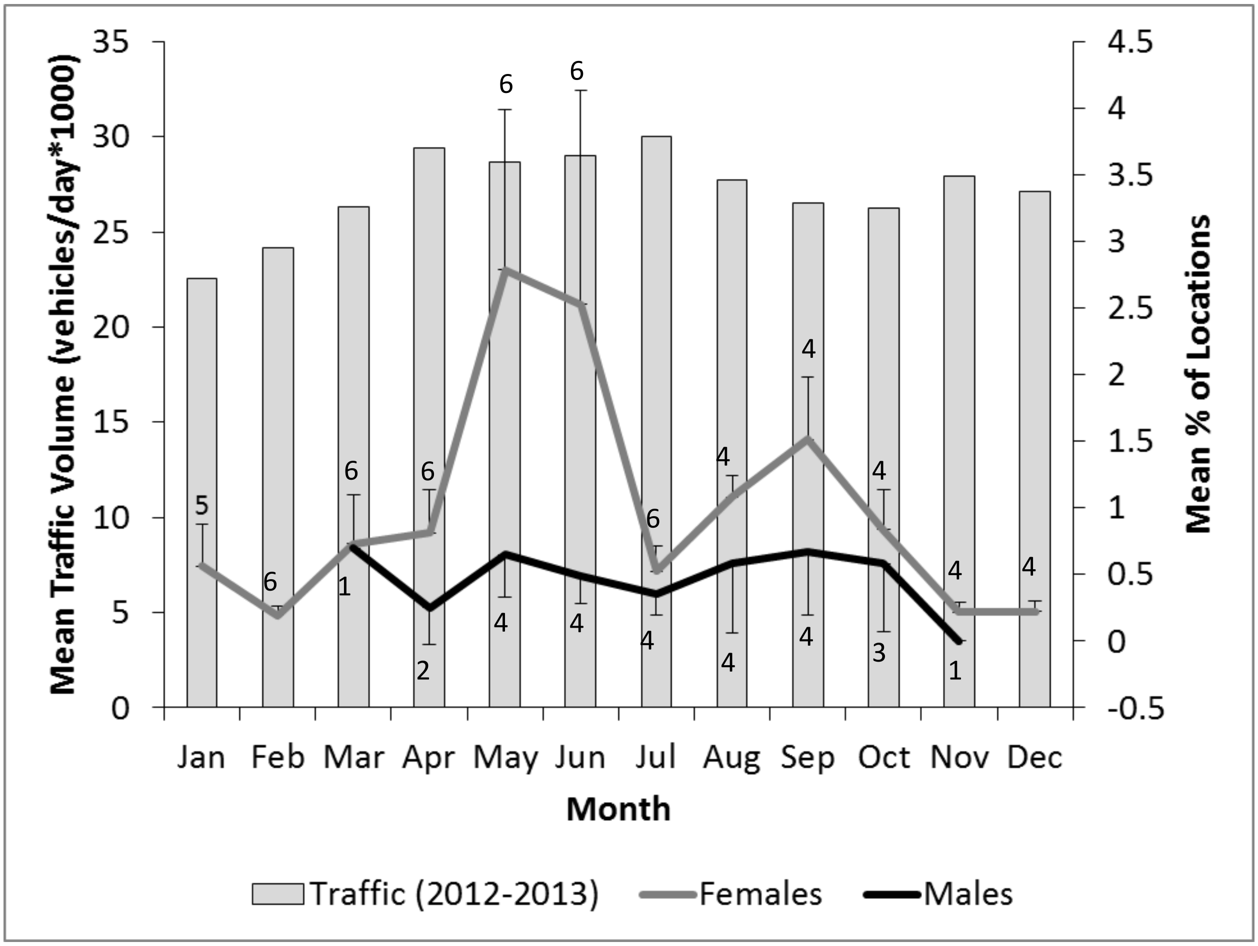

Figure 2. Mean monthly traffic volume (vehicles/day*1000) from 1 January 2012 to 31 December 2013 versus mean percent of locations with the ROW by month for 5 male and 6 female deer in the frequent user group from 15 April 2012 to 11 April 2014, in Madison, GA.

Figure 3. Mean hourly traffic volume (vehicles/hour) from 1 January 2012 to 31 December 2013 versus percent of total locations within the ROW by hour for 5 male and 6 female deer in the frequent user group from 15 April 2012 to 11 April 2014, in Madison, GA.

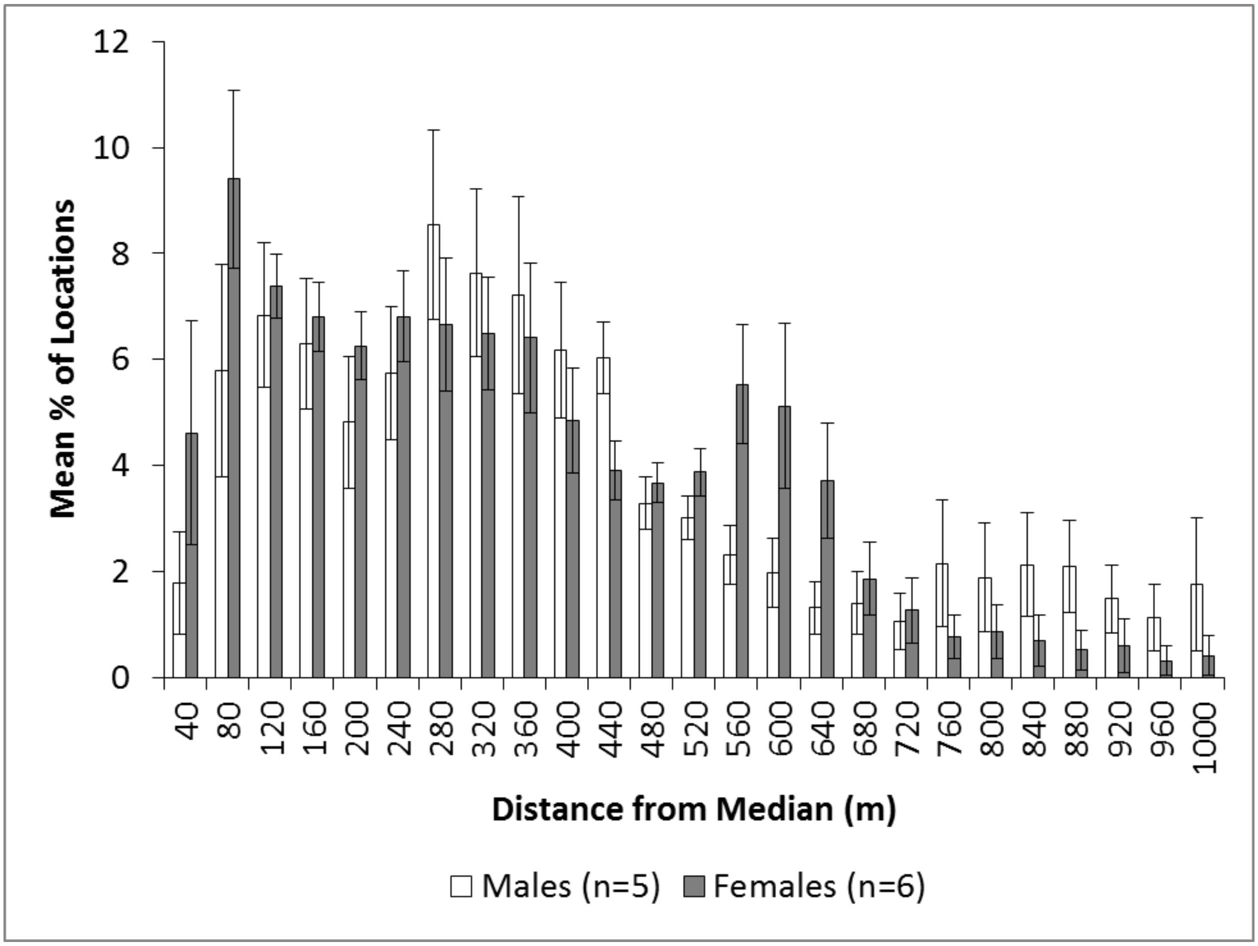

Figure 4. Mean percent of locations at 40 m increments from 0-1000 m for 5 male and 6 female deer in the frequent user group from 15 April 2012 to 11 April 2014, in Madison, GA.

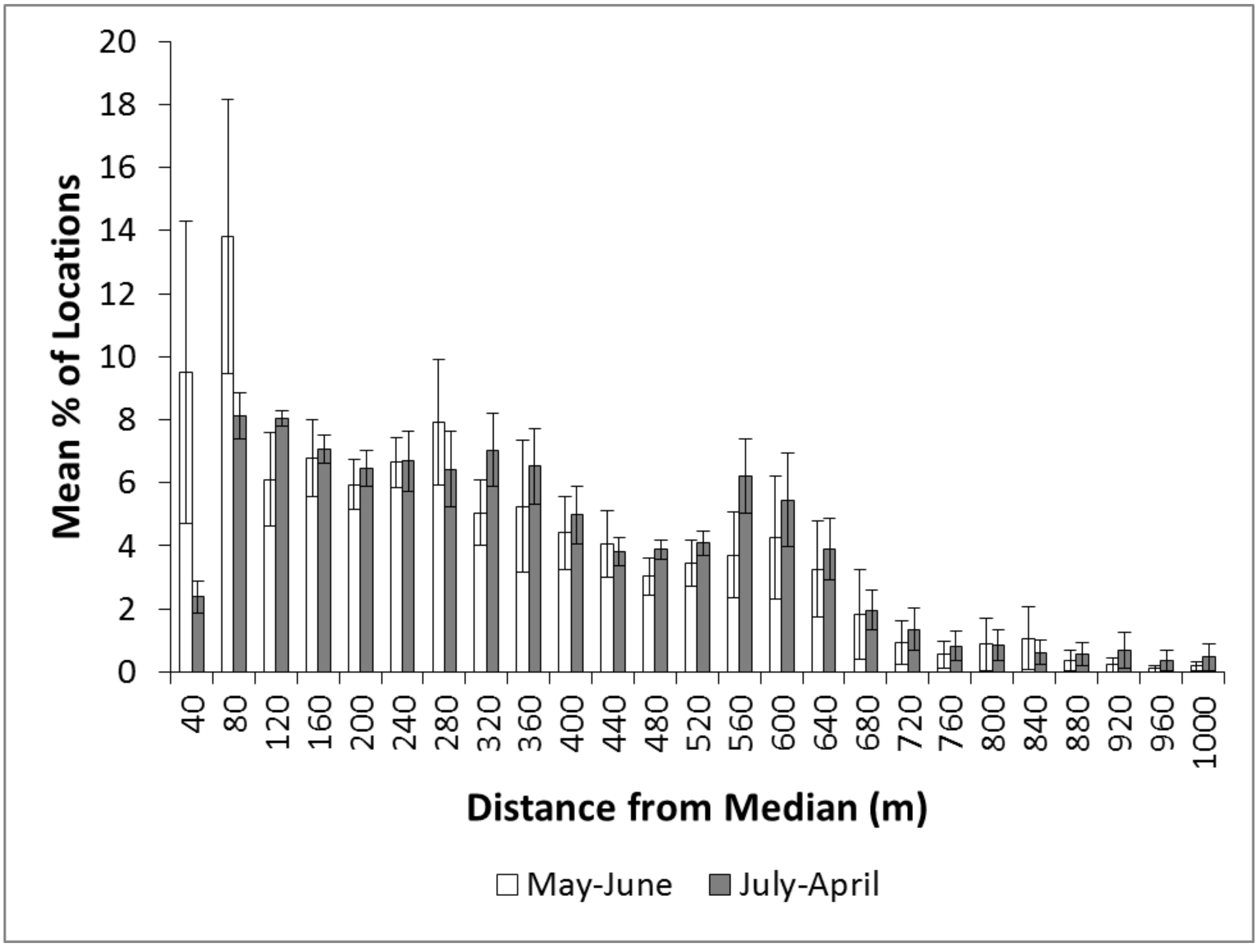

Figure 5. Mean percent of locations at 40 m increments from 0-1000 m for 6 female deer in the frequent user group comparing the months of May-June against the months of July-April from 15 April 2012 to 11 April 2014, in Madison, GA.

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Using Deer-vehicle Collisions to Map White-tailed Deer Breeding Activity in Georgia

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ABSTRACT: The most commonly used method to determine the timing of breeding for white-tailed deer (Odocoileus virginianus) is to measure fetuses from deceased animals. However, this method is resource-intensive and can only provide data for limited geographic areas. Numerous studies have reported that deer-vehicle collisions (DVCs) increase during the breeding season due to increased deer movements associated with breeding activity. Based on these observations, we obtained records of DVCs in Georgia from 2005-2012 (n = 45,811) to determine when peaks in DVCs occurred for each county in Georgia. We compared the timing of DVC peaks with (1) conception data from three counties in Georgia, (2) deer movement data from a sample of GPS-instrumented male and female deer in Harris County, Georgia, and (3) a popularized 'rut map' for the state that was based on Georgia Department of Natural Resources fetal data as well as hunter observations. We observed high concurrence among timing of peak conception, peak rut movement, and peak DVCs. At the regional level, there were strong similarities between peak DVCs and peak rut. At the county level, peak DVCs were in general concordance with the popular rut map. However, the county-based map of DVCs appeared to provide greater local specificity. For assessing the timing of the breeding season at a county or regional scale, DVC data are cost effective and less susceptible to measurement biases compared to traditional methods employing fetal measurement. In addition, mapping the peak occurrences of DVCs can be used to warn motorists of increased risk associated with deer activity at the local level.

KEY WORDS: breeding, deer-vehicle collisions, rut, white-tailed deer

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In temperate environments above 30ºN, white-tailed deer (Odocoileus virginianus) are seasonal breeders with reproduction governed by decreasing photoperiod (Lincoln 1992). Breeding and fawning seasons are shorter in duration in northern versus southern locations, which is an adaptation that mitigates seasonally limited food resources and helps fawn survival (Lincoln 1992). In the southeastern United States, where winters are milder and food is less restricted seasonally, breeding dates are more variable among deer herds. For example, in Florida, timing of breeding was as much as 6 months asynchronous among herds from four regions (Richter and Labisky 1985). Other southeastern states, including Georgia, have regions with distinct deer breeding dates, without obvious patterns relative to geographical features.

State and provincial wildlife agencies consider the timing of white-tailed deer breeding (hereafter, “rut”) when scheduling hunting seasons because deer reproductive parameters can be affected by season structure (Gruver et al. 1984, Richter and Labisky 1985). In addition, during the rut, both male and female deer increase their daily movements (Kolodzinski et al. 2010, Karns et al. 2011), which could have a positive effect on hunter success. Unfortunately, the common method for estimating the peak and range of deer breeding dates is labor intensive, costly, and subject to measurement error (Stone 2012). For this method, fetuses are collected from dead deer and measured to estimate date of conception (Hamilton et al. 1985). When only a few fetuses are collected from a location, they might not accurately represent the true distribution of breeding dates on a local or regional scale (Garrison et al. 2009). In addition, researchers often cannot rely on hunter-killed deer to provide an adequate sample because fetuses must be $\geq$ 35 days-old for accurate measurement (Hamilton et al. 1985), and deer hunting seasons often end before that stage of gestation (Stone 2012).

Deer killed as a result of deer-vehicle collisions (DVCs) can often provide important biological information. For example, samples from road-killed deer can track variation in fecundity related to differences in range condition (Cheatum and Morton 1946, Cheatum and Severinghaus 1950). Deer-vehicle collisions typically increase dramatically coincident with peak breeding activity (Jahn 1959, Bellis and Graves 1971, Puglisi et al. 1974, Allen and McCullough 1976, Steiner et al. 2014). The number and location of DVCs also have been used as an index of deer population size (Jahn 1959) and was shown to be predictive of the number of bucks killed during the firearms hunting season (McCaffery 1973). Insurance companies, transportation departments, and law enforcement agencies have used DVC data to warn motorists of increased risk of DVCs both temporally and spatially (State Farm Insurance Company 2011, Wisconsin Department of Transportation 2012, Kentucky State Police 2013).

More than 1 million DVCs occur in the United States annually (Conover et al. 1995). About 50,000 occur annually in Georgia (Bowers et al. 2005), with Georgia ranking among the top 10 states for number of DVCs (State Farm Insurance Company 2011). Approximately 30-45% of Georgia's DVCs occur during October through December, coincident with the breeding season. Similar concurrence of increased DVCs and the breeding season have been reported in Kentucky (Kentucky State Police 2013), Virginia (McShea et al. 2008), Alabama (Hussain et al. 2007), and Wisconsin (Sudharsan et al. 2006).

If seasonal differences in the frequency of DVCs are directly related to periods of increased deer movement during the rut, then DVCs should serve as an accurate index for timing of the rut. Therefore, we evaluated the timing of DVCs at the county level to assess the regional distribution of peak breeding occurrence across Georgia. We compared our estimates of peak breeding dates by examining the relationships among DVC data, seasonal deer movement data, fetal age data, and previously published region-specific estimates of deer breeding dates.

STUDY AREA

This study encompasses all 159 counties within the state of Georgia. The northern-most portion of Georgia lies within the Blue Ridge and Ridge and Valley physiographic regions and is characterized by mountainous terrain and forested habitat. The middle section of the state falls within the Piedmont Region, an area of rolling hills supporting oak-hickory-pine forests and mixed deciduous forests. The southern half of Georgia includes the Upper and Lower Coastal Plains. This diverse region contains agricultural landscapes in the western region, extensive areas of loblolly pine (Pinus taeda) or mixed hardwood forest on well-drained soils, and slash pine (Pinus elliottii) forests on poorly drained flatwoods sites.

We also monitored seasonal movements of GPS-collared deer on a privately-owned, 1,821-ha property in Harris County, Georgia. Habitat consisted of a mixture of pine, pine-hardwoods, hardwood drainages, pasture, row crops, food plots, and other open areas. Loblolly pine stands comprised approximately 54% of the land cover. Hardwood stands occurred on approximately 32% of the study site and consisted primarily of oak/hickory forests. The remainder of this property consisted of hardwood drainages, tall fescue (*Schedonorus arundinaceus*) pastures, and openings planted in corn (*Zea mays*), winter rye (*Secale cereale*), clovers (*Trifolium spp.*), bermudagrass (*Cynodon* dactylon), and ryegrass (*Lolium sp.*).

METHODS

We obtained statewide DVC data from the Georgia DOT and calculated weekly DVCs that occurred between 1 September and 31 January in each county during 2005 to 2012. For each county, we summed the weekly DVCs for that county with all surrounding counties to produce a combined-county DVC statistic. We then calculated a 3-week running average of the data as a smoothing parameter.

We compared the peak in DVCs against conception dates for counties where these data were available, some of which were collected during the 1990s. We assumed that any variation in breeding chronology of deer among years within each county was less than the variation that occurred among all counties across the state. Conception dates were derived by measuring fetuses (Hamilton et al. 1985) from hunter harvests or special collections.

We compared the occurrence of DVCs from one county (Harris County) with movement data for 19 adult ($\geq$ 2.5-years-old) deer (10 males, 9 females). We captured deer between January and July 2013 using 3-mL transmitter darts (Pneu-dart Inc., Williamsport, PA) to intramuscularly inject 440mg of Telazol® (Fort Dodge Animal Health, Fort Dodge, IA) and 315mg of xylazine hydrochloride (Congaree Veterinary Pharmacy, Cayce, SC). We fit each deer with a Lotek 7000MU GPS collar (Lotek Wireless Inc., Newmarket, Ontario, Canada). Eighty minutes after injection, we administered Tolazoline® hydrochloride (100 mg/ml; Lloyd Laboratories, Shenandoah, IA, USA), one-half intramuscularly and one-half intravenously, and monitored deer until ambulatory. We followed all animal use and handling protocols mandated by the University of Georgia Animal Use and Care Committee (A2012 06-007-Y2-A1). From 1 September through 31 January we collected locations every 30 minutes, after which we downloaded data using a UHF antenna and handheld command unit. GPS coordinates were projected in the Universal Transverse Mercator (UTM) Zone 16N coordinate system. We calculated straight-line distance between subsequent locations, and calculated the mean hourly movement rate for each deer for each week from 6 October - 28 December. We used Student’s t-tests to compare male and female mean hourly movements for each week.

We obtained a popular press ‘rut map’ derived from Georgia Department of Natural Resources fetal measurement data and refined by adding reported hunter observations (*Georgia Outdoor News* 2000; D. Kirby, *Georgia Outdoor News*, Personal Communication). We visually compared the predicted timing of the rut with our map depicting peaks in occurrence of DVCs, noting similarities and obvious discrepancies on a county or regional basis.

RESULTS

There were 45,811 reported DVCs throughout Georgia during 1 September to 31 January from 2005 through 2012. Of the 159 counties, 55 counties (35%) had <50 DVCs reported during this 7-year period. After combining DVC data with adjacent counties, only four counties in southwestern Georgia (Stewart, Quitman, Randolph, and Clay) had <100 DVCs during the study period. Peak DVC occurrence varied from mid to late October in the southeastern counties to mid-December in the southwestern corner of the state (Figure 1a). Throughout the majority of the state, peak DVCs occurred during early to mid-November. Notably, DVC peak occurrence in several counties in the northeastern mountains fell during late November.

Across all counties, DVCs peaks closely mirrored the distribution of rut dates as described by the rut map published by *Georgia Outdoor News* (Figure 2b), with some notable exceptions. Several counties in northwest Georgia with a predicted late November rut (eg. Walker, Gordon, etc.) experienced peak DVCs during early to mid-November, suggesting that the rut may occur earlier than predicted. Four counties occurring within the transition between the Upper and Lower Coastal Plains (Ben Hill, Telfair, Candler and Jenkins) experienced peak DVCs during mid-October. Predicted rut timing in these counties is early to mid-November. Discrepancies between DVC occurrence and predicted rut time may be related to low DVC sample sizes or a lack of a defined peak in DVCs in these counties.

Conception data were available for three counties: Green (n = 65; obtained during 1999-2000, 2003-2004, and 2007), Harris (n = 183; obtained during 1990-1995, 1997-1998, and 2004-2011), and Pickens (n = 300; obtained during 2005-2012). In these counties, peak DVCs occurred coincident with, or within 1 week of peak conception dates based on fetal measurements (Figure 2a-c). Timing of peak conceptions in Pickens County appeared to lag approximately 1 week behind occurrence of peak DVCs (Figure 2b).

Similarly, the mean hourly movement rate for all deer combined peaked concurrently with frequency of conceptions and the 3-week average of combined-county DVCs during the week of 10-16 November on a study site in Harris County (Figure 2c). The increase in deer activity rates was primarily due to increased movements by males (Figure 3). We observed little change in movement rates of female deer throughout the breeding season.

DISCUSSION

The timing of peak DVCs by county was consistent with data on conception dates based on fetal measurement, peaks in movement associated with the breeding season, and with published rut dates based on conception data coupled with hunter observations. Although reported annual DVCs only comprise about half of the annual DVCs that occur (Conover et al 1995), mapping the timing and distribution of reported DVCs appears to be a promising technique for predicting the timing of the peak rut. Allen and McCullough (1976) found that there was little correlation between seasonal traffic volume and DVCs. Rather, they reported that DVCs occurred at increased frequency during peak deer movement periods both seasonally and diurnally. Increased activity of adult males in Harris County was consistent with studies investigating male deer movements during the breeding season (Tomberlin 2007, Olson 2014), as well as the increased presence of males in DVCs during the breeding season (Jahn 1959, Bellis and Graves 1971, Puglisi et al. 1974, Allen and McCullough 1976, Romin and Bissonette 1996). Dispersal by yearling males, disturbance by hunters, harassment of female deer by male deer, and excursions by female deer may all occur concurrently with the breeding season, thereby contributing to increased deer activity and road crossing events (Puglisi et al. 1974, Rosenberry et al. 2001, Sudharsan et al. 2006, Kolodzinski et al. 2010).

Because many of Georgia's counties are relatively small in size, achieving valid sample sizes to determine peaks in DVCs necessitated combining county-level DVC data with data from surrounding counties. For states with fewer, larger counties it may be unnecessary to use combined-county DVCs. Also, for areas where the rut is known to occur within a shorter time frame, a sample size of less than 100 DVCs may produce meaningful results. Nevertheless, DVC data from multiple years likely will be necessary to produce similar maps. Bashore et al. (1985) observed that the proportion of deer killed on highways in Pennsylvania during each month did not significantly change from year to year; therefore counts of DVCs can likely be pooled across years to increase sample size.

DVC spatial distribution tends to be clustered around areas with high human density or high traffic volumes (Iverson and Iverson 1999). Therefore, there is potential for suburban areas with high DVCs to bias results if they are combined with neighboring rural areas that likely have fewer DVCs. However, the spatial interpolation techniques we used (Garrison et al. 2009) due to the small average size of Georgia counties likely provided increased precision of predicted rut dates and may have reduced bias associated with clustering of DVCs.

The timing of the breeding season in white-tailed deer has been shown to be responsive to management-induced changes in herd demographics. For example, on experimental areas in Mississippi and South Carolina, peak breeding dates occurred much earlier after deer sex ratios were balanced and male age structure increased (Guynn et al. 1986, Jacobson 1992). Therefore, in areas where management decisions have resulted in changes in herd demographics, DVC data collected prior to the management action should be interpreted with caution.

MANAGEMENT IMPLICATIONS

Our results indicate that DVCs can be used as an index of breeding activity in white-tailed deer herds. For assessing the timing of the breeding season at a county or regional scale, DVC data may be more cost effective, more precise, and less susceptible to measurement biases compared to traditional methods employing fetal measurement. Also, DVC data are readily available at large geographic scales for numerous years. Finally, mapped peak occurrences of DVCs at the county level can be distributed via mass media or social media outlets to warn motorists of the time period of greatest DVC risk.

ACKNOWLEDGEMENTS

We thank the Georgia DOT for providing deer-vehicle collision data and for funding this study. Daryl Kirby from *Georgia Outdoor News* graciously provided a thorough explanation of how the GON rut map was derived. The Georgia Department of Natural Resources: Wildlife Resources Division, Callaway Gardens biologist Cory Croft, and the USDA-Wildlife Services provided conception data.

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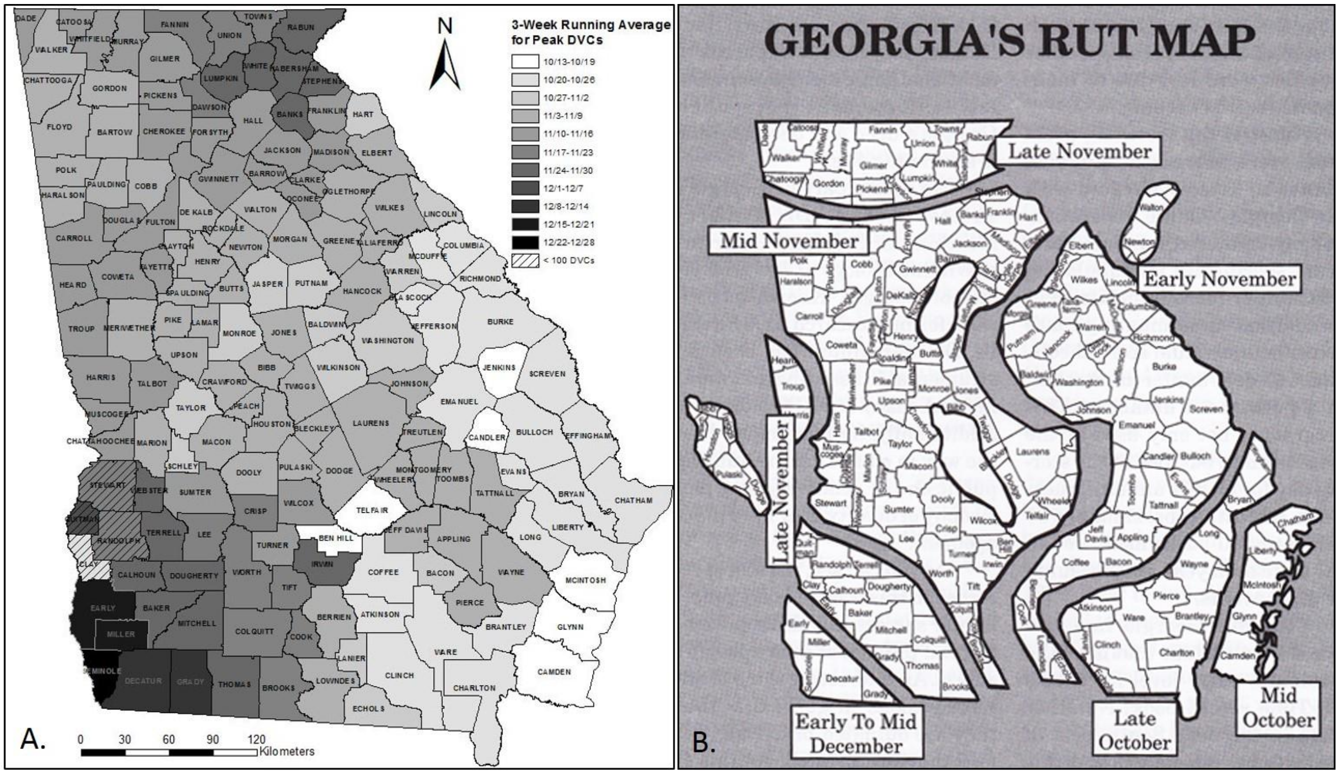

Figure 1. Map of Georgia depicting a) the peak week of DVCs for each county in Georgia, USA with combined county counts of DVCs and a 3-week running average applied, and b) predicted rutting activity throughout Georgia as reported by Georgia Outdoor News (2000).

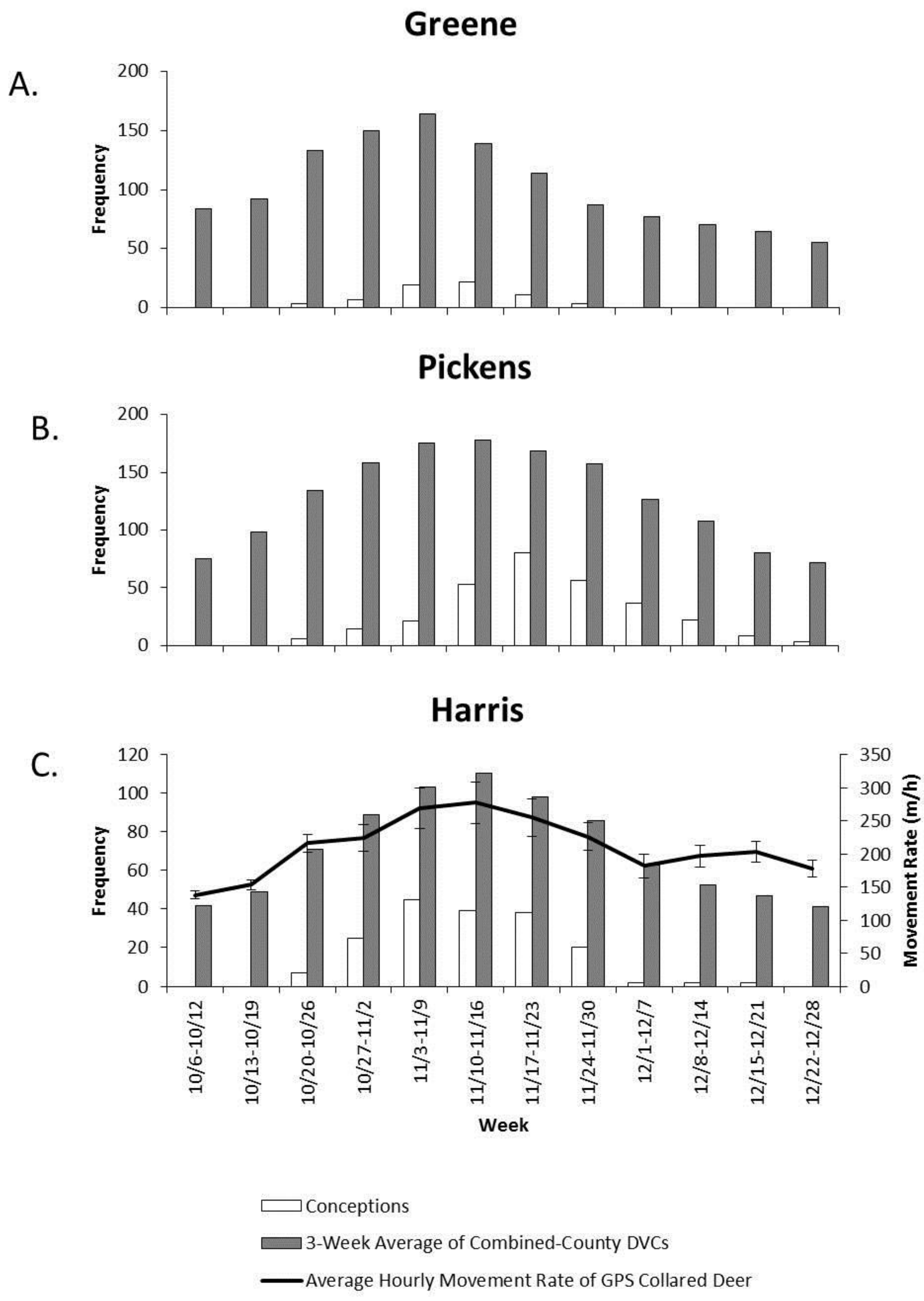

Figure 2. Frequency of conceptions versus 3-week average of combined-county deer-vehicle collisions by week from 6 October-28 December for study sites in a) Greene County, b) Pickens County, and c) Harris County, Georgia. Harris County data also includes movement rates for 19 adult deer (10 males, 9 females) ($\bar{x}$ +/- SE) by week from 6 October-28 December.

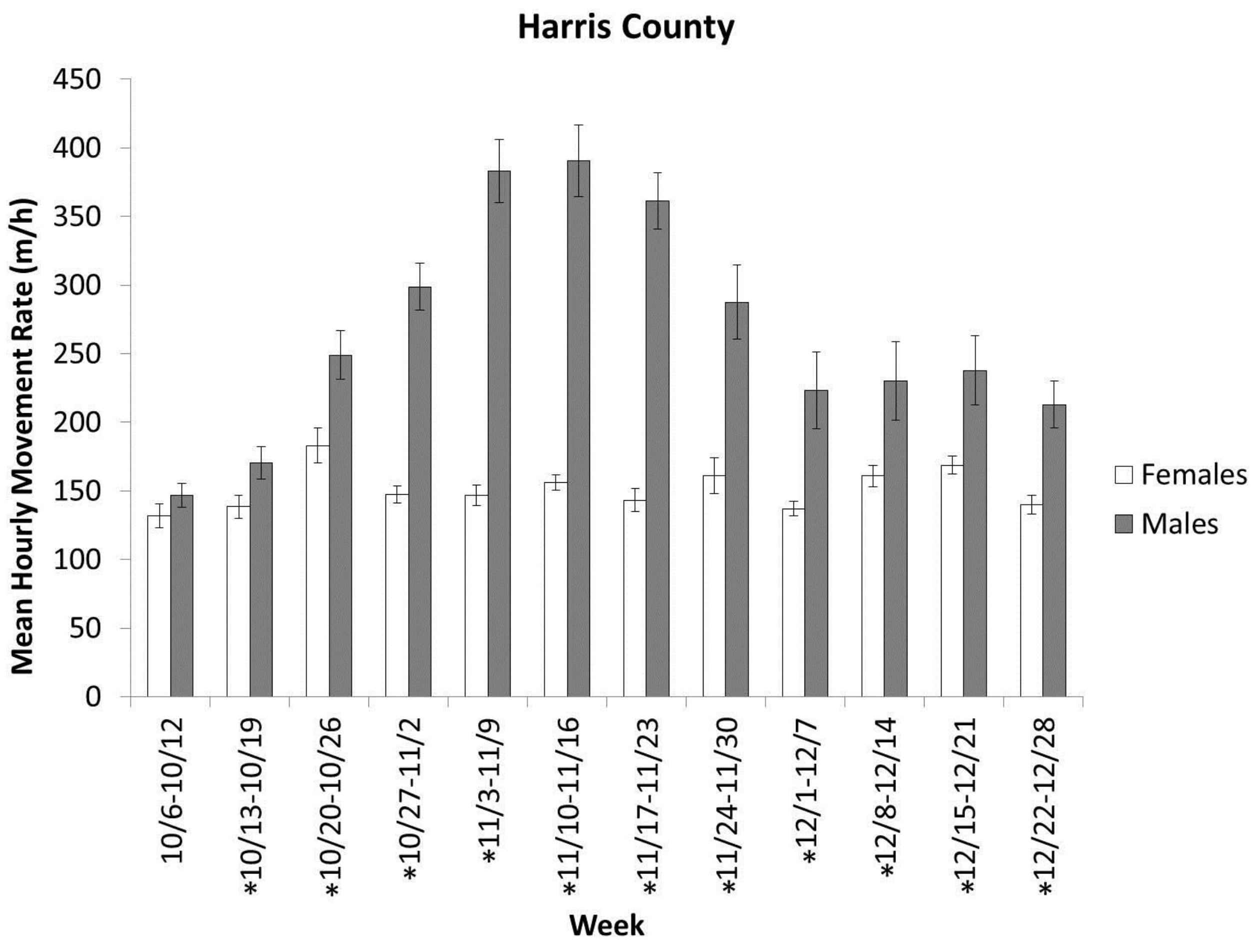

Figure 3. Mean (+/- SE) hourly movement rates (m/hr) for mature male (n = 10) and female (n = 9) GPS-collared deer by week from 6 October-28 December in Harris County, Georgia where "*" signifies P<0.05 according to a Student's t-test.