GEORGIA DOT RESEARCH PROJECT 12-35

FINAL REPORT

Development and Evaluation of Devices Designed to Minimize Deer-Vehicle Collisions: Phase III

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16. Abstract:

To better understand factors that might contribute to deer-vehicle collisions (DVC); we captured 32 deer within a 5-mile test roadway along Interstate 20 near Madison, Georgia and fitted them each with a Global Positioning System collar to monitor their use of the highway right-of-way (ROW). 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 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 statewide data on deer breeding dates. We observed high concurrence among timing of peak DVCs, peak conception, and peak rut movement. We also evaluated DVC risk based on the temporal pattern of DVCs; traffic volume; deer movement rates; and known frequency, timing, and landscape features associated with deer road-crossing activity. Our results indicated that DVC risk for individual motorists was high throughout the entire nocturnal period, not just during the crepuscular period as would be suggested solely by the incidence of DVCs without considering traffic volume. Also, the increased frequency of road crossings by deer in low-traffic, forested areas may lead to a greater risk of DVC than suggested by evaluations of DVC frequency alone.

To potentially reduce DVC risk, we recommended: (1) targeted removal of deer that were frequent ROW users, (2) warnings issued to motorists about 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.

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 deer fetus measurements. In addition, mapping the peak occurrences of DVCs can be used to strategically warn motorists of increased risk within a few weeks of peak deer breeding at the county level.

We also conducted an operational field trial to retrofit top-mounted outriggers to existing 1.2-m, woven-wire, ROW fencing. Despite repairing the existing ROW fence and adding the outrigger, access to the ROW by deer was not prevented, but these results were based on a small sample size of deer that had previously accessed the ROW. Repair and maintenance of existing ROW fencing for conversion to an outrigger-style fence likely was unjustified as neither cost-efficient nor adequately effective at preventing deer from accessing the ROW. However, the outrigger-fence design might be justified for new fence construction in un-wooded terrain and when used in conjunction with traditional 2.4-m deer exclusion fence to provide deer within the ROW a route of escape.

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FINAL PROJECT REPORT

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

GDOT RESEARCH PROJECT 12-35

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In 2004, a research team from the University of Georgia (UGA) and Berry College initiated Phase I of this collaborative research. Phase I findings were submitted to GDOT in July 2007. In Phase I, we conducted research directed at understanding the visual and auditory capabilities of white-tailed deer to objectively evaluate sight- and sound-based deterrents to deer-vehicle collisions (DVCs). Our results indicated that 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 DVCs. We concluded that wildlife warning reflectors were ineffective in changing deer behavior such that DVCs 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 between 0.25–30 kilohertz (kHz), with best sensitivity between 4–8 kHz. The upper limit of human hearing occurs 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 pure-tone 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 DVCs.

In 2007, Phase II of this collaborative effort began under the direction of UGA. Phase II findings were submitted to GDOT in December 2010. In Phase II trials with captive deer, we found that woven-wire fences less than 1.8 m in height were 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 or taller 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 2.4-m tall and a 1.2-m woven-wire fence with a top-mounted outrigger for restricting movement of free-ranging deer. 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. Additionally, we documented 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 an automated system (i.e., deer training apparatus, DTA) that trained white-tailed deer to associate a supra-threshold, white-light stimulus with a food reward through operant conditioning techniques. 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 (LCD) monitors on the DTAs. The DTA presented an effective and efficient way of training white-tailed deer, and provided an experimental platform for future research on behavior, perception, and preference. Based on the behavioral responses we observed using the DTA, we concluded that deer have greater perceptual sensitivity to shorter wavelengths, lower sensitivity to longer wavelengths, and some sensitivity to ultraviolet light.

In 2012, Phase III began under the direction of UGA. 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, fitted deer with GPS collars, and monitored movements of collared deer before construction of the experimental fence. Part B began in 2013 and included construction of the experimental fence and monitoring of deer movements 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.

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 DVCs 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 selected I-20 test roadway segment was ideal for this experiment because it had only one major breach along its entire length. Potential breaches occurred at both ends of the experimental fences, but one end was at an urbanized area that probably deterred deer movements and the other end was at an underpass that would allow deer to pass safely under I-20. This I-20 test roadway segment was further considered ideal because it contained heavily forested habitat, as well as mixed agriculture and forest habitat on both sides of the road. These associated habitat features represented most of the major habitat types that occur along roadways throughout much of Georgia. However, because the existing fence was built in 1979 and received no maintenance during its service, it was in general disrepair with extensive damage from fallen woody debris and overgrown vegetation. Collaborators agreed that repair of the existing fence would be necessary during Phase III, Part B, before construction of the new outrigger fence could begin. Research findings from Phase III, Part A were submitted to GDOT in November 2014.

In accordance with Phase III, Part A, during February-June 2012 and January-April 2013, we captured 32 deer and fitted them each with a GPS collar. 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 size were 103.6 ± 11.9 ha ($\bar{x}$ ± SE; range = 29.9 - 329.8 ha) and 17.0 ± 1.5 ha (range = 5.7 - 36.0 ha), respectively. Frequent users (359.5 ± 41.7 m) were closer to the highway median than occasional (715.3 ± 236.4 m) and rare (766.6 ± 72.3 m) users, but occasional and rare users were the same distance 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) targeted 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 (GDNR) 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 were 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. The rut map has been posted online by GDNR (http://www.georgiawildlife.com/rut-map).

We entered into Phase III, Part B of this collaborative research in February 2013. However, unforeseen delays associated with environmental regulatory compliance within GDOT made it impossible for us to award the fencing job as scheduled. Therefore, at the request of GDOT, the bid process was halted temporarily. In addition, in May 2013, research collaborators made the joint decision to shorten the length of the experimental fence from 4.8 miles on each side of I-20 to 2.5 miles on each side. We received final approval from GDOT to again move forward with the fencing job in October 2013. The job was awarded to Athens Fence Company in December 2014 and work began in January 2014. The fence was completed in March 2014; inspected by all research collaborators in April 2014; and mutually approved for operation within a few days following completion of minor modifications. Beginning then, we conducted monthly inspections of the entire length of experimental fence and routinely made repairs as necessary.

In addition to monthly inspections of the experimental fence for physical damage that might have allowed deer to breach the fence and enter the ROW or roadway, we used trail cameras to continuously monitor deer and other wildlife use of roadway underpasses and culverts to travel beyond the experimental fence. We downloaded traffic volume data from GDOT's website and monitored and recorded road-killed deer within the experimental section of I-20 and the adjacent ROW. We evaluated costs of repairing and otherwise maintaining the experimental fence.

To our knowledge, no previous studies have evaluated DVC risk along a section of roadway based on observed DVCs, traffic volume, deer movement rates, and known frequency and timing of deer road-crossing activity. We used confirmed DVC data from 19 local counties and real-time traffic volume data from a permanent traffic counter located near the center of our test roadway segment of I-20 to evaluate temporal patterns in DVCs and traffic volume. In addition, we used movement data from 25 GPS-collared deer (13 males, 12 females) to identify seasonal (spring = April-June, summer = July-September, fall = October-December, winter = January-March) patterns in deer road-crossing behavior. Collectively, we used these data to determine relative risk of DVCs on a temporal scale. Deer movements and DVCs were primarily crepuscular during all seasons; however, road crossings were mostly nocturnal with 44% of road crossings occurring between 0000 and 0559 hours when traffic was lowest. Approximately 60% of GPS-collared deer crossed roads, with only 7 deer accounting for over 90% of all road crossings. Approximately 73% of daily traffic occurred between 0700-1859 hours. Nearly twice the number of daily DVCs occurred during the fall (9.82 DVCs/day) than during the next highest season (winter; 4.94 DVCs/day). The temporal pattern of road crossings explained over 61% of the variation in DVC risk per individual driver (hourly DVCs/hourly traffic) for all seasons. Our results indicated that DVC risk for individual motorists was high throughout the entire nocturnal period, not just during the crepuscular period as would be suggested solely by the incidence of DVCs without considering traffic volume. We recommend DVC mitigation efforts focus on: (1) increasing driver vigilance and reducing vehicle speed during nocturnal periods, especially during the fall season; (2) targeted removal of deer along roadways; (3) habitat modifications that increase motorist visibility, reduce roadside attraction, and prevent access to rights-of-way; and (4) integrating infrared camera technology with modern vehicles to better detect deer and other wildlife along roads at night.

In another analysis using movement data collected from the 32 GPS-collared deer during March 2012 to February 2014, we constructed 19 mathematical models to better understand patterns in road-crossing behavior of deer. For this analysis, we did not consider road-crossing data associated with I-20 because we assumed the GDOT boundary fence may have acted as a semi-permeable barrier that would have influenced road crossings in that intact or broken sections of fence may have dictated where road crossings occurred rather than landscape features. Focusing on roads used by deer in our study, we categorized them based on size (low, medium, or high vehicular use). We identified locations where GPS-collared deer crossed roadways by creating movement paths between subsequent GPS points and then intersecting the paths with road locations. Our findings indicate that traffic volume, distance to riparian areas, and the amount of forested area influenced the frequency of road crossings. Roadways that were predominately located in wooded landscapes (80-90% forest) and 200-300 m from riparian areas were crossed frequently. Additionally, we found that areas of low traffic volume (i.e., county roads, etc.) had the highest frequencies of deer crossings. Analyses utilizing only records of DVC locations cannot separate the relative contribution of deer crossing rates and traffic volume.

Increased frequency of road crossings by deer in low-traffic, forested areas may lead to a greater risk of DVC than suggested by evaluations of DVC frequency alone. This analytical technique can provide an additional tool for mangers, allowing them to model segments of roadways that have an increased likelihood of deer crossings and, therefore, better focus DVC mitigation efforts. Possible solutions include the introduction of signage that warns motorists of an increased threat and removal of dense vegetation along roadways to reduce deer crossing behavior and allow motorists to more easily see deer when they do cross.

In 2013, the U.S. Forest Service Technology and Development Center requested assistance with the development of a DVC safety training video entitled "Avoiding Wildlife-vehicle Collisions". Dr. Miller contributed a segment to the video entitled "How Deer Sense the World". The video received a bronze award at the 36th Telly Awards. The video can be found at https://www.youtube.com/playlist?list=PLY3mgDGCphgO9JnuaxQSsCTcvw9h6Wd1A.

By April 2014, representatives from Athens Fence Company had repaired the existing 1.2 m tall GDOT boundary fence on both sides of a 2.5-mile section of I-20. In addition, they had attached a 1.5-foot steel outrigger arm to the top of each existing verticle fence post and strung 4 evenly spaced strands of high-tensile smooth wire, which spanded from outrigger to outrigger for the entire 2.5-mile section of experimental fence. From May – October 2014, the entire fence was surveyed once per month for damage and potential breach locations. Minor damage and potential breaches were repaired during the survey with hand tools and local resources (i.e. sticks, rocks, logs, etc.). Major damages were repaired as soon as possible. For repair sites, we recorded the date, location, person hours, a brief description of the damage or potential breach, and other relevant notes. In addition, we monitored animal movements through 2 concrete culverts that passed under I-20 within the 2.5-mile section of fence with infrared-triggered trail cameras. The I-20 ROW was surveyed for road-killed deer (RKD) once per week during the entire study. Location of RKD was recorded, as well as sex and age if they could be determined.

Because of delays in repairs to the existing fence and construction of the experimental fence, as discussed previously, only 3 adult female GPS-collared deer (#47, #85, #13) were available during both the pre- and post-treatment fencing evaluations. After the outrigger fence was constructed, Deer #47 crossed the ROW at least 48 times and circumvented the fence end 26 times. In general, she crossed the fence more after the outriggers were installed than she did before. After fence construction Deer #85 crossed the ROW at least 9 times and, although she had the opportunity to circumvent fence ends, we did not document circumvention. In general, frequency of ROW use by Deer #85 did not differ before vs. after fence construction. However, movement data suggested that Deer #85 likely selected the ROW for parturition during spring of 2013 and 2014. During June 2014, she was eventually struck by a vehicle and died between the I-20 westbound lane and the westbound Exit 114 off-ramp. Unlike deer #47 and #85, Deer #13 was located near the center of the 2.5-mile experimental fence. Although her home range did not include either fence end, she crossed the ROW at least 15 times. In general, Deer #13 used the ROW less before fence construction than after fence construction. When reviewing all crossing data for these 3 deer, we think they likely used small gaps (18 cm or less in size) under the fence and random locations along the fence without obvious gaps to enter and exit the ROW. Despite repairing the fence and adding the outrigger, access to the ROW was not prevented. However, our results on the efficacy of the experimental fence are based on a small sample size of deer that had previously accessed the ROW. We have no information on the ability of this experimental fence to deter deer that had not previously experienced the fence or ROW, such as might occur after new roadway construction.

We observed no RKD on our experimental section of I-20 during the pre-treatment periods before construction of the experimental fence. After fence construction, 5 RKD were observed (4 adult females, 1 fawn of unknown sex). Of these, a fawn and an adult female were found dead in close proximity to each other.

We identified 12 species of wildlife in 4,117 photos taken by the trail cameras mounted in 2 culverts that passed under I-20 within the 2.5-mile section of our study area. Of these, 3 deer accounted for 9 photos before fence construction and no deer were photographed in culverts after fence construction.

The cost of parts and labor for retrofitting outriggers to the existing ROW fence, including an environmental assessment, was approximately $137,448 ($27,490/mile). The cost of maintenance was estimated at $59/mile/year. Although the ROW fence was located in a wooded area where trees and limbs damaged the fence from above, the most common repairs were small gaps (18 cm or less in size) under the fence. Retrofitting the ROW fence was logistically complicated and costly. Further, despite previous success on naïve deer during Phase II of our research, an outrigger fence design may be less effective on deer that are experienced at jumping fences. Therefore, we recommend this design only be used with new construction, with a caveat that the design must eliminate, or at least minimize, gaps under the fence and be maintained regularly. Although damage from trees and limbs was minimal during our monitoring period, deer quickly took advantage of tree-damaged areas of fence. Therefore, we also recommend only using this experimental fence design in open areas. Finally, because breaches were common, a 2.4-m deer exclusion fence is likely the most practical option for excluding deer from an interstate. However, it is important for such fences to incorporate methods to escape the ROW, should deer gain access. It is possible that a 2.4-m deer exclusion fence could be the primary deterrent for keeping deer from entering a ROW and when linked to a 1.2-m fence fitted with a top-mounted outrigger facing away from the roadway; this combined design could be used to mostly keep deer from entering the ROW and allowing them to exit the ROW when infrequent breaches do occur.

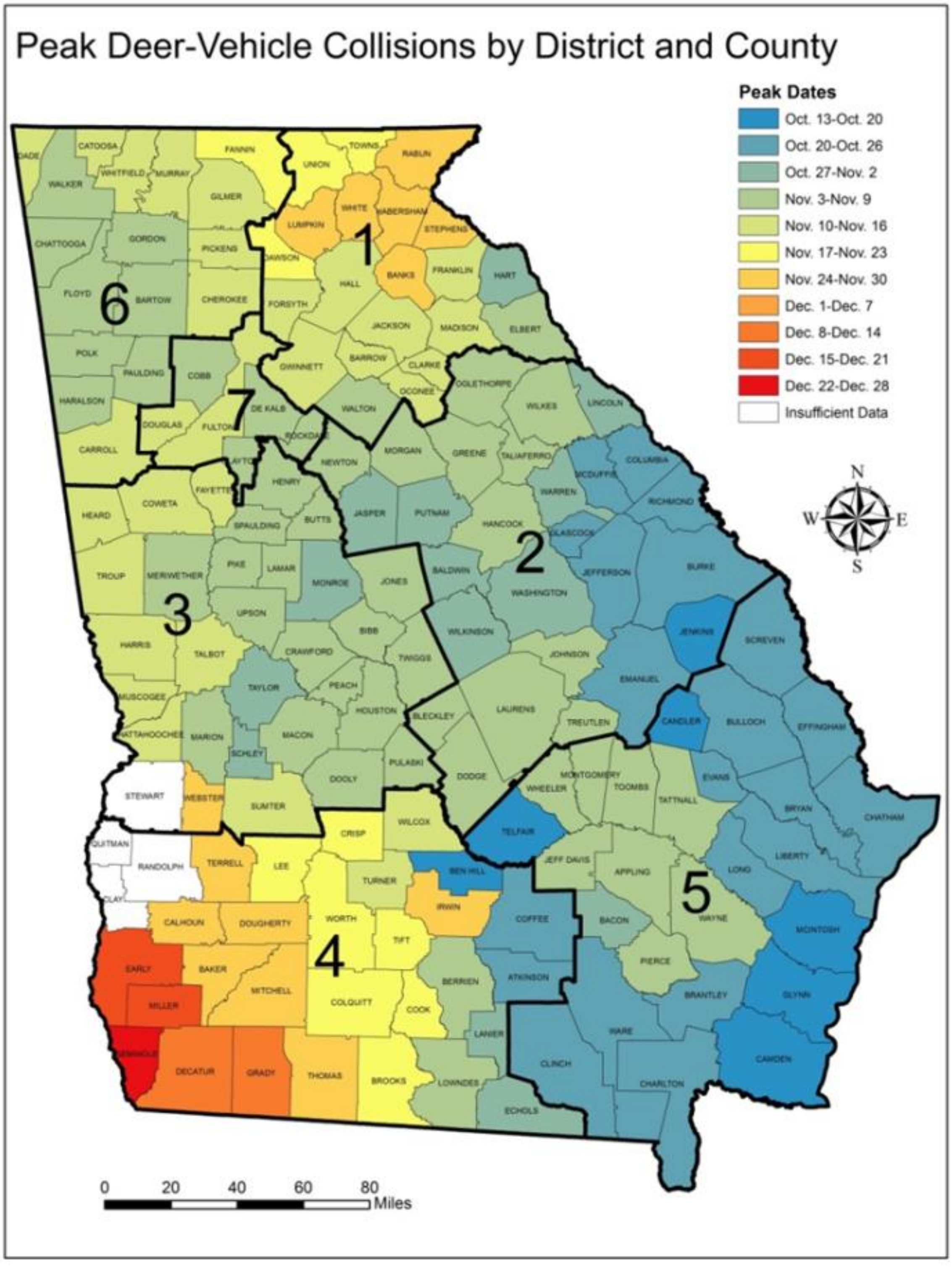
In October 2012, Mr. Bradley Ehrman (GDOT Technical/Implementation Manager) asked that we provided recommendations on how GDOT should best monitor efficacy of the experimental fence after the study ended based on DVC-crash data. In addition, he inquired about how best to monitor fence efficacy if GDOT decided to install the experimental fence on a larger scale. Similarly, in July 2015, Mr. David Jared (GDOT Assistant State Research Engineer) asked that we provided each GDOT district office with county-specific DVC-risk estimates based on deer movement data that would be useful for alerting local motorists of peaks in seasonal and daily deer movements.

After careful consideration of our research findings, we offer the following suggestions relative to fence design, cost, efficacy and monitoring.

1. Although outrigger fence designs have been effective at reducing fence-crossing behavior of captive and free-ranging deer, we suggest retrofitting outriggers to existing ROW fencing is neither cost-efficient nor adequately effective in many cases. Furthermore, costs associated with repair of existing ROW fencing to facilitate conversion to an outrigger-style fence likely is unjustified when considering the infrequent or nonexistent maintenance of interstate ROW fences. In addition, the requirement for a separate environmental assessment before maintenance, repair, and installation of outrigger fences further complicates the cost inefficiency of this method. Although it is possible for deer to sometimes breach standard 2.4-m deer exclusion fence, especially by navigating gaps

under the fence, we believe the 2.4-m deer fence is the best option for excluding deer from an interstate highway. However, we do believe the outrigger fence design might be well suited for new construction projects in non-wooded terrain. In addition, the outrigger design when used together with a 2.4-m deer exclusion fence likely would allow any deer trapped within the ROW to safely escape.

2. In addition to monitoring RKD within sections of I-20 with a perceived high-risk of DVCs, systematic counts of live deer within the ROW at locations most prone to highway crossings (e.g., 80-90% forest cover, 200-300 m from riparian areas) during nighttime and at a nadir of traffic volume could serve as a useful index to driver risk. Because our research showed a relatively small percentage of deer accounted for most ROW use by deer, targeted removal of those deer in high-risk sections of roadway might be effective at lowering risk of DVCs. At a minimum, signage at these locations could alert motorists about increased risk during hours of darkness when traffic volume is low.
3. For the map shown on the next page, we combined the rut map that is posted online by GDNR (http://www.georgiawildlife.com/rut-map) with GDOT's District Office Map to show the timing for greatest risk of DVCs for counties in each district office. To be as safe as possible, motorists should be warned to be especially cautious while driving for at least 1-2 weeks before and 1-2 weeks after the week of peak DVCs in their particular county, especially during hours of darkness when traffic volume is low. We recommend that GDOT coordinate with GDNR to issue motorist alerts in late September each year via major news agencies and social media (Facebook, Instagram, Twitter, Pinterest), as well as via email to all GDOT district offices or county-level offices.



Peak Deer-Vehicle Collisions by District and County

DISSERTATIONS AND THESES RESULTING FROM PHASES I, II AND III:

Cohen, B. S. 2011. Visual thresholds in white-tailed deer as determined by behavioral assay. M.S. Thesis. University of Georgia, Athens, Georgia, USA.

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.

Gulsby, W. D. 2010. Effects of fences on roadway crossings and home range distribution of white-tailed deer. M.S. Thesis. University of Georgia, Athens, Georgia, USA.

Miller, E. A. 2013. Using captive white-tailed deer to investigate visual perception and age-related morphometrics. M.S. Thesis. University of Georgia, Athens, Georgia, USA.

Stickles, J. H. 2014. Using GPS telemetry to assess deer-vehicle collision risk in Georgia. M.S. Thesis. University of Georgia, Athens, Georgia, USA.

Stull, D. W. 2009. Behavioral responses of captive deer to visual and physical barriers designed to minimize deer-vehicle collisions. M.S. Thesis. University of Georgia, Athens, Georgia, USA.

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

PUBLICATIONS RESULTING FROM PHASES I, II AND III (PHASE III, Part B DOCUMENTS ATTACHED):

Cohen, B. S., D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2012. An automated device for training white-tailed deer to visual stimuli. Wildlife Society Bulletin 36:194-198.

Cohen, B. S., D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2014. Behavioral measure of the light-adapted visual sensitivity of white-tailed deer. Wildlife Society Bulletin 38:480-485.

D'Angelo, G. J., R. J. Warren, K. V. Miller, and G. R. Gallagher. 2004. Evaluation of strategies designed to reduce deer-vehicle collisions: An annotated bibliography. 74 pp. Posted on the Internet at: www.dot.state.ga.us/dot/construction/materials-research/b-admin/research/onlinereports/Deer_Review.pdf and www.forestry.uga.edu/h/research/wildlife/devices/GADOTLiteratureReview.pdf.

D'Angelo, G. J., S. A. Valitzski, K. V. Miller, R. J. Warren, G. R. Gallagher, A. R. De Chicchis, and D. M. Jared. 2005. Thinking outside the marketplace: a biologically based approach to reducing deer-vehicle collisions. Proceedings of the International Conference on Ecology and Transportation 6:662-665.

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 roadside behavior. Wildlife Society Bulletin 34:1175-1183.

D'Angelo, G. J., A. R. De Chicchis, D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2007. Hearing range of white-tailed deer as determined by auditory brainstem response. Journal of Wildlife Management 71:1238-1241.

D'Angelo, G. J., a. Glasser, M. Wendt, G. A. Williams, D. A. Osborn, G. R. Gallagher, R. J. Warren, K. V. Miller, and M. T. Pardue. 2008. Visual specialization of an herbivore prey species, the white-tailed deer. Canadian Journal of Zoology 86: 735-743.

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.

Kramer, D. W., T. J. Prebyl, J. H. Stickles, D. O. Osborn, B. J. Irwin, N. P. Nibbelink, R. J. Warren, and K. V. Miller. 2015. Assessing deer road crossings using GPS locations. Journal of the Southeast Association of Fish and Wildlife Agencies (In Review).

Stickles, J. H., D. B. Stone, C. S. Evans, K. V. Miller, R. J. Warren, D. A. Osborn, and C. H. Killmaster. 2014. Using deer-vehicle collisions to map white-tailed deer breeding activity in Georgia. Journal of the Southeast Association of Fish and Wildlife Agencies 2:202-207.

Stickles, J. H., B. S. Cohen, D. A. Osborn, R. J. Warren, and K. V. Miller. 2015. Space-use patterns of white-tailed deer (Odocoileus virginianus) along an interstate highway in Georgia, USA. Wildlife Society Bulletin (In Review).

Stull, D. W., W. D. Gulsby, J. A. Martin, G. J. D'Angelo, G. R. Gallagher, D. A. Osborn, R. J. Warren, and K. V. Miller. 2011. Comparison of fencing designs for excluding deer from roadways. Human-Wildlife Interactions 5:47-57.

PRESENTATIONS RESULTING FROM PHASES I, II AND III

Cohen, B., D. A. Osborn, G. R. Gallagher, K. V. Miller, and R. J. Warren. 2012. Visual sensitivity of white-tailed deer as determined by behavioral assay. Annual Meeting, Association of Southeastern Biologists, Athens, GA (abstract).

Cohen, B., D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2012. Behavioral confirmation of the visual sensitivity of white-tailed deer. Annual Meeting, The Wildlife Society, Portland, OR (abstract).

Cohen, B. S., D. A. Osborn, G. R. Gallagher, K. V. Miller, and R. J. Warren. 2012. Sensitivity of white-tailed deer to ultraviolet and infrared light. Annual Meeting of the Southeast Deer Study Group, Sandestin, FL (abstract 35:44)

Cohen, B., D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2011. Development and use of an automated device for conducting visual discrimination tests with white-tailed deer. American Society of Mammalogists Annual Meeting, Portland, OR (abstr).

Cohen, B., D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2011. An automated device for training deer to a visual stimulus. Annual Meeting of the Southeast Deer Study Group, Oklahoma City, OK (abstract 34:xx).

Cohen, B., D. A. Osborn, R. J. Warren, and K. V. Miller. 2010. An automated device for self-training captive deer for behavioral research. Annual Meeting, Georgia Chapter, The Wildlife Society, Forsyth, GA.

D’Angelo, G. J., A. R. De Chicchis, D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2007. Hearing range of white-tailed deer as determined by auditory brainstem response. Poster Presentation. 14th Annual Conference of The Wildlife Society, Tuscon, Arizona.

D’Angelo, G. J., M. T. Pardue, G. A. Williams, G. R. Gallagher, D. A. Osborn, R. J. Warren, and K. V. Miller. 2007. An examination of the visual system of white-tailed deer. 30th Annual Conference of the Southeast Deer Study Group, Ocean City, Maryland.

D'Angelo, G. J., J. G. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2006. Ineffectiveness of wildlife warning reflectors for altering white-tailed deer roadside behavior. 13th Annual Conference of The Wildlife Society, Anchorage, Alaska.

D'Angelo, G. J., A. R. De Chicchis, D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2006. Hearing range of white-tailed deer as determined by auditory brainstem response. Fall Meeting, Georgia Chapter of The Wildlife Society, Athens, Georgia.

D'Angelo, G. J., J. G. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2006. Do wildlife warning reflectors alter white-tailed deer roadside behavior. Invited Speaker. 6th International Deer Biology Congress, Prague, Czech Republic.

D'Angelo, G. J., S. A. Valitzski, G. R. Gallagher, K. V. Miller, and R. J. Warren. 2006. Research to develop and evaluate strategies designed to minimize deer-vehicle collisions. Annual Georgia Department of Transportation Research Collaborator Meeting, Atlanta, Georgia.

D'Angelo, G. J., J. G. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2006. Ineffectiveness of wildlife warning reflectors for altering white-tailed deer roadside behavior. 29th Annual Conference of the Southeast Deer Study Group, Baton Rouge, Louisiana.

D'Angelo, G. J., J. G. D'Angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren. 2006. Ineffectiveness of wildlife warning reflectors for altering white-tailed deer roadside behavior. Daniel B. Warnell School of Forestry and Natural Resources Graduate Student Symposium, Athens, Georgia.

D'Angelo, G. J., K. V. Miller, R. J. Warren, G. R. Gallagher, D. A. Osborn, and D. M. Jared. 2005. Research at University of Georgia: A biologically based approach to reducing deer-vehicle collisions. Invited Speaker and Participant. Special meeting on Deer-Vehicle Crash Reductions: Setting a Strategic Agenda, Madison, Wisconsin.

D'Angelo, G. J., D. A. Osborn, A. R. De Chicchis, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2005. Development and evaluation of devices designed to minimize deer-vehicle collisions. Poster Presentation. 12th Annual Conference of The Wildlife Society, Madison, Wisconsin.

D'Angelo, G. J., S. A. Valitzski, K. V. Miller, R. J. Warren, G. R. Gallagher, D. A. Osborn, and D. M. Jared. 2005. Thinking outside the marketplace: A biologically based approach to reducing deer-vehicle collisions. Poster Presentation. Fall Meeting, Georgia Chapter of The Wildlife Society, Rome, Georgia.

D'Angelo, G. J., S. A. Valitzski, K. V. Miller, R. J. Warren, G. R. Gallagher, D. A. Osborn, and D. M. Jared. 2005. Thinking outside the marketplace: A biologically based approach to reducing deer-vehicle collisions. Invited Poster Presentation. International Conference on Ecology and Transportation, San Diego, California.

D’Angelo, G. J., D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2004. Development and evaluation of devices designed to minimize deer- vehicle collisions. Fall Meeting, Georgia Chapter of The Wildlife Society, Athens, Georgia.

Gulsby, W. D., D. W. Stull,, G. J. D’Angelo, G. R. Gallagher, D. Jared, J. A. Martin, K. V. Miller, D. A. Osborn, and R. J. Warren. 2011. Part 1: Comparison of fencing designs for excluding deer from roadways; Part 2: Effects of roadside fencing on deer movements and home ranges. Final Project Meeting, Georgia Department of Transportation, Atlanta, GA.

Gulsby, W. D., D. W. Stull, D. A. Osborn,, G. J. D’Angelo, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2011. Efficacy of roadside fencing for preventing deer crossings and its effects on deer movements and home range distribution. Annual Meeting of the Southeast Deer Study Group, Oklahoma City, OK (abstract 34:43).

Gulsby, W. D., D. W. Stull, D. A. Osborn,, G. J. D’Angelo, S. B. Roberts, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2010. Efficacy of roadside fencing for preventing deer crossings and its effects on deer movements and home range distribution. Berryman Institute Biennial Symposium, Logan, UT. (abstract).

Miller, E. A., B. S. Cohen, D. A. Osborn, G. R. Gallagher, R. J. Warren, and K. V. Miller. 2012. An automated device for training deer for behavior-based experiments. Annual Meeting, Association of Southeastern Biologists, Athens, GA

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. 2013. Hunting season avoidance behavior. Oral presentation for Oglethorpe County Rotary Club, Crawford, GA, 15 Nov 2013.

Stickles, J. H. 2013. Lessons learned from GPS data. Oral presentation at the Deer Management Research Group Field Day, Jessup, Georgia.

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.

Stickles, J. H. 2014. Minimizing deer-vehicle collisions along Georgia's Interstates: Progress Report. Oral presentation at Deer Management Research Group annual meeting, Harris County, Georgia.

Stickles, J. H., B. S. Cohen, D. A. Osborn, R. J. Warren, and K. V. Miller. 2015. Using GPS telemetry to assess der-vehicle collision risk. Annual Meeting or the Southeast Deer Study Group, Little Rock, GA (abstract 38:44).

Stickles, J. H., Evans, C. S., Stone, D. B., Osborn, D. A., Warren, R. J., Miller, K. V., and C. H. Killmaster. 2014. Using Deer-Vehicle Collisions to Map Breeding Activity in Georgia. Oral presentation at University of Georgia: Warnell School of Forestry & Natural Resources Graduate Student Symposium, Athens, Georgia.

Stickles, J. H., C. S. Evans, D. B. Stone, K. V. Miller, R. J. Warren, D. A. Osborn, C. H. Killmaster. 2014. Using deer-vehicle collisions to map breeding activity in Georgia. Annual Meeting or the Southeast Deer Study Group, Athens, GA (poster, abstract 37:68).

Stickles, J. H., D. A. Osborn, K. V. Miller, and R. J. Warren. 2013. Field trial of a retrofitted fence to mitigate deer-vehicle collisions. Annual Fall Meeting, Georgia Chapter of The Wildlife Society, Athens, GA. (poster)

Stickles, J. H. D. A. Osborn, K. V. Miller, and R. J. Warren. 2013. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. Annual Meeting of The Wildlife Society, Milwaukee, WI (abstract).

Stickles, J. H. D. A. Osborn, K. V. Miller, and R. J. Warren. 2013. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. International Conference on Ecology and Transportation, Scottsdale, AZ (abstract P-19).

Stickles, J. H. D. A. Osborn, K. V. Miller, and R. J. Warren. 2013. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. Georgia Department of Transportation Institute, Transportation Research Poster Session, Atlanta, GA (poster; abstract).

Stickles, J. H., Osborn, D. A., Warren, R. J., and K. V. Miller. 2013. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. Poster presentation at the Wildlife Damage Management conference, Clemson, South Carolina.

Stickles, J., D. A. Osborn, K. V. Miller, and R. J. Warren. 2012. Operational field trial of retro fitted fence to mitigate deer-vehicle collisions. Annual Fall Meeting, Georgia Chapter of The Wildlife Society, Athens, GA.

Stickles, J.H., D.A. Osborn, R.J Warren, and K.V. Miller. 2012. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. Oral presentation at Georgia Department of Natural Resources: Wildlife Resources Division Meeting.

Stickles, J.H., D.A. Osborn, R.J Warren, and K.V. Miller. 2013. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. Oral presentation at University of Georgia: Warnell School of Forestry & Natural Resources Graduate Student Symposium, Athens, Georgia.

Stickles, J.H., D.A. Osborn, R.J Warren, and K.V. Miller. 2012. Operational field trial of a retrofitted fence to mitigate deer-vehicle collisions. Oral presentation at Deer Management Research Group Field Day, Albany, Georgia.

Stickles, J. H., D. B. Stone, C. S. Evans, K. V. Miller, R. J. Warren, D. A. Osborn, and C. H. Killmaster. 2014. Using deer-vehicle collisions to map white-tailed deer breeding activity in Georgia. Annual Meeting, Southeastern Association of Fish and Wildlife Agencies, Destin, FL.

Stickles, J. H., D. B. Stone, C. S. Evans, K. V. Miller, R. J. Warren, D. A. Osborn, C. H. Killmaster. 2014. Can deer-vehicle collisions predict the rut in Georgia? Georgia Chapter, The Wildlife Society, Tifton, GA.

Stickles, J. H., D. B. Stone, C. S. Evans, K. V. Miller, R. J. Warren, D. A. Osborn, C. H. Killmaster. 2014. Using deer-vehicle collisions to map white-tailed deer breeding activity in Georgia. Annual Conference, The Wildlife Society, Pittsburgh, PA (abstract).

Stickles, J.H., D.B Stone, C.S. Evans, D.A. Osborn, R.J Warren, K.V. Miller, and C.H. Killmaster. 2014. Using Deer-Vehicle Collisions to Map Breeding Activity in Georgia. Georgia Department of Transportation Institute, Transportation Research Poster Session, Atlanta, GA (poster; abstract).

Valitzski, S. A., G. J. D'Angelo, D. A. Osborn, G. R. Gallagher , K. V. Miller, and R. J. Warren. 2006. Evaluation of sound as a deterrent for reducing deer-vehicle collisions. Fall Meeting, Georgia Chapter of The Wildlife Society, Athens, Georgia.

Valitzski, S. A., G. J. D’Angelo, D. A. Osborn, G. R. Gallagher , K. V. Miller, and R. J. Warren. 2007. Behavioral responses of white-tailed deer to vehicle-mounted sound-producing devices. 30th Annual Conference of the Southeast Deer Study Group, Ocean City, Maryland.

Valitzski, S. A., G. J. D’Angelo, D. A. Osborn, G. R. Gallagher , K. V. Miller, and R. J. Warren. 2007. Behavioral responses of white-tailed deer to vehicle-mounted sound-producing devices. Daniel B. Warnell School of Forestry and Natural Resources Graduate Student Symposium, Athens, Georgia.

Valitzski, S. A., G. J. D’Angelo, D. A. Osborn, G. R. Gallagher , K. V. Miller, and R. J. Warren. 2007. Evaluation of sound as a deterrent for reducing deer-vehicle collisions. International Conference on Ecology and Transportation, Little Rock, Arkansas.

USING GPS TELEMETRY TO ASSESS DEER-VEHICLE COLLISION RISK IN GEORGIA

by

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BS, State University of New York College of Environmental Science and Forestry, 2007

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

White-tailed deer (*Odocoileus virginianus*) are often a hazard to motorist safety in the United States. It is estimated that >1 million deer-vehicle collisions (DVCs) contribute to approximately 29,000 injuries, up to 200 deaths (Conover et al. 1995), and losses of $4.6 billion in vehicle damage and medical expenses each year (Insurance Information Institute 2010). Approximately 50,000 DVCs occur annually in Georgia, accounting for nearly 14% of vehicle collisions reported state-wide (Bowers et. al 2005). Currently, Georgia ranks among the top 10 states in numbers of DVCs (State Farm Insurance Company 2011). Unless effective DVC mitigation techniques are developed, future increases in deer populations, road networks, and traffic, will likely lead to increased DVCs along with associated personal and economic losses.

Although legal hunting is advocated to balance deer populations within ecological and social parameters, hunters are increasingly faced with numerous physical and financial challenges with regard to land access that may limit the effectiveness of hunting as a management tool (Brown et al. 2000). Where legal hunting is not an effective method of deer management, DVCs are a primary source of mortality for deer (Etter et al. 2002, Porter et al. 2004). Given this reality, it is necessary for transportation agencies and the auto industry to work in conjunction with biologists and wildlife agencies to develop effective DVC mitigation strategies.

Structures such as fences, overpasses, and underpasses can be effective at mitigating DVCs, but 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 limited or simply not well understood (Hedlund et al. 2004, Glista et al. 2009).

DVCs in Georgia are clustered spatially. 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; traffic volume played 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 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 along roadside 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 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, few studies have analyzed fine-scale deer movements relative to roadways. Past studies have referenced spatial and temporal use of roadways 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 spatial resolution to provide the fine-scale data needed to assess collision risk based on animal behavior (Gulsby et al. 2011).

I used global positioning system (GPS) telemetry to evaluate spatial and temporal use of roads by deer relative to the temporal distribution of traffic and DVCs. I assessed deer-vehicle collision risk and recommended mitigation strategies in 3 manuscript chapters. Chapter 2 describes three classes of deer relative to a high traffic (>20,000 vehicles/day) interstate highway and how several adult females selected the interstate ROW for parturition. Chapter 3 identifies the temporal distribution of road crossings to be relatively constant throughout the night, meaning DVC risk was high from dusk to dawn rather than only at crepuscular periods when DVCs tend to peak. In Chapter 4, I used the temporal distribution of DVCs as an index of deer movement to create a map illustrating the week of greatest DVC risk during the fall breeding season for each county in Georgia. I evaluated the results of this map using conception and deer movement data for counties where these data were available.

Literature Cited

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

Bellis, E.D. and H. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232-237.

Bowers, J.W., A. Hammond, K. Kammermeyer, C. Martin, S. McDonald, N. Nicholson, J. Robbins, T. Touchstone, and G. Waters. 2005. Georgia's deer management plan 2005-2014. Georgia Department of Natural Resources, Wildlife Resources Division, Game Management Section, Social Circle, Georgia.

Brown, T.L., D.J. Decker, S.J. Riley, J.W. Enck, T.B. Lauber, P.D. Curtis, and G.F. Mattfeld. 2000. The future of hunting as a mechanism to control white-tailed deer populations. Wildlife Society Bulletin 28:797-807.

Carbaugh, B., J. Vaughan, E. Bellis, and H. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management 39:570-581.

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.

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 movement of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

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

Glista, D.J., T.L. DeVault, and J.A. DeWoody. 2009. A review of mitigation measures for reducing wildlife mortality on roadways. Landscape and Urban Planning 91:1-7.

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.

Gunson, K.E., G. Mountrakis, and L.J. Quackenbush. 2011. Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. Journal or Environmental Management 92:1074-1082.

Hedlund, J.H., P.D. Curtis, G. Curtis, and A.F. Williams. 2004. Methods to reduce traffic crashes involving deer: What works and what does not. Traffic Injury Prevention 5:122-131.

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

Insurance Information Institute. 2010. <http://www.iii.org/ >. Accessed 16 Aug 2012.

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.

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 of female white-tailed deer during estrus at two Mid-Atlantic sites. American Midland Naturalist 163:366-373.

Long, E.S., D.R. Diefenbach, C.S. Rosenberry, and B.D. Wallingford. 2008. Multiple proximate and ultimate causes of natal dispersal in white-tailed deer. Behavioral Ecology 19:1235-1242.

Long, E.S., D.R. Diefenbach, B.D. Wallingford, and C.S. Rosenberry. 2009. Influence of roads, rivers, and mountains on natal dispersal of white-tailed deer. Journal of Wildlife Management 74:1242-1249.

Nixon, C.M., P.C. Mankin, D.R. Etter, L.P. Hansen, P.A. Brewer, J.E. Chelsvig, T.L. Esker, and J.B. Sullivan. 2007. White-tailed deer dispersal behavior in an agricultural environment. American Midland Naturalist 157:212-220.

Nixon, C.M., P.C. Mankin, D.R. Etter, L.P. Hansen, P.A. Brewer, J.E. Chelsvig, T.L. Esker, and J.B. Sullivan. 2008. Migration behavior among female white-tailed deer in central and northern Illinois. American Midland Naturalist 160:178-190.

Olson, A.K. 2014. Spatial use and movement ecology of mature male white-tailed deer in Northcentral Pennsylvania. Master's Thesis. University of Georgia, Athens.

Peek, F.W. and E.D. Bellis. 1969. Deer movements and behavior along an interstate highway. Highway Research News 36:36-42.

Porter, W.F., H.B. Underwood, and J.L. Woodard. 2004. Movement behavior, dispersal, and the potential for localized management of deer in a suburban environment. Journal of Wildlife Management 68:247-256.

Puglisi, M.J., J.S. Lindzey, and E.D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799-807.

State Farm Insurance Company. 2011. <http://www.statefarm.com/>. Accessed 16 Aug 2012.

Steiner, W., F. Leisch, and K. Hackländer. 2014. A review on the temporal pattern of deer-vehicle accidents: impact of seasonal, diurnal, and lunar affects in cervids. Accident Analysis and Prevention 66:168-181.

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.

Waring, G.H., J.L. Griffis, and M.E. Vaughn. 1991. White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. Applied Animal Behaviour Science 29:215-223.

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.

CHAPTER 2

DEER-VEHICLE COLLISION RISK IN CENTRAL GEORGIA: ASSESSMENT OF TEMPORAL VARIATION IN TRAFFIC VOLUME AND DEER MOVEMENT[1]

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[1] Stickles, J. H., D.A. Osborn, B.S. Cohen, R.J Warren, and K.V. Miller. To be submitted to the *Journal of Environmental Management*

Abstract

Past studies have measured deer-vehicle collision (DVC) risk based on spatial and temporal incidence of DVCs. However, no studies have integrated DVCs, traffic, deer movement rates, and deer road crossings to evaluate DVC risk. Using hourly DVC data, traffic data, deer movement rates, and road crossings, we evaluated DVC risk for spring (April – June), summer (July – September), fall (October – December), and winter (January – March) seasons in Central Georgia. We obtained data from 25 deer (13 males, 12 females) instrumented with global positioning system (GPS) collars. Deer movements and DVCs were primarily crepuscular during all seasons; however road crossings were mostly nocturnal with 44% of road crossings occurring between 0000 and 0559 hours when traffic was lowest. Approximately 60% of GPS collared deer crossed roads, with only 7 deer accounting for >90% of all road crossings. Approximately 73% of daily traffic occurred between 0700-1859 hours. Nearly twice the number of daily DVCs occurred during the fall (9.82 DVCs/day) than during the next highest season (winter; 4.94 DVCs/day). The temporal pattern of road crossings explained >61% of the variation in DVC risk per individual driver (hourly DVCs/hourly traffic) for all seasons. Our results indicated that DVC risk for individual motorists was high throughout the entire nocturnal period, not just during the crepuscular period as would be suggested solely by the incidence of DVCs without considering traffic volume. We recommend mitigation efforts focus on: 1) increasing driver vigilance and reducing vehicle speed during nocturnal periods, especially during the fall season, 2) targeted removal of deer along roadways, 3) habitat modifications that increase motorist visibility, reduce roadside attraction, and prevent access to rights-of-way, and 4) integrating infrared camera technology with modern vehicles to better detect deer and other wildlife along roads at night.

Introduction

Each year in the United States, >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).

The occurrence of DVCs is related to at least three variables—roadside/roadway features, deer behavior/movements, and traffic volume. In Georgia, DVCs are clustered spatially 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 problematic sections of roadway may reduce the incidence of DVCs (Hubbard et al. 2000, Gunson et al. 2011).

Deer behavior is the most reliable predictor of DVCs, with traffic volume playing only a minor role in their occurrence (Steiner et al. 2014). On both diurnal and seasonal scales, peaks in DVC occurrence coincide with periods of increased deer movement (Allen and McCullough 1976, Steiner et al. 2014). Previous studies have used incidence of DVCs to assess motorist risk (Allen and McCullough 1976, Haikonen and Summala 2001), but more recently, global positioning system (GPS) technology has been used to study elk (*Cervus elaphus*; Dodd et al. 2007, Gagnon et al. 2007) and grizzly bear (*Ursus arctos*; Waller and Servheen 2005) behavior relative to roads to assess risks and to implement mitigation techniques. Although Basinger (2013) used GPS technology to identify landscape features that facilitate road crossings by white-tailed deer (*Odocoileus virginianus*), we are unaware of any studies that have integrated incidence of DVCs, deer movement, road crossings, and traffic volume. Therefore, we integrated these factors to assess DVC risk in central Georgia.

Study Area

We captured deer and instrumented them with GPS collars in an 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, in Morgan County Georgia. Outside of the right-of-way (ROW), the western portion of the study area was primarily forested on both sides of the highway with planted loblolly pines (*Pinus taeda*) 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.

Along both sides of I-20 was a 1.2-m woven-wire fence, built by Georgia Department of Transportation (GDOT) in 1979. Due to lack of maintenance, the fence was in various stages of disrepair leaving numerous breaches for deer to access the I-20 ROW.

Methods

Deer Capture & Monitoring

From February-June 2012 and January-April 2013, we darted deer within 0.5-km of I-20 using 3 ml transmitter darts (Pneu-dart Inc., Williamsport, Pennsylvania, USA) containing 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. We identified deer as adults ($\geq$1.0 years-old at time of capture) based upon tooth replacement and wear (Severinghaus 1949). Each deer was outfitted with a FOLLOWiT Tellus 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 300 mg injection (150mg [IV] + 150mg [IM]) of Tolazine® (tolazoline hydrochloride; Congaree Veterinary Pharmacy, Cayce, South Carolina, USA). All deer were monitored until ambulatory. Animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A2011 08-023-R1).

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

Deer Movement and Road Crossings

We used ArcGIS 10.2 (Environmental Systems Research Institute, Inc., Redlands, California, USA) to view GPS locations. We removed erroneous locations involving impossible dates, times, or coordinates. To calculate movement rates, we excluded locations with > 1 hour between successive points. For individual deer, we excluded months with >12% data loss and we excluded deer with <4 months of qualifying data. Herein, a calendar month with ≥ 88% of hourly locations for an individual deer is referred to as a "deer month." We determined hourly distance traveled by calculating the distance between successive points for individual deer. We then calculated a monthly mean distance traveled per hour for each deer and used the hourly means to calculate an overall mean across all deer by month. Mean daily distance for each deer was calculated as the sum of all hourly movements divided by the total number of days represented by the data for the individual animal. Because deer behavior is the most reliable predictor of DVCs (Steiner et al. 2014), and the seasonal distribution of DVCs was consistent among years (Allen and McCullough 1976, Bashore et al. 1985), it is reasonable to assume that deer movement rates, road crossings, and traffic patterns are consistent among years. Therefore, we combined these data across years to increase sample size for each month. We pooled monthly data into four biologically meaningful seasons with regard to deer movement in our study area: Spring (April-June), Summer (July-September), Fall (October-December), and Winter (January-March).

To identify road crossing events, we converted points to lines using Geospatial Modeling Environment (Beyer 2014) to create hourly movement paths between successive points for each deer. We then used ArcGIS 10.2 to spatially select and export data from the line segments that crossed roads. To account for unequal numbers of deer months within seasons, we calculated the percent of the total road crossings that occurred during each hour.

Traffic

We obtained traffic volume from a permanent traffic counter located near the center of the segment of I-20 that represented our study area. We calculated mean traffic volume per hour for each month from 1 May 2012 – 31 July 2014. Although traffic patterns may influence deer behavior along roads (Killmaster et al. 2006), and different types of roads have different traffic volumes, the pattern of traffic is likely similar on different road types due to the diurnal pattern of human activity. Therefore, we assumed that the diel distribution of traffic on secondary roads was similar to the distribution on our study site on I-20. Traffic was reported as number of vehicles per hour, therefore we could not determine hourly changes in traffic speed or the types of vehicles used.

Deer-vehicle Collisions

We obtained DVC data for 1 May 2012 – 31 July 2014 from GDOT and isolated data from 19 counties (Baldwin, Barrow, Butts, Clarke, Greene, Gwinnett, Hancock, Henry, Jackson, Jasper, Jones, Monroe, Morgan, Newton, Oconee, Oglethorpe, Putnam, Rockdale, and Walton) surrounding our study site. We assumed deer behavior in these counties was similar to our study site, and therefore temporal patterns of DVCs would also be similar. DVC data were collected by law enforcement agencies and reported to GDOT. Because clock time was used in police reports of DVCs, we standardized these data to Eastern Standard Time. We calculated the proportion of hourly vehicle collisions within each month across years. Although response times to DVCs were not known, DVCs likely were reported to local police within a few minutes of occurrence.

However, police often round time to the nearest 5 or 10 minutes or to the nearest hour or half hour in crash reports (Haikonen and Summala 2001). We assumed that any potential bias in unreported DVCs was consistent among seasons and years in our study.

Within season, we calculated hourly DVC risk per motorist within the counties that comprised our study area by dividing the number of hourly DVCs by mean hourly traffic volume. We visually compared hourly DVC risk against hourly DVC occurrence, hourly deer movement, and hourly percent of total road crossings for each season. Similarly, we compared total DVCs by hour against mean hourly traffic volume, percent of total road crossings by hour, and hourly deer movement. Finally, within season, we used linear regression to compare mean hourly distance traveled and percent of total road crossings by hour (independent variables) against hourly DVC risk (dependent variable).

Results

We captured 32 adult deer (20 males, 12 females). Due to collar malfunctions, mortalities, unsuccessful acquisition of locations, and collar error we obtained partial data sets on 25 deer (13 males, 12 females) accounting for 151,873 hourly GPS locations over 223 deer months (Spring - 13 males, 12 females, 76 deer months; Summer - 13 males, 9 females, 64 deer months; Fall - 7 males, 8 females, 39 deer months; Winter - 4 males, 11 females, 44 deer months). Deer were primarily crepuscular during all seasons with peak movement occurring at sunrise and sunset (Figure 2.1).

We recorded 1,429 road crossings by 15 deer (8 males, 7 females) over 95 deer months averaging 0.39 ± 0.09 crossings per day. A majority of road crossings (n = 919) were contributed by one female (#47). As evidenced by tight clusters of locations during May and June, deer #47 likely birthed fawns in a small wooded patch surrounded by three roads, including I-20 and two paved two-lane county roads. Regardless, #47 crossed roads frequently throughout the year with 421 crossings occurring outside the months of May and June. Despite the large number of crossings made by Deer #47, she survived through the study period. Only seven deer accounted for >90% of all road crossings. Two deer that crossed roads regularly (male #65; n = 43, 0.47 crossings/day; female #85 n = 17, 0.07 crossings/day) were killed by vehicles during the study. Road crossings were mostly nocturnal with 60%, 72%, 80%, and 89% of all crossings occurring at nighttime hours during spring, summer, fall, and winter, respectively. Approximately 44% of all road crossings occurred from 0000-0559 hours, when traffic was lowest (Figure 2.1).

For all seasons, greatest traffic volume occurred from 1500-1559 hours and the lowest occurred from 0200-0259 hours. Across seasons, approximately 73% of daily traffic occurred between 0700-1859 hours. DVC patterns did not follow traffic volume patterns throughout a 24-hour period. During daylight hours, traffic volume was high but DVCs were low. However, during nighttime hours, traffic volume and frequency of DVCs appeared closely related.

There were 4,531 reported DVCs within the counties that comprised our study area. For all seasons the distribution of DVCs was crepuscular with morning peaks in DVCs occurring concurrently with deer movement at sunrise for spring and summer, and one hour prior to sunrise during fall and winter (Figure 2.1). Evening peaks in DVCs occurred one hour after sunset for all seasons. There were 4.67, 3.26, 9.82, and 4.94 DVCs/day for spring, summer, fall, and winter, respectively. Fall accounted for 44% of the annual DVCs with November alone accounting for 20% of annual DVCs.

Although DVCs occurred at greater frequencies during crepuscular hours, when considering traffic volumes, an individual motorist was at elevated risk throughout the entire nocturnal period (Figure 2.2). For all seasons, the hourly DVC risk (i.e., hourly DVCs/hourly traffic volume) for individual drivers was better explained by hourly road crossings ($R^2_{Spring} = 0.729$, $P < 0.01$, $y = 0.037x - 0.006$; $R^2_{Summer} = 0.613$, $P < 0.01$, $y = 0.0015x + 0.0006$; $R^2_{Fall} = 0.614$, $P < 0.01$, $y = 0.0038x + 0.0031$; $R^2_{Winter} = 0.699$, $P < 0.01$, $y = 0.0018x + 0.0031$), than by hourly movement rates ($R^2_{Spring} = 0.115$, $P = 0.11$, $y = 8E\text{-}05x + 0.0017$; $R^2_{Summer} = 0.046$, $P = 0.31$, $y = 4E\text{-}05x + 0.0028$; $R^2_{Fall} = 0.137$, $P = 0.07$, $y = 0.0001x + 0.0039$; $R^2_{Winter} = 0.019$, $P = 0.52$, $y = 2E\text{-}05x + 0.0081$).

Discussion

Although deer movement is an important variable in the occurrence of DVCs, deer are only a traffic hazard when they are crossing or are in close proximity to roads. Although deer were moving at an increased rate at sunset, a majority of road crossings did not occur until one hour after sunset. Road crossings and DVCs remained elevated throughout the night, even when deer movement had declined to near daytime levels. As morning traffic increased, road crossings declined rapidly, concurrent with DVCs. Past studies have identified DVC peaks at dawn and dusk, and have attributed such increases to increased deer movement and reduced visibility (Allen and McCullough 1976, Haikonen and Summala 2001, Steiner et al. 2014). Insurance companies, law enforcement agencies, and transportation agencies often warn motorists of DVC risk during dawn and dusk, but these warnings have been based on incomplete information, failing to recognize that deer frequently cross and interact with roads throughout the entire night. Studies from Michigan and Pennsylvania also showed that deer activity relative to roads appeared constant from dusk to dawn (Carbaugh et al. 1975, Allen and McCullough 1976), and researchers in Tennessee who surveyed deer with aerial infrared imaging observed deer congregated along roads during nighttime survey periods (Beaver et al. 2014). Therefore, risk of encountering deer within the roadway remains elevated throughout all nighttime hours, not just the hours surrounding dawn and dusk.

Deer that regularly cross roads are a primary threat to motorist safety. Although 60% of the deer in our study crossed roads, the fact that most of the crossings were represented by very few deer indicates that there are individual differences among deer with regard to crossing roads. 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). This pattern suggests that DVC mortality may remove individuals that cross roads frequently or during periods of high risk. Perhaps targeted removal of individuals with the highest propensity for crossing roads could mitigate DVCs to some extent.

Deer behavior seemed to be influenced by traffic as they tended to avoid crossing roads during daylight hours when traffic was greatest, and crossed roads frequently when traffic was lowest. Peaks in DVCs at dawn and dusk were likely a product of elevated levels of traffic during hours when deer were crossing roads, resulting in fewer successful crossings (Allen and McCullough 1976, Hussain et al. 2007, Steiner et al. 2014). On a seasonal basis, motorists were nearly two times more likely to strike a deer during fall than during the next highest season for DVCs (winter). Based on our data, the primary period of midday rest during the fall breeding season was shorter than other seasons, and deer were crossing roads later into the morning and earlier in the afternoon when traffic levels were elevated. Factors such as incentive to breed, escaping harassment from other deer or hunters, or to access desirable seasonal resources may cause deer that normally avoid crossing roads to cross roads more frequently (Sudharsan et al. 2006, Kolodzinski et al. 2010, Steiner et al. 2014). Although the temporal pattern of nighttime crossings during fall was similar to other seasons, road crossings must have increased to produce the nearly doubling of daily DVCs that we observed during that season. However, the lower number of GPS collared deer during the fall season may have limited our ability to detect an increase in road crossings.

Management Implications

Because DVCs occur 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 nighttime motorists, especially those traveling between the hours of 0000-0559, were at greatest risk of being involved in a DVC. Substantially decreased traffic during late-night hours 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 crossing roadways during nighttime travel from dusk to dawn. Such programs should focus on increased DVC risk associated with late-night travel and the fall breeding season with recommendations to increase vigilance and reduce vehicle speed.

Because a high percentage of road crossings were contributed by relatively few individual deer, targeted removal of deer observed along roadsides may aid in reducing encounters between motorists and deer throughout the year. However, removals may not significantly reduce encounters that occur during seasonal periods of major deer movement.

The fact that diel DVC risk appeared coincident with road crossings indicates that habitat modifications should focus on reducing crossings. Roadside fencing is a viable option for preventing deer access to roads and directing them to safe crossing areas such as over passes or under passes. Removing desirable resources from roadsides, such as high quality forage, thick bedding cover, or standing water, may also help mitigate road crossings throughout much of the year.

Finally, the greatest risk of being involved in a DVC occurs at night when human visibility is limited. Advancements in modern night-vision technology, such as infrared or thermographic cameras, have the potential to be integrated with modern vehicles or advanced roadside warning systems to detect wildlife standing in or along roads, and possibly give motorists more time to reduce their speed (Zhou 2013). Future research should consider development and testing such systems for the purpose of DVC mitigation.

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. Tzilkowski, and E. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769-774.

Basinger, P.S. 2013. Rutting behavior and factors influencing vehicle collisions of white-tailed deer in middle Tennessee. Master’s thesis. University of Tennessee, Knoxville.

Beaver, J.T., C.A. Harper, R.E. Kissell Jr., L.I. Muller, P.S. Basinger, M.J. Goode, F.T. Van Manen, W. Winton, and M.L. Kennedy. 2014. Aerial vertical-looking infrared imagery to evaluate bias of distance sampling techniques for white-tailed deer. Wildlife Society Bulletin 38:419-427.

Beyer, H. L. 2014. Geospatial Modelling Environment Software. <www.spatialecology.com> Accessed 15 September 2014.

Bowers, J.W., A. Hammond, K. Kammermeyer, C. Martin, S. McDonald, N. Nicholson, J. Robbins, T. Touchstone, and G. Waters. 2005. Georgia's deer management plan 2005-2014. Georgia Department of Natural Resources, Wildlife Resources Division, Game Management Section, Social Circle, Georgia.

Carbaugh, B., J. Vaughan, E. Bellis, and H. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management 39:570-581.

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.

Dodd, N.L., J.W. Gagnon, S. Boe, R.E. Schweinsburg. 2007. Assessment of elk highway permeability by using global positioning system telemetry. Journal of Wildlife Management 71:1107-1117.

Falk, N. W., H. Graves, and E. Bellis. 1978. Highway right-of-way fences as deer deterrents. Journal of Wildlife Management 42:646-650.

Gagnon, J.W., T.C. Theimer, N.L. Dodd, S. Boe, and R.E. Schweinsburg. 2007. Traffic volume alters elk distribution and highway crossings in Arizona. Journal of Wildlife Management 71:2318-2323.

Gunson, K.E., G. Mountrakis, and L.J. Quackenbush. 2011. Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. Journal or Environmental Management 92:1074-1082.

Haikonen, H. and H. Summala, 2001. Deer-vehicle crashes – extensive peak at 1 hour after sunset. American Journal of Preventive Medicine 21:209-213.

Hubbard, M. W., B. Danielson, and R. 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.

Insurance Information Institute. 2010. <http://www.iii.org/ >. Accessed 16 Aug 2012.

Killmaster, C.H., D.A. Osborn, R.J. Warren, and K.V. Miller. 2006. Effect of roads and traffic on deer movements in a Georgia park. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 60:54-58.

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 of female white-tailed deer during estrus at two Mid-Atlantic sites. American Midland Naturalist 163:366-373.

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

Severinghaus, C.W. 1949. Tooth development and wear as criteria of age in white-tailed deer. Journal of Wildlife Management 13:195-216.

State Farm Insurance Company. 2011. <http://www.statefarm.com/>. Accessed 16 Aug 2012.

Steiner, W., F. Leisch, and K. Hackländer. 2014. A review on the temporal pattern of deer-vehicle accidents: impact of seasonal, diurnal, and lunar affects in cervids. Accident Analysis and Prevention 66:168-181.

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.

Waller, J.S. and C. Servheen. 2005. Effects of transportation infrastructure on grizzly bears in Northwestern Montana. Journal of Wildlife Management 69:985-1000.

Zhou, Debao. 2013. Thermal image-based deer detection to reduce accidents due to deer-vehicle collisions. Department of Mechanical and Industrial Engineering, Northland Advanced Transportation Systems Research Laboratories, University of Minnesota Duluth, Duluth, Minnesota.

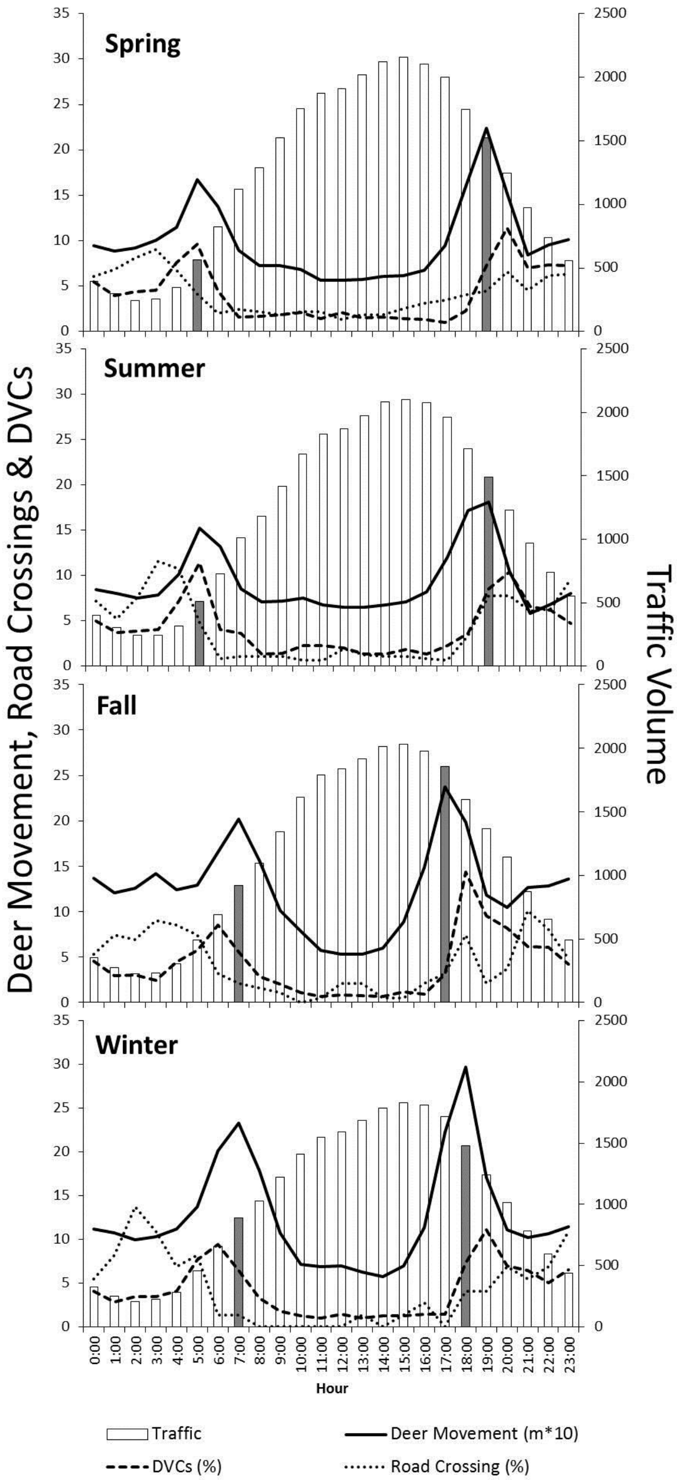

Figure 2.1. Seasonal mean hourly traffic volume, percent of total hourly deer-vehicle collisions, mean hourly distance moved (m*10), and percent of total road crossings from 1 May 2012-31 July 2014. Gray traffic bars indicate the hours of sunrise and sunset.

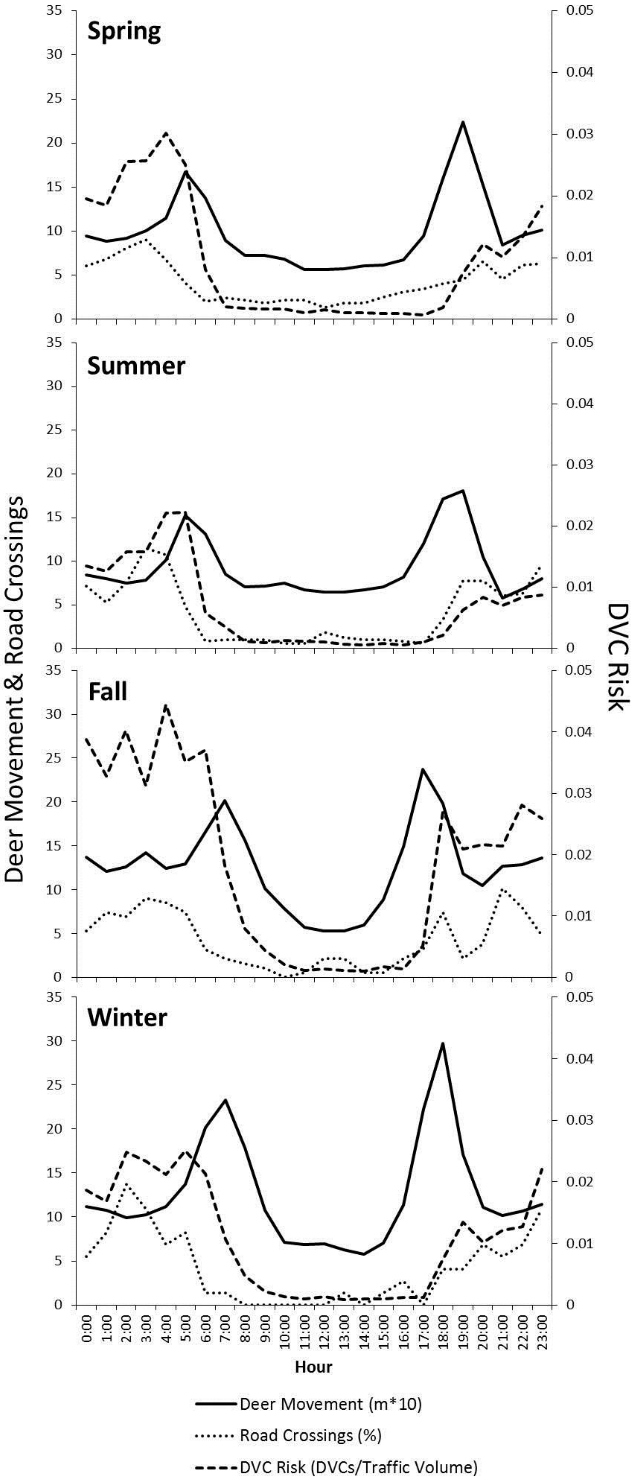

Figure 2.2. Seasonal hourly deer-vehicle collision risk, percent of total hourly road crossings, and mean hourly distance moved from 1 May 2012-31 July 2014.

CHAPTER 3

MOVEMENT PATTERNS OF WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) ALONG AN INTERSTATE HIGHWAY IN GEORGIA, USA [1]

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[1] Stickles, J. H., D.A. Osborn, B.S. Cohen, R.J Warren, and K.V. Miller. To be submitted to the *Journal of Environmental Management*

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 highway median to the home range centroid differed among groups ($P < 0.01$; $F_{2, 27}=8.46$). Home range centroids for frequent users were closer (359.5 ± 41.7 m) to the I-20 median than rare users (766.6 ± 72.3 m; $P < 0.01$), but did not differ between frequent and occasional users ($P > 0.05$, 715.3 ± 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 2100-0259 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.

Introduction

Each year in the United States, >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 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 ($\geq$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 each of 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 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.), an aerial image of the study area, and GPS locations of the ROW fence, 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 (>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 ArcToolbox. 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 area 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 >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 $\geq$ 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 (13 adult males, 11 adult females, 7 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 $\geq$ 12 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 ± 11.9 ha ($\bar{x}$ ± SE; range = 29.9 - 329.8 ha) and 17.0 ± 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 ± 41.7 m) were closer ($P < 0.01$) to the I-20 median than rare (766.6 ± 72.3 m) users, but did not differ between frequent and occasional users ($P > 0.05$, 715.3 ± 236.4 m) or between occasional and rare users ($P > 0.05$).

Group Descriptions

Sixteen of the collared animals (7 adult males, 5 adult females, 3 juvenile males, 1 juvenile female) were considered rare users of the ROW (Figure 3.1). The percentage of ROW locations for these 16 individuals ranged from 0% to 0.07%. The number of locations within the ROW did not exceed 2 for any month (Table 3.1). 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 road crossings occurred on I-20.

Five deer (4 adult males, 1 juvenile male) were occasional users of the ROW (Figure 3.1). The percentage of ROW locations for these five 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 3.1). 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 three locations occurred on the opposite side of the median accounting for a minimum of six total road crossings on I-20.

The frequent user group consisted 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 3.1). The percentage of ROW locations for these 11 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 3.1). 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 direction of traffic (n = 123) twice, and four deer crossed at least two directions of traffic (n = 8) twice accounting for a minimum of 278 road crossings on I-20.

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 ± 579 vehicles/day; Figure 3.2) and lowest during January (22,524 ± 375 vehicles/day; Figure 3.2). Seasonal use of the ROW by frequent users peaked in May and June and was reflective of increased ROW use by females (Figure 3.2). 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 3.2). 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 2006 ± 19 vehicles/hour from 1500-1559 to 231.4 ± 1.7 vehicles/hour from 0200-0259 hours (Figure 3.3). Deer ROW usage occurred primarily during nighttime hours (2000-0659), for both sexes with about 37% of locations within the ROW occurring between 2100-0259 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 3.4). 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 3.5). This increased ROW use was reflective of three adult females. We observed tight clustering of locations during a period of ≥ 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 2100-0259 were at greatest risk of encountering deer within the ROW. 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 vegetation surrounding the ROW fence was not maintained allowing mast producing trees and shrubs to grow along the fence line. 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.

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. Tzilkowski, and E. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769-774.

Bellis, E.D. and H. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232-237.

Bowers, J.W., A. Hammond, K. Kammermeyer, C. Martin, S. McDonald, N. Nicholson, J. Robbins, T. Touchstone, and G. Waters. 2005. Georgia's deer management plan 2005-2014. Georgia Department of Natural Resources, Wildlife Resources Division, Game Management Section, Social Circle, Georgia.

Carbaugh, B., J. Vaughan, E. Bellis, and H. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management 39:570-581.

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

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 Southeast Association of Fish and Wildlife Agencies 58:292-301.

DeYoung, R. and K. V. Miller. 2011. White-tailed Deer Behavior. Pages 311-351 in: D. Hewitt, editor. White-tailed Deer Ecology and Management. CRC Press, Boca Raton, FL.

Dodd, N.L., J.W. Gagnon, S. Boe, R.E. Schweinsburg. 2007. Assessment of elk highway permeability by using global positioning system telemetry. Journal of Wildlife Management 71:1107-1117.

Fahrig, L. and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society 14:21 <http://www.ecologyandsociety.org/vol14/iss1/art21/>. Accessed 18 August 2014.

Falk, N. W., H. Graves, and E. Bellis. 1978. Highway right-of-way fences as deer deterrents. Journal of Wildlife Management 42:646-650.

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

Gagnon, J.W., T.C. Theimer, N.L. Dodd, S. Boe, and R.E. Schweinsburg. 2007. Traffic volume alters elk distribution and highway crossings in Arizona. Journal of Wildlife Management 71:2318-2323.

Georgia Outdoor News. 2000. Georgia whitetail journal. Georgia Outdoor News Inc., Marietta, Georgia.

Glista, D.J., T.L. DeVault, and J.A. DeWoody. 2009. A review of mitigation measures for reducing wildlife mortality on roadways. Landscape and Urban Planning 91:1-7.

Grovenburg, T.W., J.A. Jenks, R.W. Klaver, C.C. Swanson, C.N. Jacques, and D. Todey. 2009. Seasonal movements and home ranges of white-tailed deer in north-central South Dakota. Canadian Journal of Zoology 87:878-885.

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.

Gunson, K.E., G. Mountrakis, and L.J. Quackenbush. 2011. Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. Journal or Environmental Management. 92:1074-1082.

Hedlund, J.H., P.D. Curtis, G. Curtis, and A.F. Williams. 2004. Methods to reduce traffic crashes involving deer: What works and what does not. Traffic Injury Prevention 5:122-131

Hubbard, M. W., B. Danielson, and R. 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.

Insurance Information Institute. 2010. <http://www.iii.org/ >. Accessed 16 Aug 2012.

Jahn, L.R. 1959. Highway mortality as an index of deer-population change. Journal of Wildlife Management 23:187-197.

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.

Keenan, M. T. 2010. Hunter distribution and harvest of female white-tailed deer in Pennsylvania. Master’s Thesis. Pennsylvania State University, State College.

Killmaster, C.H., D.A. Osborn, R.J. Warren, and K.V. Miller. 2006. Effect of roads and traffic on deer movements in a Georgia park. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 60:54-58.

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 of female white-tailed deer during estrus at two Mid-Atlantic sites. American Midland Naturalist 163:366-373.

Kranstauber, B., R. Kays, S.D. LaPoint, M. Wikelski, and K. Safi. 2012. A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. Journal of Animal Ecology 81:738-746.

Long, E.S., D.R. Diefenbach, B.D. Wallingford, and C.S. Rosenberry. 2009. Influence of roads, rivers, and mountains on natal dispersal of white-tailed deer. Journal of Wildlife Management 74:1242-1249.

Long, E.S., D.R. Diefenbach, C.S. Rosenberry, and B.D. Wallingford. 2008. Multiple proximate and ultimate causes of natal dispersal in white-tailed deer. Behavioral Ecology 19:1235-1242.

Nixon, C.M., P.C. Mankin, D.R. Etter, L.P. Hansen, P.A. Brewer, J.E. Chelsvig, T.L. Esker, and J.B. Sullivan. 2007. White-tailed deer dispersal behavior in an agricultural environment. American Midland Naturalist 157:212-220

Nixon, C.M., P.C. Mankin, D.R. Etter, L.P. Hansen, P.A. Brewer, J.E. Chelsvig, T.L. Esker, and J.B. Sullivan. 2008. Migration behavior among female white-tailed deer in central and northern Illinois. American Midland Naturalist 160:178-190.

Olson, A.K. 2014. Spatial use and movement ecology of mature male white-tailed deer in Northcentral Pennsylvania. Master’s Thesis. University of Georgia, Athens.

Peek, F.W. and E.D. Bellis. 1969. Deer movements and behavior along an interstate highway. Highway Research News 36:36-42.

Puglisi, M.J., J.S. Lindzey, and E.D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799-807.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

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

Romin, L.A. and J.A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. Great Basin Naturalist 56:1-11.

Ruediger, B. 2004. Carnivore conservation and highways: understanding the relationships, problems and solutions. Pp. 132-149 in N. Fascione, A. Delach, and M. Smith, editors. People and predators: from conflict to coexistence. Island Press, Washington D.C., USA.

Scanlon, J.J., and M.R. Vaughan. 1985. Movements of white-tailed deer in Shenandoah National Park, Virginia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 39:396-402.

Severinghaus, C.W. 1949. Tooth development and wear as criteria of age in white-tailed deer. Journal of Wildlife Management 13:195-216.

State Farm Insurance Company. 2011. <http://www.statefarm.com/>. Accessed 16 Aug 2012.

Steiner, W., F. Leisch, and K. Hackländer. 2014. A review on the temporal pattern of deer-vehicle accidents: impact of seasonal, diurnal, and lunar affects in cervids. Accident Analysis and Prevention 66:168-181.

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.

Waller, J.S. and C. Servheen. 2005. Effects of transportation infrastructure on grizzly bears in Northwestern Montana. Journal of Wildlife Management 69:985-1000.

Waring, G.H., J.L. Griffis, and M.E. Vaughn. 1991. White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. Applied Animal Behaviour Science 29:215-223.

Warnell School of Forest Resources. 2008. <http://warnell.forestry.uga.edu/Warnell/Bettinger/GPS/UGA_GPS.htm>. Accessed 15 September 2013.

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.

Table 3.1. 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**
Residents												
# 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)

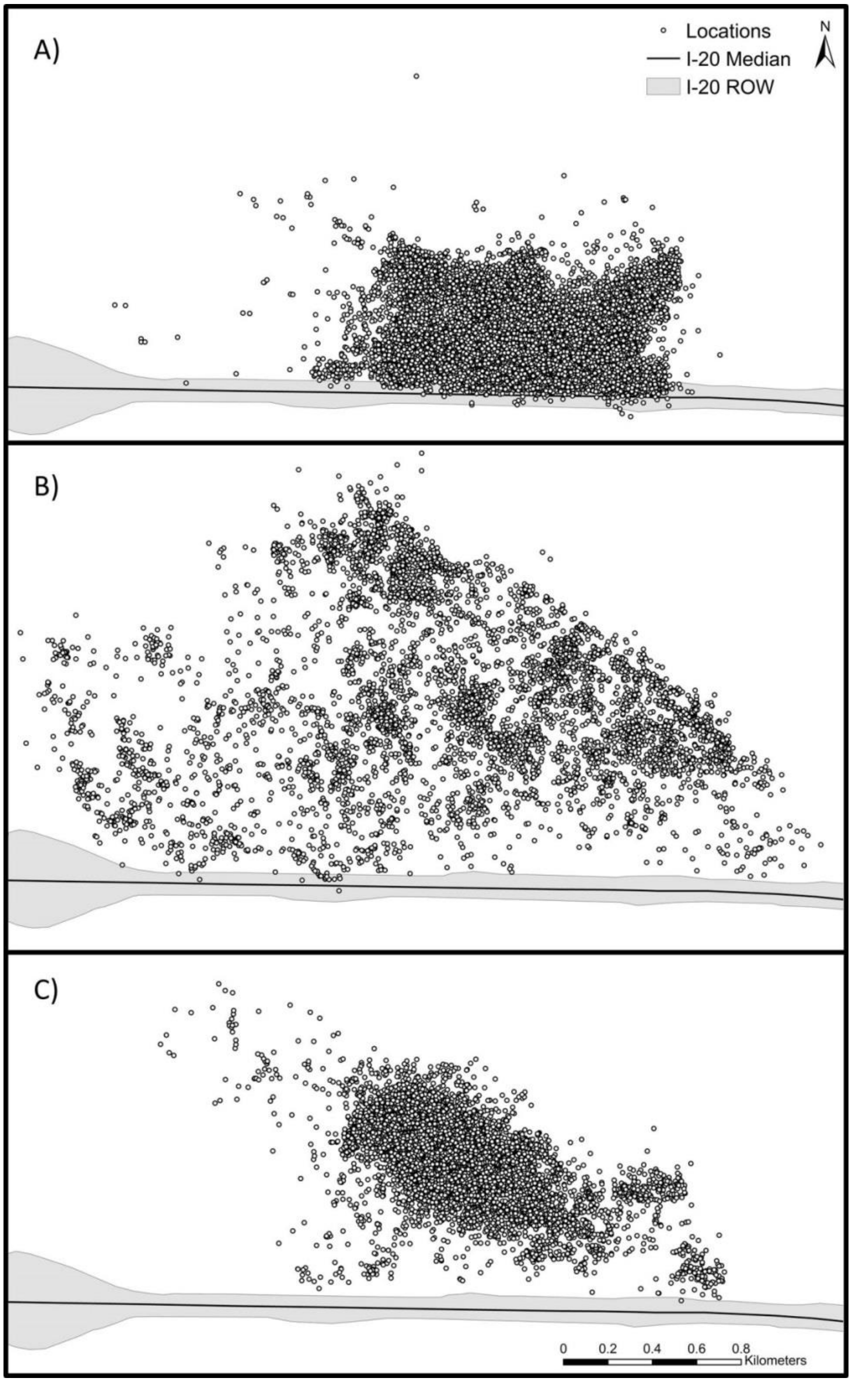

Figure 3.1. GPS locations demonstrating ROW use for: A) frequent users (adult female; n = total [ROW] 13,525 [1,220]; date range = 30 May 2012 to 28 February 2014), B) occasional users (adult male; n = 6,825 [14]; date range = 2 February 2013 to 29 May 2013; 29 August to 28 February 2014), and C) rare 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.

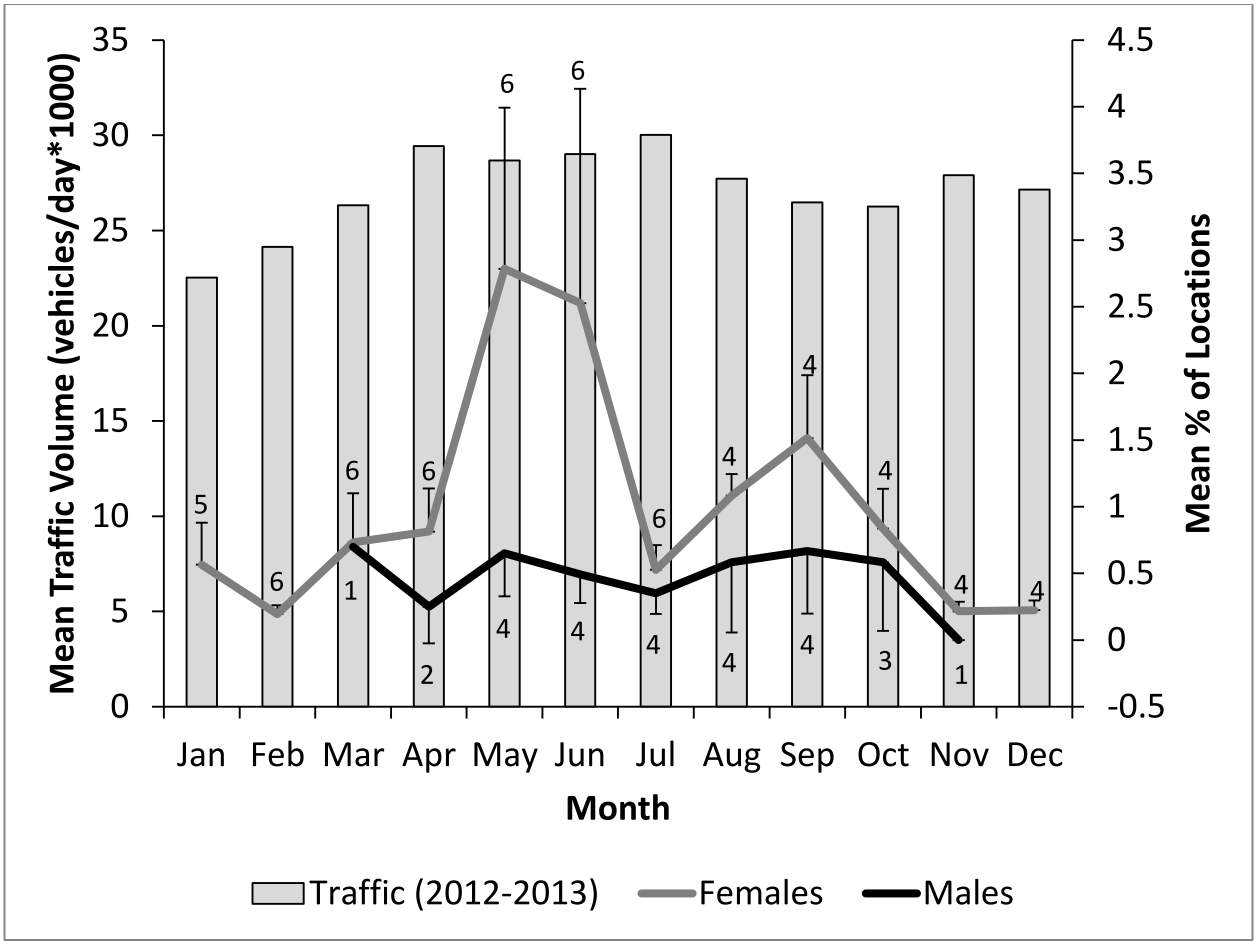

Figure 3.2. Mean monthly traffic volume (vehicles/day*1000) from 1 January 2012 to 31 December 2013 versus mean percent of locations with the ROW by month for 5 male and 6 female deer in the frequent user group from 15 April 2012 to 11 April 2014, in Madison, GA.

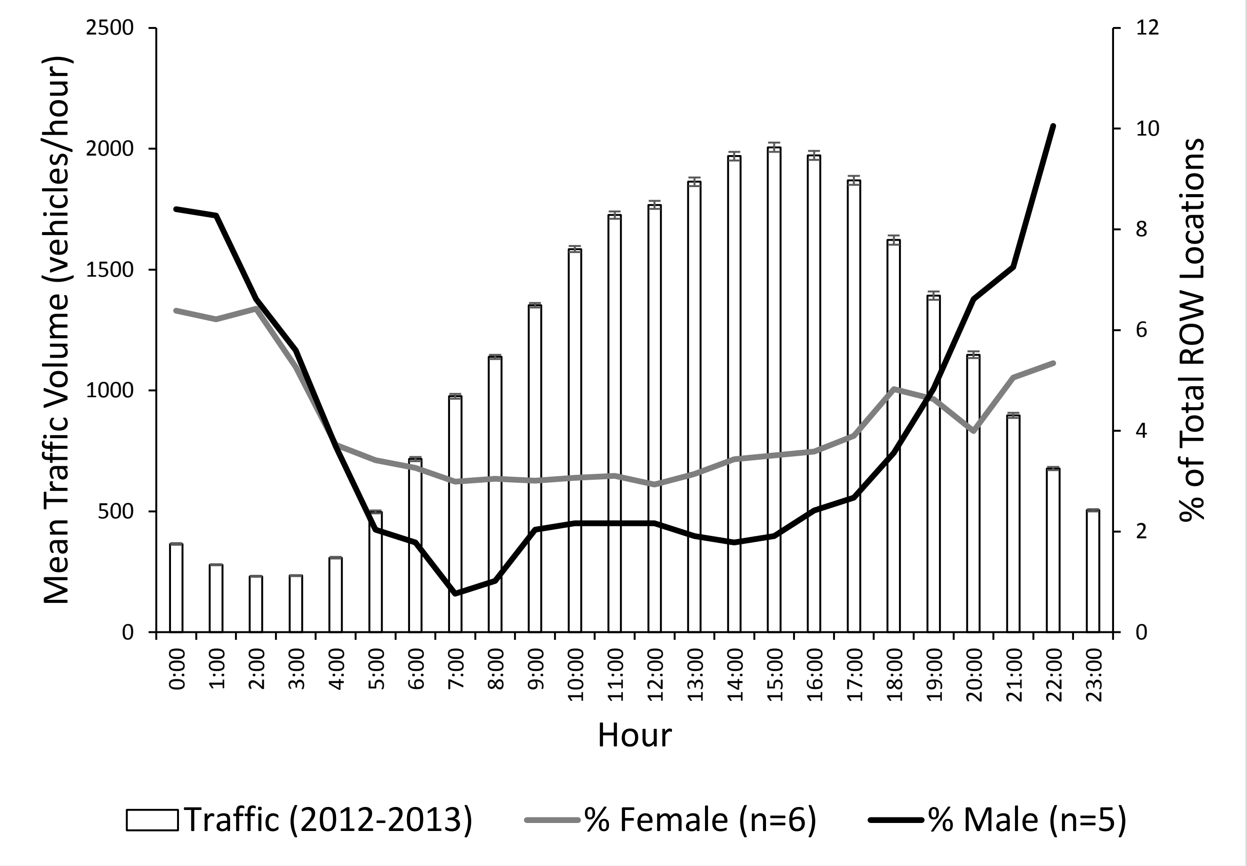

Figure 3.3. Mean hourly traffic volume (vehicles/hour) from 1 January 2012 to 31 December 2013 versus percent of total locations within the ROW by hour for 5 male and 6 female deer in the frequent user group from 15 April 2012 to 11 April 2014, in Madison, GA.

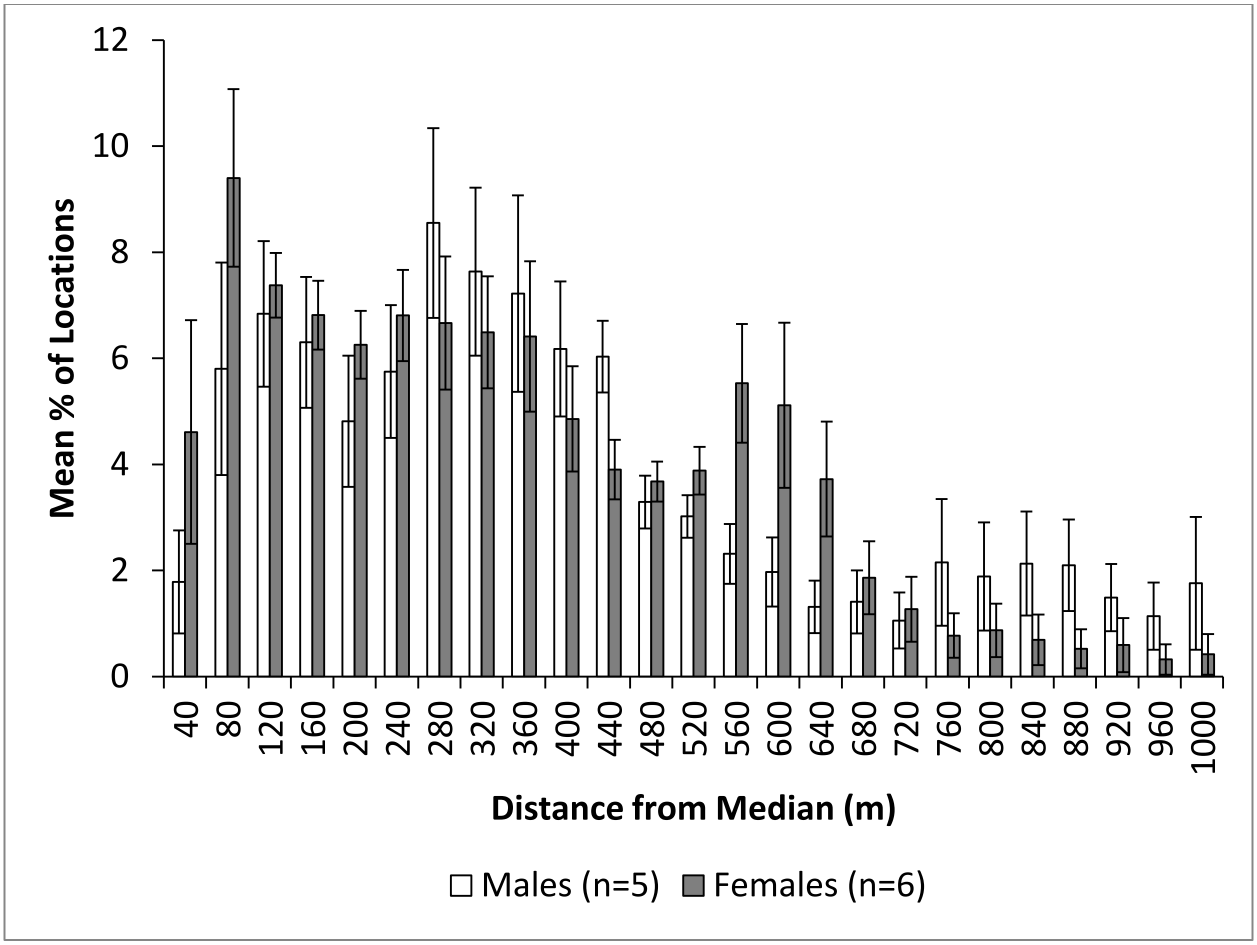

Figure 3.4. Mean percent of locations at 40 m increments from the ROW median for 5 male and 6 female deer in the frequent user group from 15 April 2012 to 11 April 2014, along a test section of I-20 near Madison, GA.

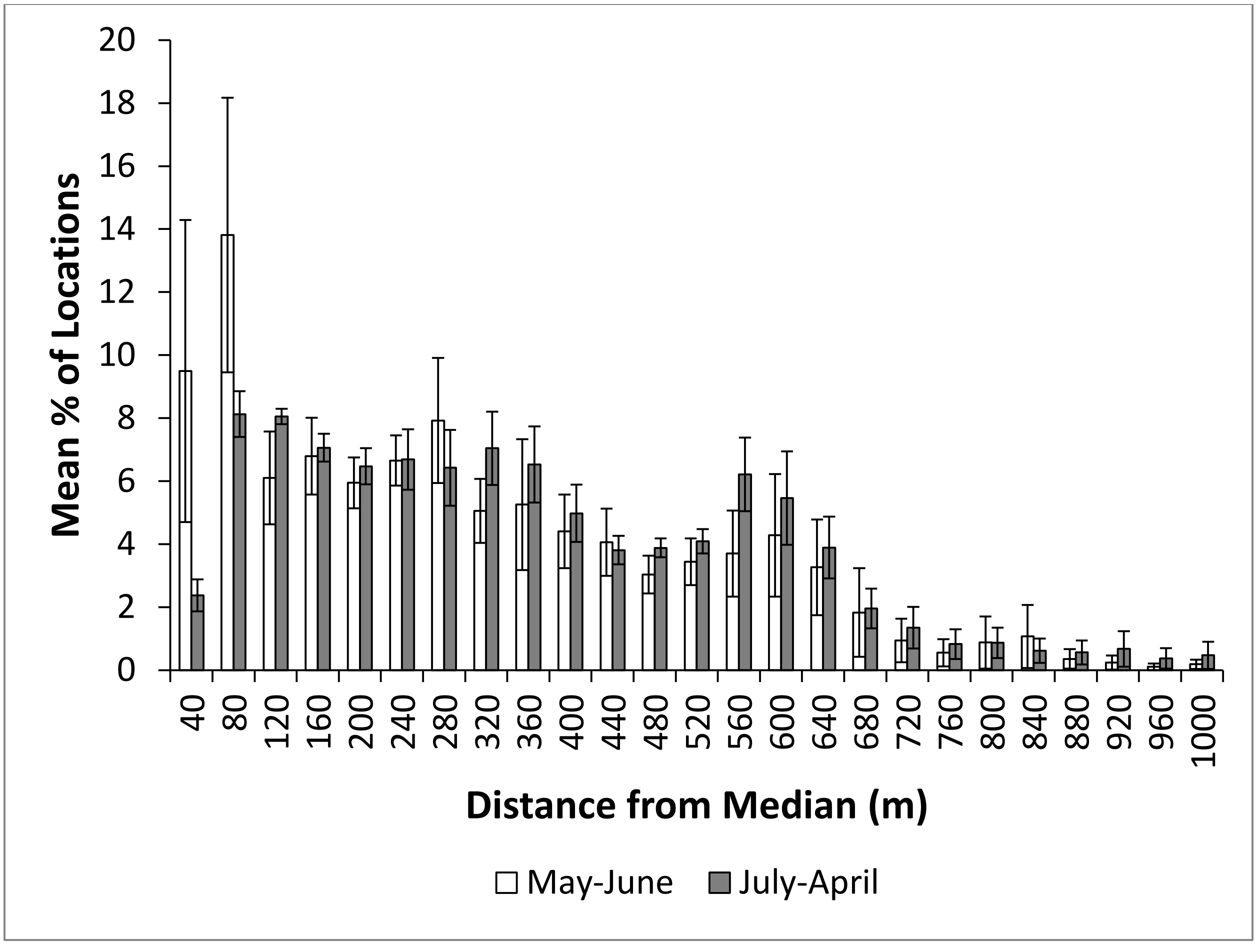

Figure 3.5. Mean percent of locations at 40 m increments from the ROW median for 6 female deer in the frequent user group comparing May-June locations against July-April locations along a test section of I-20 near Madison, GA.

CHAPTER 4

USING DEER-VEHICLE COLLISIONS TO MAP WHITE-TAILED DEER BREEDING ACTIVITY IN GEORGIA [1]

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[1] Stickles, J. H., D.B. Stone, C.S. Evans, K.V. Miller, R.J. Warren, D.A. Osborn, and C.H. Killmaster. Accepted by the *Journal of Southeastern Association of Fish and Wildlife Agencies* Reprinted here with permission of the publisher.

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.

Introduction

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 improves 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, measuring fetuses, which is 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 DVCs 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 (The University of Georgia Museum of Natural History 2008).

We also monitored seasonal movements of GPS-collared deer on a privately-owned, 1,821-ha property in Harris County which is in the piedmont region of 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 spp.).

Methods

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

In Pickens, Harris, and Greene Counties we were able to obtained datasets from prior studies that evaluated the timing of conception based on measuring fetuses (Hamilton et al. 1985) from hunter harvests or culls. These data were provided by the Georgia Department of Natural Resources, the United States Department of Agriculture, Wildlife Services, and private consulting biologists. We visually compared the weekly distribution of the smoothed combined-county DVCs against the weekly distribution of conception dates for each of these three counties. We also used a two-sample Kolmogorov-Smirnov test (a = 0.05) to compare the distribution functions of the weekly DVC data and the conceptions dates in each county.

As an additional comparison, we visually compared the occurrence of DVCs from Harris County with movement data for 19 adult ($\geq$ 2.5-years-old) deer (10 males, 9 females) captured at a research site within that county. 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. 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 DNR 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 ($\bar{x}$ = 5726 $\pm$ 578). 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 4.1a). 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, DVC peaks closely mirrored the distribution of rut dates as described by the rut map published by Georgia Outdoor News (Figure 4.1b), with some notable exceptions. Several counties in northwest Georgia with a predicted late November rut (eg. Walker, Gordon, etc.) had 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, but 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 peak where DVCs occurred at similar frequencies for several weeks in these counties (n = 5).

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 4.2a-c). We detected no difference in the distribution functions of the conception data and the occurrence of DVCs (Harris County: D = 0.33, P = 0.70; Pickens County: D = 0.20, P = 0.99; Greene County: D = 0.33, P = 0.89). However, timing of peak conceptions in Pickens County and Greene County appeared to lag slightly behind occurrence of peak DVCs (Figure 4.2a-b).

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 4.2c). The increase in deer activity rates was primarily due to increased movements by males ($t_{17} > 2.10$; $P < 0.05$ from 13 October to 28 December; Figure 4.3). 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 Georgia has the smallest average county size of any U.S. state, 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 <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 analysis techniques we used, 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.

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. Tzilkowski, and E. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769-774.

Bellis, E.D. and H. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232-237.

Bowers, J.W., A. Hammond, K. Kammermeyer, C. Martin, S. McDonald, N. Nicholson, J. Robbins, T. Touchstone, and G. Waters. 2005. Georgia's deer management plan 2005-2014. Georgia Department of Natural Resources, Wildlife Resources Division, Game Management Section, Social Circle, Georgia.

Cheatum, E.L. and C.W. Severinghaus. 1950. Variations in fertility of white-tailed deer related to range conditions. Transactions of the North American Wildlife Conference 15: 170-189.

Cheatum, E.L., and G.H. Morton. 1946. Breeding season of white-tailed deer in New York. Journal of Wildlife Management 10:249-263.

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.

Garrison, E., R. Kiltie, L. Perrin, and G. Mohr. 2009. White-tailed deer breeding chronology project. Florida Fish and Wildlife Conservation Commission Preliminary Summary Report, Tallahassee, Florida.

Georgia Outdoor News. 2000. Georgia whitetail journal. Georgia Outdoor News Inc., Marietta, Georgia.

Gruver, B.J., D.C. Guynn Jr., H.A. Jacobson. 1984. Simulated effects of harvest strategy on reproduction in white-tailed deer. Journal of Wildlife Management 48:535-541.

Guynn, D.C., J.R. Sweeney, and R.J. Hamilton. 1986. Adult sex ratio and conception dates in a South Carolina deer herd. Annual Meeting of the Southeast Deer Study Group 9:13.

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.

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.

Iverson, A.L. and L.R Iverson. 1999. Spatial and temporal trends of deer harvest and deer-vehicle accidents in Ohio. Ohio Journal of Science 99:84-94.

Jacobson, H.A. 1992. Deer condition response to changing harvest strategy, Davis Island, Mississippi. Pages 98-108 in R.D. Brown, editor. The biology of deer. Springer, New York, New York.

Jahn, L.R. 1959. Highway mortality as an index of deer-population change. Journal of Wildlife Management 23:187-197.

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.

Kentucky State Police (KSP). 2013. Deer/Auto Collisions in Kentucky. KSP. <http://kentuckystatepolice.org/deerauto.htm>. Accessed 24 April 2014.

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 of female white-tailed deer during estrus at two Mid-Atlantic sites. American Midland Naturalist 163:366-373.

Lincoln, G.A. 1992. Biology of seasonal breeding in deer. Pages 565-574 in R.D. Brown, editor. The biology of deer. Springer, New York, New York.

McCaffery, K.R. 1973. Road-kills show trends in Wisconsin deer populations. Journal of Wildlife Management 37:212-216.

McShea, W.J., C.M. Stewart, L.J. Kearns, S. Liccioli, and D. Kocka. 2008. Factors affecting autumn deer-vehicle collisions in a rural Virginia county. Human-Wildlife Conflicts 2:110-121.

Olson, A.K. 2014. Spatial use and movement ecology of mature male white-tailed deer in Northcentral Pennsylvania. Master's Thesis. University of Georgia, Athens.

Puglisi, M.J., J.S. Lindzey, and E.D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799-807.

Richter, A.R. and R.F. Labisky. 1985. Reproductive dynamics among disjunct white-tailed deer herds in Florida. Journal of Wildlife Management 49: 964-971.

Romin, L.A. and J.A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle Reservoir, Utah. Great Basin Naturalist 56:1-11.

Rosenberry, C.S., M.C. Conner, and R.A. Lancia. 2001. Behavior and dispersal of white-tailed deer during the breeding season. Canada Journal of Zoology 79:171-174.

State Farm Insurance Company. 2011. <http://www.statefarm.com/>. Accessed 16 Aug 2012.

Steiner, W., F. Leisch, and K. Hackländer. 2014. A review on the temporal pattern of deer-vehicle accidents: impact of seasonal, diurnal, and lunar affects in cervids. Accident Analysis and Prevention 66:168-181.

Stone, D.B. 2012. Novel data as a source for assessing breeding phenology of white-tailed deer (Odocoileus virginianus) in South Carolina. Master's Thesis. Clemson University, Clemson, South Carolina.

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.

The University of Georgia Museum of Natural History. 2008. Physiographical regions of Georgia. <http://naturalhistory.uga.edu>. Accessed 2 September 2014.

Tomberlin, J.W. 2007. Movement, activity, and habitat use of male white-tailed deer at Chesapeake Farms, Maryland. Master's Thesis. North Carolina State University, Raleigh.

Wisconsin Department of Transportation. 2012. Motor vehicle-deer crashes in 2012. <http://www.dot.wisconsin.gov/safety/motorist/crashfacts/docs/deerfacts.pdf>. Accessed 24 April 2014.

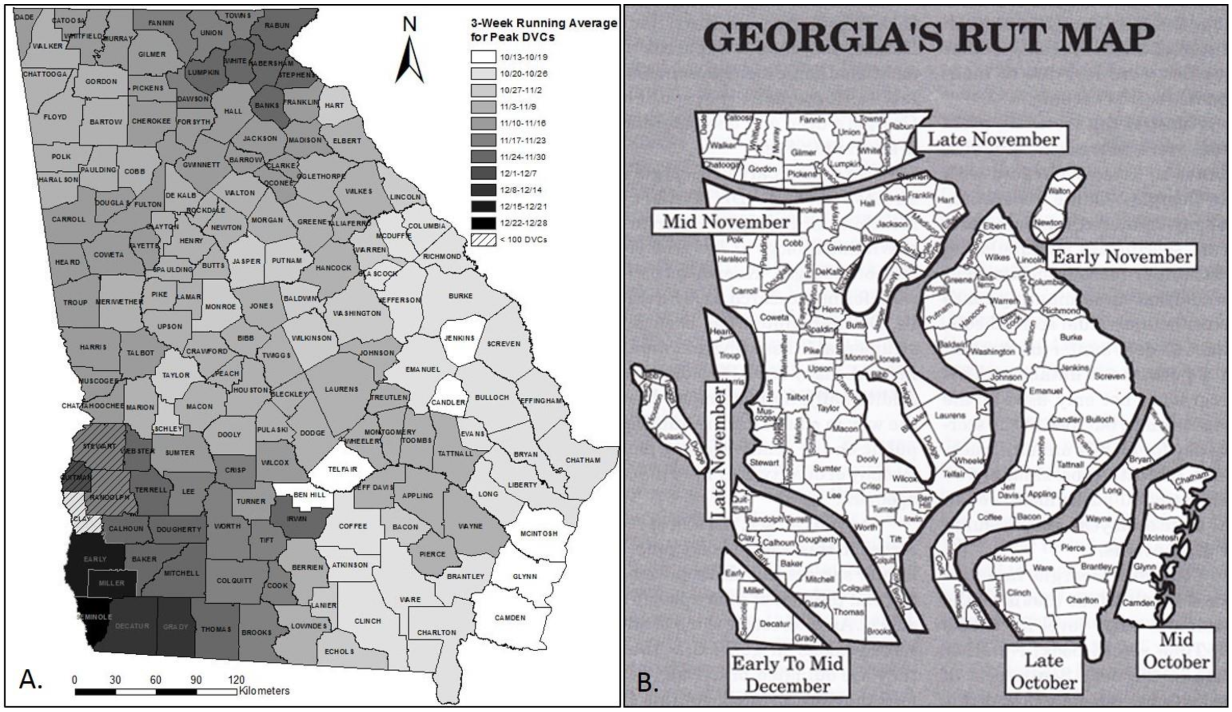

Figure 4.1. Map of Georgia depicting a) the peak week of DVCs for each county in Georgia, USA with combined county counts of DVCs and a 3-week running average applied, and b) predicted rutting activity throughout Georgia as reported by Georgia Outdoor News (2000).

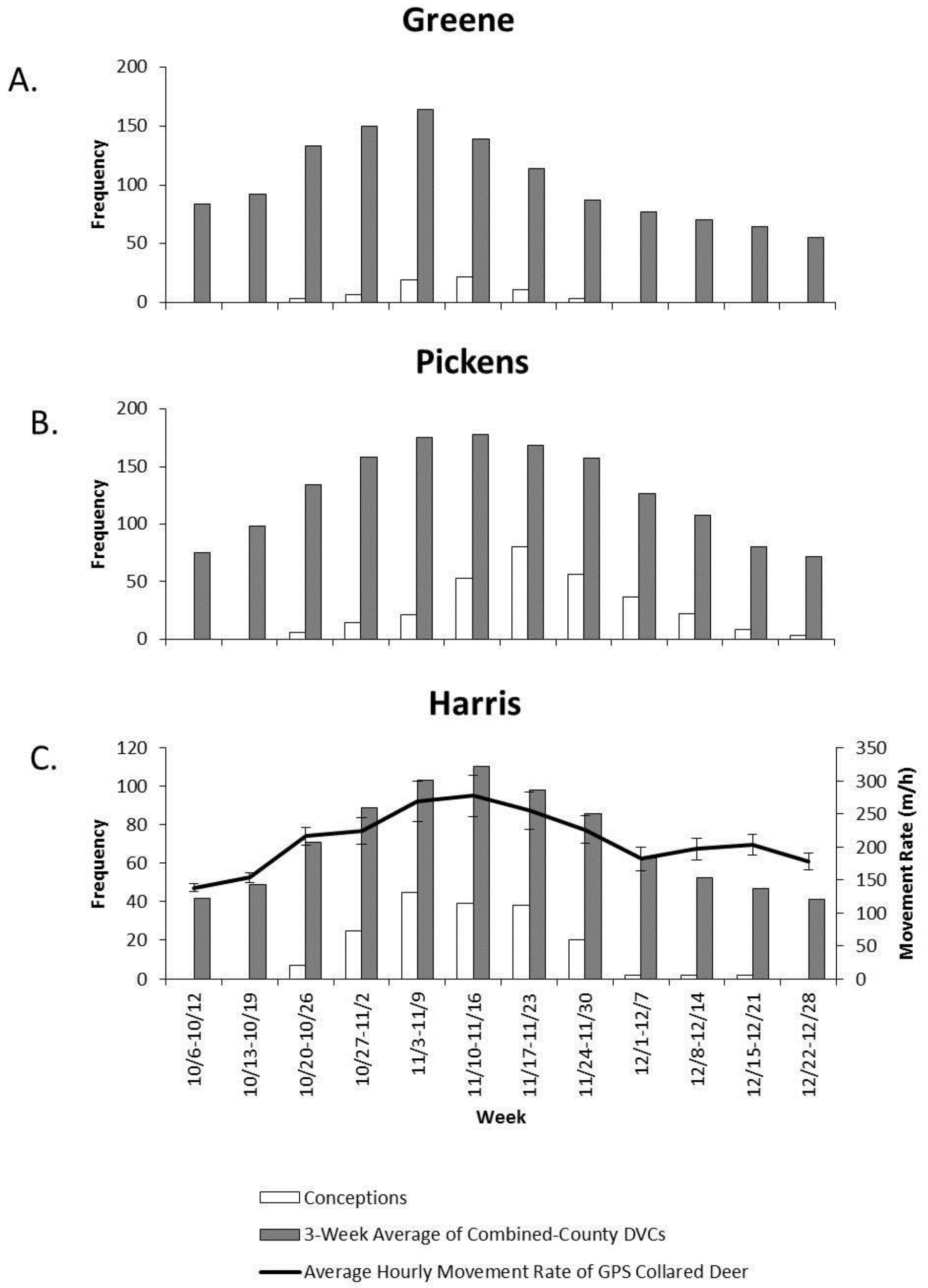

Figure 4.2. Frequency of conceptions versus 3-week average of combined-county deer-vehicle collisions by week from 6 October-28 December for study sites in a) Greene County, b) Pickens County, and c) Harris County, Georgia. Harris County data also includes movement rates ($\bar{x}$ +/- SE) for 19 adult deer (10 males, 9 females) by week from 6 October-28 December.

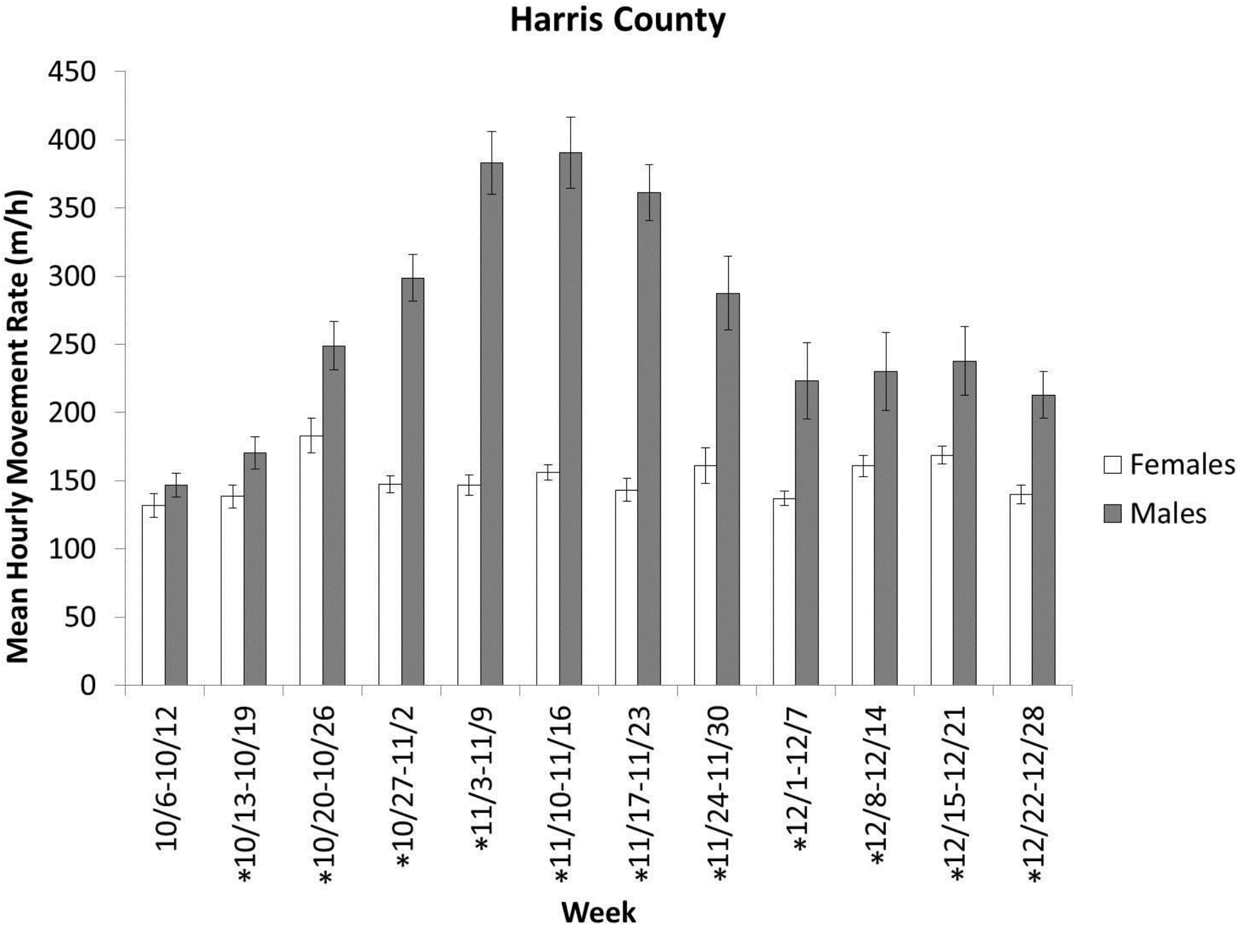

Figure 4.3. Mean (+/- SE) hourly movement rates (m/hr) for mature male (n = 10) and female (n = 9) GPS-collared deer by week from 6 October-28 December in Harris County, Georgia where "*" signifies P<0.05 according to a Student's t-test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Future increases in deer populations, road networks, and traffic will likely lead to increased DVCs. Although hunting can be an effective way to manage deer populations and mitigate DVCs, it may not always be a viable deer management option in some locations. Given this reality, it is important that transportation agencies and the auto industry work closely with wildlife biologists to develop alternative management strategies and technologies to mitigate DVCs. Below I have highlighted the major findings and management options of the manuscript chapters presented in my thesis. Funding for these studies was provided by the Georgia Department of Transportation and Federal Highway Administration.

Chapter 2

Major Findings

- Deer congregate near roads and cross them most frequently at night, especially during late night hours when traffic is lowest. Also, increased movement associated with the fall breeding season increases DVC risk.
- The majority of road crossings are done by only a small portion of the population in the vicinity of the roadway.
- Road crossings are the primary behavior responsible for DVCs, and road crossings occur mostly at night when human visibility is most limited.

Management Options

- Driver education programs should warn motorists of the increased risk of encountering deer crossing roadways during nighttime travel. Programs should focus on increased DVC risk associated with late-night travel and the fall breeding season with recommendations to increase vigilance and reduce vehicle speed.
- Targeted removal of deer observed along roadsides may aid in reducing encounters between motorists and deer.
- Roadside fencing can be used to direct deer to safe crossing areas.
- Roadside vegetation management should focus on reducing forage and cover, helping to reduce incentive for deer to congregate near roads and increasing visibility for motorists.
- Future research should focus on the development and testing of infrared camera technology integrated with vehicle display screens so that deer along roadsides can be observed more easily.

Chapter 3

Major Findings

- I classified deer into 3 groups based on their use of the I-20 ROW: 1) frequent users, 2) occasional users, 3) rare users.
- At least 3 adult female deer selected the I-20 ROW to birth their fawns, leading to increased ROW usage during May and June. This was the first time this behavior has been documented in white-tailed deer.
- ROW usage by “frequent users” was primarily at night when traffic was lowest.
- Approximately 34% of all deer captured were “frequent users” of the I-20 ROW, and of those 85% of all locations within the ROW were contributed by 6 deer.

Management Options

- Targeted removal of deer observed along roadsides may aid in reducing encounters between motorists and deer.
- Driver education programs should warn motorists of the increased risk of encountering deer along highway ROWs during nighttime travel with recommendations to increase vigilance and reduce vehicle speed.
- Roadside ROW fencing should be maintained regularly and kept free and clear of trees and shrubs.
- Vegetation management within highway ROWs should focus on reducing forage and cover, helping to reduce incentive for deer to access the ROW for feeding, bedding, and birthing fawns, and increasing visibility for motorists.

Chapter 4

Major Findings

- Because deer movement (i.e., deer crossing roads) is necessary for DVCs to occur, DVCs can serve as an index of deer movement. Based on this concept, we used the incidence of DVCs to determine the week of peak risk for each county in Georgia and mapped the results.

Management Options

- 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.

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Assessing Deer Road Crossings Using GPS Locations. Kramer et al.

Using GPS Telemetry to Determine Roadways Most Susceptible to Deer-Vehicle Collisions

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Abstract:

More than 1 million wildlife-vehicle collisions occur annually in the United States. The majority of these accidents involve white-tailed deer (Odocoileus virginianus), and result in >$4.6 billion in damage and >200 human fatalities. Prior research has used collision locations to

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assess site-specific as well as landscape features that contribute to risk of deer-vehicle collisions. As an alternative approach, we calculated road-crossing locations from 25 GPS-instrumented white-tailed deer near Madison, Georgia (n=154,131 hourly locations). We identified crossing locations by creating movement paths between subsequent GPS points and then intersecting the paths with road locations. Using AIC model selection, we determined whether 10 local and landscape variables were successful at identifying areas where higher frequencies of deer crossings were likely to occur. Our findings indicate that traffic volume, distance to riparian areas, and the amount of forested area influenced the frequency of road crossings. Roadways that were predominately located in wooded landscapes and 200-300 meters from riparian areas were crossed frequently. Additionally, we found that areas of low traffic volume (i.e., county roads, etc.) had the highest frequencies of deer crossings. Analyses utilizing only records of deer-vehicle collision locations cannot separate the relative contribution of deer crossing rates and traffic volume. Increased frequency of road crossings by deer in low-traffic, forested areas may lead to a greater risk of deer-vehicle collision than suggested by evaluations of deer-vehicle collision frequency alone.

Key words: Deer-vehicle collision, GPS, human-wildlife conflict, Odocoileus virginianus, roadways, white-tailed deer

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The number of annual deer-vehicle collisions (DVCs) in the United States has been estimated to be over 1 million (Putman 1997, Hussain et al. 2007). These collisions result in >$4.6 billion in damage and >200 fatalities annually (Conover et al. 1995, Conover 1997, Conover 2002, National Traffic Safety Administration 2002, Huijser et al. 2009). Further, DVCs can impact deer populations, with an estimated fatality rate of 90% (Conover et al. 1995,Huijser et al. 2009) resulting in the loss of 900,000 deer annually, which approximates 15% of the annual deer harvest in the United States (Adams and Ross 2015). In many suburban areas, the number of deer killed via DVCs often outnumbers the number of deer harvested by hunters (Frye 2006).

Due to the crepuscular nature of deer, most accidents tend to occur in the hours surrounding dusk and dawn. These peaks are associated with patterns of traffic volume and deer activity (Allen and McCullough 1976, Kammermeyer and Marchinton 1977, Arnold 1978, Finder et al. 1999). Recent studies have found that there are relatively high frequencies of DVCs in areas of increased vehicle speed and increased traffic volume (Nielson et al. 2003, Ng et al. 2008, McShea et al. 2008). However, conflicting reports indicate that traffic volume and vehicle speeds are unrelated to the occurrence of DVCs (Bissonette and Kassar 2008).

Landscape structure can mediate deer behavior by influencing habitat selection, movement patterns, and home-range size (Kie et al. 2002). However, the role in which landscapes mediate road crossing is not clear, with regional studies often providing differing results (Bellis and Graves 1971, Puglisi et al. 1974, Rost and Bailey 1979, Hussain et al. 2007, Found and Boyce 2011a). Collisions most often occur on roadways that are adjacent to forested areas or that are in close proximity of riparian areas (Romin and Bissionette 1996, Finder et al. 1999, Stewart et al. 2007, Farrell and Tappe 2007). The landscape configuration may also contribute to DVCs because edge density, patch density and diversity have been shown to influence movement patterns in deer (Kie et al. 2002, Plante et al. 2004). For a more thorough analysis of past wildlife-vehicle collision research, see the Gunson et al. (2011) review.

Prior research has focused on post-hoc analysis, using white-tailed deer and mule deer (O. hemionus) mortality locations to determine likely causes (Bellis and Graves 1971, Puglisi et al. 1974, Rost and Bailey 1979, Romin and Bissonette 1996, Finder et al. 1999, Found and Boyce 2011a). Unfortunately, these analyses are confounded because many accidents are not reported, driver knowledge of DVC risk may bias realized risk, and the influence of traffic volume and deer road-crossing frequency cannot be separated when assessing DVC risk to motorists. We assessed whether an alternate approach using radio-instrumented deer would enhance assessment of DVC risk. Our objective was to determine landscape, anthropogenic and hydrological characteristics that determine where deer are likely to cross roadways. We hypothesized that specific landscape features mediate deer crossings. Identifying such features can help focus DVC mitigation efforts in areas that pose the most risk to motorists.

STUDY AREA

The focal area was located immediately southeast of Madison, Georgia, in Morgan County (33°35′17″N 83°28′21″W). The city of Madison has approximately 4,000 residents and lies along U.S. Interstate 20 (I-20). The landscape within the study area transitions from the urban areas of Madison to large patches of deciduous and coniferous forests, and a variety of agricultural lands. Elevation of the region ranged from approximately 120 to 250m, with the majority of the variation being a result of small hydrological features (streams and creeks). Our focal area consisted of approximately 101.73 km2 (39.27 square miles) and was split into two sections by I-20 (Figure 1). A 1.2-m woven wire fence, used to delineate the I-20 right-of-way, was in various stages of disrepair. There were additional roadways of varying activity, including U.S. Route 278, county roads (e.g., Bethany Road, Bethany Church Road) and smaller single-lane paved or dirt roads within the study area.

METHODS

Capture

During winter and spring of 2012 and 2013, we captured and collared 32 white-tailed deer. Captured deer were outfitted with ear tags for individual identification and FOLLOWiT Tellus Medium GPS collars with UHF download/remote drop-off capabilities (FOLLOWiT Wildlife, Lindesberg, Sweden). All animal capture and handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A2011 08-023-R1). Collars were programmed to collect 24 locations per day at equal intervals for a 2-year period. The collars were equipped with a VHF beacon allowing for regular mortality checks, a remote UHF drop mechanism, and a UHF download system allowing the user to download data remotely.

Modeling Procedures

Of the 32 collared animals, we used the data of 25 individuals that crossed roads, including 8 adult females, 9 adult males, 1 juvenile female and 7 juvenile males. Due to mortalities, collar failures and premature releases, we did not obtain 24 continuous months of data from each individual animal, however, the cumulative data of all individuals represent a continuous 2-year period, March 2012 to February 2014.

We used ArcInfo v.10.1 (Environmental Systems Research Institute, Redlands, California) to perform data manipulation to estimate locations of deer crossings. We created line segments between chronologically ordered points for each individual and calculated where a line crossed a section of road (Georgia Department of Transportation 1993, Riginos et al. 2013). We excluded any road segments that were not within 200 meters of a deer location point, assuming that any road that was within the range was eligible to be crossed. Additionally, we removed I-20 from the analysis based on the assumption that the right-of-way fence may have acted as a semi-permeable barrier that would have influenced road crossings in that intact or broken sections of fence may have dictated where road crossings occurred rather than landscape features. To address the assumption that an individual crossed a roadway directly between the two GPS points, we used a 10-m circular moving window to calculate the total numbers of crossings within the window. We then created a sampling point every 10 meters along all roadways within the focal region that represented the total number of deer crossings at each point between March 2012 and February 2014.

Predictor Variables

We identified 10 variables as potential predictors of deer crossing locations, including road type, percent forest, percent agriculture, edge density, patch density, Shannon's diversity index, distance from stream, slope, terrain ruggedness and slope position (Table 1). We binned the road segments into three categorical levels based on roadway size (i.e., low, medium and high use) with dirt and single-lane roads as low (e.g., private access roads), county and local roads as medium (e.g., Bethany Rd) and state routes as high (e.g., Route 278). We obtained habitat data from the 2011 National Land Cover Database (NLCD) which provided 20 land cover classes at a 30x30 meter resolution (Jin et al. 2013). We reclassified the NLCD raster by combing all forest types (conifer, deciduous and mixed) into one class and did the same for all types of agriculture (pasture/hay and cultivated crops). The reclassification was done because we assumed that all types of forest represent equal security cover as roads are perceived as threats, and we assume that both types of agriculture present foraging opportunities (Bellis and Graves 1971, Puglisi et al. 1974, Rost and Bailey 1979, Romin and Bissonette 1996).

The landscape metrics (patch density, edge density, and Shannon's diversity) were included because they have been identified as predictors of ungulate movements (Kie et al. 2002, Plante et al. 2004). Percent forest and agriculture, along with the three landscape metrics (edge, patch, Shannon's) were calculated via Fragstats V.4 (McGarigal et al. 2012) using a square moving window at two different spatial scales (200m and 500m) to document variability within habitat scales. We obtained riparian layers to calculate the distance of a sampling point from a stream or riparian area (Georgia Department of Transportation 1996). We included the distance from riparian zones due to studies that have shown that drainages and riparian zones can influence deer movement, specifically when approaching roadways (Mansfield and Miller 1975, Dusek et al. 1988, Reeve 1988).

The three topographical metrics were derived from a digital elevation model (DEM)from the U.S. Geological Survey, National Map Server (2013). Slope, terrain ruggedness and slope position were included because they can influence deer movements directly by aiding or hindering movement and indirectly by contributing to environmental constraints such as vegetation composition, sun exposure, and hydrology (Rost and Bailey 1979, Ganskopp and Vavra 1987). Terrain ruggedness was determined by calculating the standard deviation of elevation within 200 meters and slope position is equal to the elevation of the cell minus the mean elevation within 200 meters. Slope position values greater than 0 were elevated areas such as hilltops, values near zero were at median elevation or on side-slopes, and negative values were valleys or low-lying areas.

Statistical analyses

Statistical analysis was performed in R (R Core Team 2013). Given the distribution of the data for number of road crossings, we used general linear models with a negative binomial distribution to predict the number of road crossings at sample locations using the 'MASS' package (Poch and Mannering 1996, Venables and Ripley 2002). To address the zero inflation of the data of having over 6,000values of zero deer crossings out of the 7,175 generated data points, we subset the data by randomly selecting 1,000 points from the original 6,000. The random sampling of zero-valued points created a total data set of 2,175 points. We calculated Pearson product-moment correlation coefficient among potential predictor variables twice, once including the 200-m landscape variables and then a second time using the 500-m landscape variables. We found that there were similar correlations regardless of landscape scale and excluded any variables that had a coefficient value greater than or equal to +/-0.70. After removing correlated predictor variables, we were left with seven potential predictor variables—road type, edge density, percent forest, distance to streams, slope, slope position and terrain ruggedness.

We built 19 models using different combinations of land cover, hydrology, and terrain variables that may best explain the number of deer crossings. As we were interested in identifying the spatial scale (200 m or 500 m) at which land cover variables best explained deer crossings, we performed AICc model selection in two stages (Burnham and Anderson 2002). First, we conducted model selection for each spatial scale independently (200m and 500m), including a null model (i.e., the intercept-only model), calculated AIC and reported models receiving at least 95% of the weight. Following the two scale-independent analyzes, we then performed a final model selection using the top models from each buffer size, again including a null model.

RESULTS

When performing model selection using the 200-m moving window for landscape characteristics, we found that the model containing only road type and edge density as predictor variables had the lowest AICc ($\text{AICcw}_i = 0.64$) while the global model resulted in an AICc value that was greater than the top model by 1.17 ($\text{AICcw}_i = 0.36$) (Table 2). Within the best model, road type and edge density were both significant ($\underline{P} \leq 0.05$) and had 95% confidence intervals that did not cross zero (Table 3); whereas, in the global model, only road type and edge density were significant ($\underline{P} \leq 0.05$). All other considered models, including the null model, received less than 0.0001 model weight (w_i). The parameter estimates for road type suggest that areas of high crossing frequency most often occur along less active/developed segments of road (dirt and single-lane roads) (Figure 2).

When model selection included landscape metrics from a 500-m moving window, there was a slight change in the outcome. The global model containing all seven predictors was the top model ($\text{AICcw}_i = 0.498$), while the model containing only road type, distance to stream and percent forest as predictors had an ΔAICc value that was less than 2 ($\text{AICcw}_i = 0.492$). In the top model, the predictors of road type, distance to stream and percent forest were significant ($\underline{P} \leq 0.001$), as was slope position ($\underline{P} \leq 0.015$). The confidence intervals of all significant predictors did not cross zero. In the second best model only containing three predictors—road type, distance to stream and percent forest—each were significant ($\underline{P} \leq 0.05$) and their confidence intervals did not cross zero.

Following the combined model selection procedure, which included five models (the two top models from the 200-m landscape buffer, the two top models from the 500-m buffer and a null model), we determined that the global model that included landscape predictors from a 500-m buffer best fit the data (Table 2, Figure 3). In this case, the top model carried a weight ($AICcw_i$) of 0.50, while the 500-m model of road type, distance to stream and perfect forest carried the remaining 0.496. We compared the observed values of the data against the predicted values created from our simplest of the two competing top model which contained the predictors of road type, distance to streams, and percentage of forest cover within a 500m buffer (Figure 4). The largest discrepancy between the observed and predicted values occurred at crossing frequencies of 0 and 1, with observed values of 0 being under-represented, and values of 1 being over-represented. This pattern is likely due to our subset of the data, given the inflated frequency of 0 crossing values.

DISCUSSION

Our results coincide with previous research in that deer tend to avoid areas of high human activity (Bellis and Grave 1971, Romin and Bissonette 1996, Jepsen and Topping 2004, Sawyer et al. 2006, Sawyer et al. 2009), with crossings occurring in higher frequency in areas of low traffic volume. Additionally, vegetation cover has been documented to be an important factor in deer crossing, with deer in our study crossing more frequently (10 or more crossings) in areas that were composed of approximately 80-90% forest (Finder 1998, Iverson and Iverson 1999, Farrell and Tappe 2007).

While prior research suggests that deer tend to cross roadways along riparian areas (Romin and Bissionette 1996, Finder et al. 1999, Gunson et al. 2009), we found that areas 200-300 meters from riparian areas experienced the highest frequency of crossings. The distance from riparian areas has implications for the construction of large underpass culverts along riparian areas to act as wildlife movement corridors (Reed et al. 1975, Braden et al. 2008).

Our method is unique in that we used GPS-instrumented deer to identify high frequency crossing areas to determine DVC risk, while previous works have focused on deer mortality locations to determine high-risk areas. Although using DVC locations can be useful for identifying landscape variables that contributed to deer mortality, DVCs may be influenced by road type. More specifically, roads with greater traffic volume, such as state highways, may negatively influence deer crossing behavior and success. Despite fewer crossings on high traffic roadways, lower crossing success may accumulate mortality data more quickly and in greater quantities than roadways with less traffic. Therefore DVC risk models built using DVC data may be a better representation of increased risk for deer than for motorists. In our study, deer crossed low traffic roads more frequently than high traffic roads. Because traffic volume was lower, individual motorist risk of encountering a deer was greater, thus justifying the need to identify landscape variables that facilitate road crossing.

Our technique can provide an additional tool for mangers, allowing them to model segments of roadways that have an increased likelihood of deer crossings, and therefore better focus mitigation efforts. Possible solutions include the introduction of signage that warns motorists of an increased threat, which has been effective in mitigating DVCs (Sullivan et al. 2004, Found and Boyce 2011b). Alternatively the removal of dense vegetation along roadways removes security cover and may increase the ability of motorists to see deer (Rost and Bailey 1978, Jaren et al. 1991).

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LITERATURE CITED

Adams, K. and M. Ross. 2015. QDMA's Whitetail Report 2015. Quality Deer Management Association, Bogart, Georgia.

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

Arnold, D. A. 1978. Characteristics and costs of highway deer kills. Pages 92-101 in C. M. Kirkpatrick, editor. Wildlife and People, Proceedings of the John S. Wright Forestry Conference, Department of Forestry and Natural Resources and the Cooperative Extension Service, Purdue University, West Lafayette, Indiana.

Bellis, E. D. and H. B. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232-237.

Bissonette, J. A. and C. A. Kassar. 2008. Locations of deer-vehicle collisions are unrelated to traffic volume or posted speed limit. Human-Wildlife Conflicts 2:122-130.

Braden, A. W., R. R. Lopez, C. W. Roberts, N. J. Silvy, C. B. Owen and P. A. Frank. 2008. Florida Key Deer *Odocoileus virginianus clavium* underpass use and movements along a highway corridor. Wildlife Biology 14:155-163.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York, New York.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298-305.

_____. 2002. Resolving human-wildlife conflicts: the science of wildlife damage management. Lewis Publishers, Boca Raton, Florida.

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.

Dusek, G. L., A. K. Wood and R. J. Mackie. 1988. Habitat use by white-tailed deer in prairie-agricultural habitat in Montana. Prairie Naturalist 20:135-142.

Farrell, M. C. and P. A. Tappe. 2007. County-level factors contributing to deer-vehicle collisions in Arkansas. Journal of Wildlife Management 71:2727-2731.

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.

Frye, B. 2006. Deer Wars: Science, Tradition, and the Battle over Managing Whitetails in Pennsylvania. Pennsylvania State University Press, University Park, Pennsylvania.

Found, R. and M. S. Boyce. 2011a. Predicting deer-vehicle collisions in an urban area. Journal of Environmental Management 92:2486-2493.

_____ and _____. 2011b. Warning signs mitigate deer-vehicle collisions in an urban area. Wildlife Society Bulletin 35:291-295.

Ganskopp, D. and M. Vavra. 1987. Slope use by cattle, feral horses, deer, and bighorn sheep. Northwest Science 61:74-81.

Georgia Department of Transportation. 1993. Georgia Statewide Core Base Map. <https://data.georgiaspatial.org>. Accessed 1 May 2014

_____. 1996. Morgan County Rivers.<https://data.georgiaspatial.org> Accessed 1 May 2014

Gunson, K. E., A. P. Clevenger, A. T. Ford, J. A. Bissonette and A. Hardy. 2009. A comparison of data sets varying in spatial accuracy used to predict the occurrence of wildlife-vehicle collisions. Environmental Management 44:268-277.

Gunson, K. E., G. Mountrakis and L. J. Quackenbush. 2011. Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. Journal of Environmental Management 92:1074-1082.

Huijser, M. P., J. W. Duffield, A. P. Clevenger, R. J. Ament and P. T. McGowen. 2009. Cost-benefit analysis of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. Ecology and Society 12:15.

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.

State Farm Insurance.2012. It's West Virginia Again. <https://www.statefarm.com/about-us/newsroom/2012/10/23/deer-vehicle-confrontations>.Accessed 13 May 2014.

Iverson, A. L. and L. R. Iverson. 1999. Spatial and temporal trends of deer harvest and deer-vehicle accidents in Iowa. Ohio Journal of Science 99:84-94.

Jaren, V., R. Andersen, M. Ulleberg, P. H. Pederson and B. Wiseth. 1991. Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. Alces 27:93-99.

Jepsen, J. U. and C. Topping. 2004. Modelling roe deer (*Capreolus capreolus*) in a gradient of forest fragmentation: behavioral plasticity and choice of cover. Canadian Journal of Zoology 82:1528-1541.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J. and Xian, G. 2013.A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sensing of Environment 132:159-175.

Kammermeyer, K. E. and R. L. Marchinton. 1977. Seasonal change in circadian activity of radio-monitored deer. Journal of Wildlife Management 41:315-317.

Kie, J. G., R. T. Bowyer, M. C. Nicholson, B. B. Boroski and E. R. Loft. 2002. Landscape heterogeneity at differing scales: effects on spatial distribution of mule deer. Ecology 83:530-544.

Kuijper, D. P. J., J. P. G. M. Cromsigt, M. Churski, B. Adam, B. Jedrzejewska and W. Jedrezejewski. 2009. Do ungulates preferentially feed in forest gaps in European temperate forest? Forest Ecology and Management 258:1528-1535.

Mansfield, T. M. and B. D. Miller. 1975. Highway deer-kill district 02 regional study. Caltrans internal report. Sacramento, California.

McGarigal, K., S. A. Cushman and E. Ene. 2012. FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps. University of Massachusetts, Amherst, Massachusetts.

McShea, W. J., C. M. Stewart, L. J. Kearns, S. Liccioli and D. Kocka. 2008. Factors affecting autumn deer-vehicle collisions in a rural Virginia county. Human-Wildlife Conflicts 2:110-121.

McShea, W. J., H. B. Underwood and J. H. Rappole (Eds.). 1997. The science of overabundance: deer ecology and population management. Smithsonian Institution Press, Washington, DC.

National Highway Traffic Safety Administration. 2002. The economic impact of motor vehicle collisions 2000, U.S. Department of Transportation, Washington, D.C.

Nielson, C. K., R. G. Anderson and M. D. Grund. 2003. Landscape influences on deer-vehicle accident areas in an urban environment. Journal of Wildlife Management 67:46-51.

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 2:102-109.

Plante, M., K. Lowel, F. Potvin, B. Boots and M. Fortin. 2004. Studying deer habitat on Anticosti Island, Québec: relating animal occurrences and forest map information. Ecological Modeling 174:387-399.

Poch, M. and F. Mannering. 1996. Negative binomial analysis of intersection-accident frequencies. Journal of Transportation Engineering 122:105-113.

Puglisi, M. J., J. S. Lindzey and E. D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799-807.

R Core Team 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reed, D. F., T. N. Woodard and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management 39:361-367.

Reeve, A. F. 1988.Vehicle-related mortality of mule deer in Nugget Canyon, Wyoming. Wyoming Cooperative Fisheries and Wildlife Research Unit, Laramie.

Riginos, C., K. Krasnow, E. Hall, M. Graham, S. Sundaresan, D. Brimeyer, G. Fralick and D. Wachob. 2013. Mule deer (Odocoileus hemionus) movement and habitat use patterns in relation to roadways in northwest Wyoming. Report of Conservation Research Center, Teton Science Schools to Wyoming Department of Transportation, Cheyenne, Wyoming..

Romin, L. A. and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads in Jordanelle Reservior, Utah. Great Basin Naturalist 56:1-11.

Rost, G. R. and J. A. Bailey.1979.Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43:634-641.

Sawyer, H., R. Nielson, F. Lindzey and L. McDonald. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. Journal of Wildlife Management 70:396-403.

Sawyer, H., M. Kauffman and R. Nielson. 2009. Influence of well pad activity on winter habitat selection patterns of mule deer. Journal of Wildlife Management 73:1052-1061.

Stewart, C. M., W. J. McShea and B. P. Piccolo. 2007. The impact of white-tailed deer on agricultural landscapes in 3 national historical parks in Maryland. Journal of Wildlife Management 71:1525-1535.

Sullivan, T. L., A. F. Williams, T. A. Messmer, L. A. Hellinga and S. Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. Wildlife Society Bulletin 32:907-915.

United State Geological Survey. 2013. National Map. <http://nationalmap.gov/viewer.html>. Accessed 10 May 2014.

Venables, W. N. and Ripley, B. D. 2002. Modern Applied Statistics with S. Fourth Edition. Springer Publishing Company, New York, New York.

Table 1. Definition and description of local and landscape variables included in the analysis of deer roadway crossing, Morgan County, Georgia, 2012-2014.

Variable	Definition
Local-Level	
Road Type	Three categories of assumed traffic activity level: low (dirt and single-lane roads), medium (county and local roads) and high (state routes)
Distance to Stream	The distance of a sampling point from a stream or riparian area
Slope	The mean slope within a 200-m buffer of a sample location
Slope Position	Equal to the elevation of the cell minus the mean elevation within 200 m.
Terrain Ruggedness	The standard deviation of elevation within 200 m
Landscape-Level	
Percent Forest	Percentage of landscape classified as conifer, mixed or deciduous forest (NLCD 2011) within a 200-m or 500-m buffer surrounding the crossing location
Percent Agriculture	Percentage of landscape classified as agriculture (NLCD 2011) within a 200-m or 500-m buffer surrounding the crossing location
Edge Density	Sum of lengths (m) of all edge segments divided by the total landscape area (m^2)
Patch Density	The number of patches in the landscape divided by the total landscape area
Shannon's Diversity	A measure of both patch type richness and relative abundance

Table 2. Akaike's Information Criterion including number of parameters (K), AICc, ΔAICc, and Akaike weights (w_i) for candidate models relating to variables influencing road crossing by white-tailed deer on a study area in Morgan County, Georgia during 2012-2014. All other models evaluated received less than 0.0001 weight.

Model	K	AICc	ΔAICc	w_i
200m*				
Road Type + Edge Density	4	6603.88	0	0.64246
Global	9	6605.05	1.17	0.35737
500m*				
Global	9	6584.63	0	0.49939
Road Type + Distance to Stream + Percent Forest	5	6584.65	0.02	0.49282
Only Top Models				
Global (500m)	9	6584.63	0	0.503284
Road Type + Distance to Stream + Percent Forest (500m)	5	6584.66	0.03	0.496665
Road Type + Edge Density (200m)	4	6603.88	19.25	3.3E-05
Global (200m)	9	6605.05	20.42	1.85E-05
Null	1	7223.90	639.27	7.69E-140

Table 3. Model estimates and confidence intervals for the top models for each of the two spatially explicit analyses (200m and 500m) relating to variables influencing road crossing by white-tailed deer on a study area in Morgan County, Georgia during 2012-2014.

Model Name	Model Predictors	Estimate	P-value	95% Confidence Interval	
200m				2.5%	97.5%
Global	Intercept	1.39	< 0.0001	0.826	1.949
	Road Type (Medium)	-1.75	< 0.0001	-1.94	-1.559
	Road Type (High)	-3.02	< 0.0001	-3.357	-2.6988
	Edge Density	0.003	< 0.0001	0.002	3.319
	Percent Forest	-0.002	0.133	-0.004	7.066
	Distance to Stream	-0.0005	0.026	-0.001	-8.448
	Slope	-0.005	0.831	-0.049	4.015
	Terrain Ruggedness	0.10	0.394	-0.147	3.475
	Slope Position	0.017	0.310	-0.018	5.119
Road Type + Edge Density	Intercept	1.267	< 0.0001	1.129	1.407
	Road Type (Medium)	-1.674	< 0.0001	-1.822	-1.529
	Road Type (High)	-2.9	< 0.0001	-3.21	-2.606
	Edge Density	0.003	< 0.0001	0.002	0.004
500m					
Road Type + Distance to Stream + Percent Forest	Intercept	0.728	< 0.0001	0.409	1.047
	Road Type (Medium)	-0.948	< 0.0001	-1.161	-0.735
	Road Type (High)	-2.177	< 0.0001	-2.523	-1.839
	Distance to	-0.001	< 0.0001	-0.001	-0.0002

	Stream				
	Percent Forest	0.013	< 0.0001	0.009	0.017
Global	Intercept	1.481	< 0.0001	0.874	2.091
	Road Type (Medium)	-0.87	< 0.0001	-1.088	-0.654
	Road Type (High)	-2.148	< 0.0001	-2.494	-1.81
	Edge Density	-0.002	0.057	-0.003	0.0001
	Percent Forest	0.0134	< 0.0001	0.009	0.017
	Distance to Stream	-0.001	< 0.0001	-0.002	-0.0005
	Slope	0.015	0.592	-0.028	0.059
	Terrain Ruggedness	-0.299	0.46	-0.554	-0.045
	Slope Position	0.009	0.015	-0.025	0.043

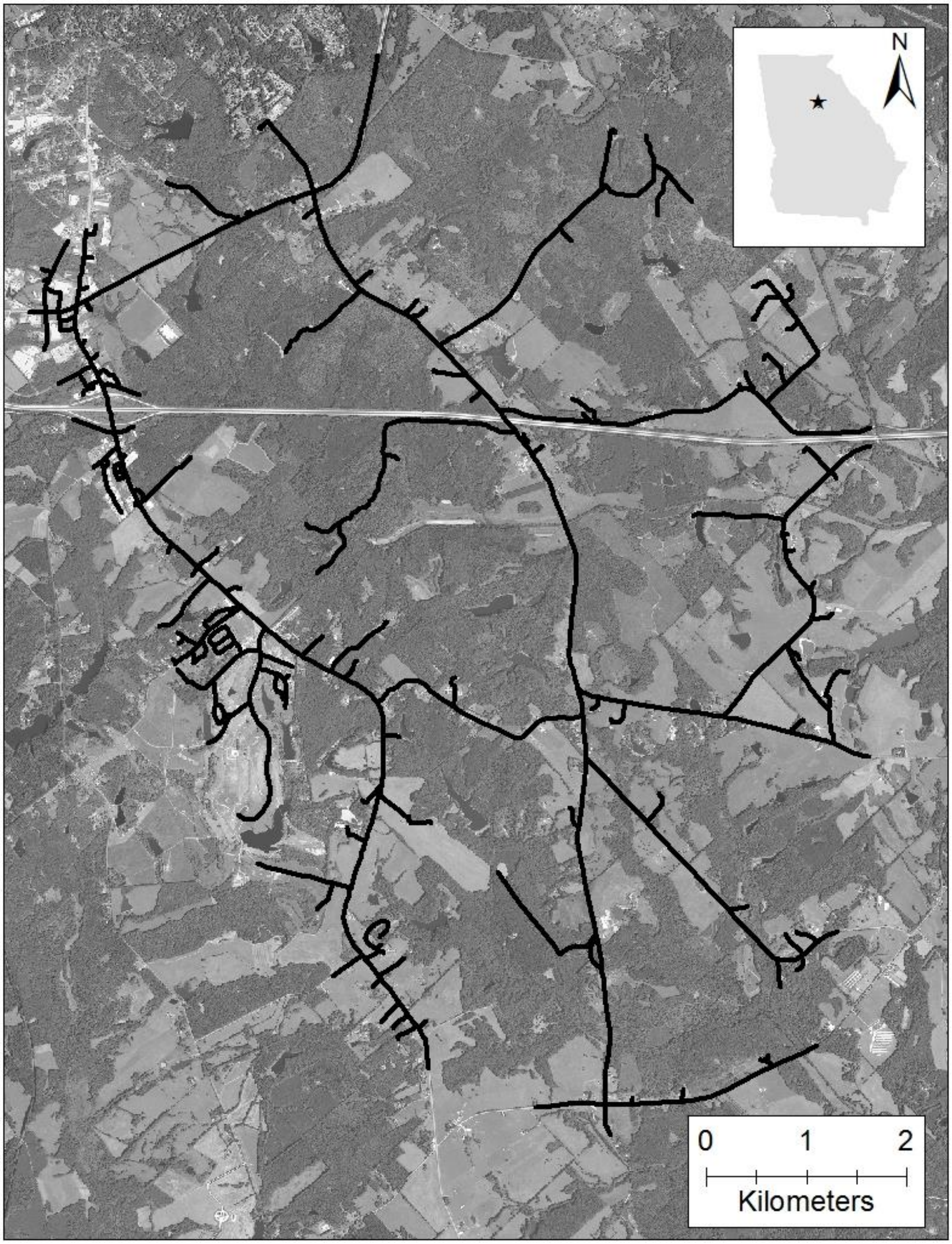

Figure 1. Focal roads used to determine variables influencing road crossing by white-tailed deer during 2012-2014. Roadways are located southeast of the city of Madison in Morgan County, GA.

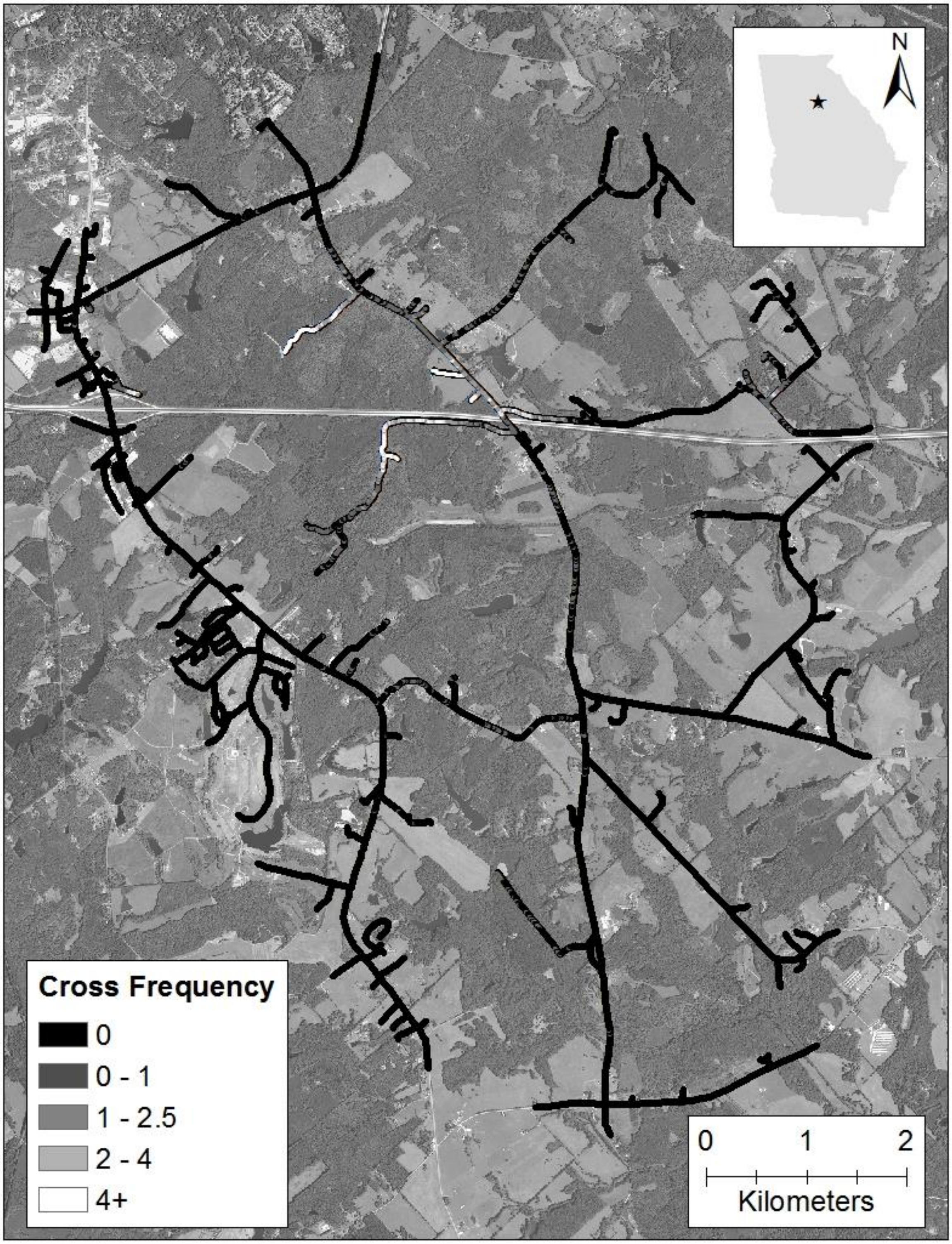

Figure 2. The frequency at which collared white-tailed deer crossed focal roadways during 2012-2014.

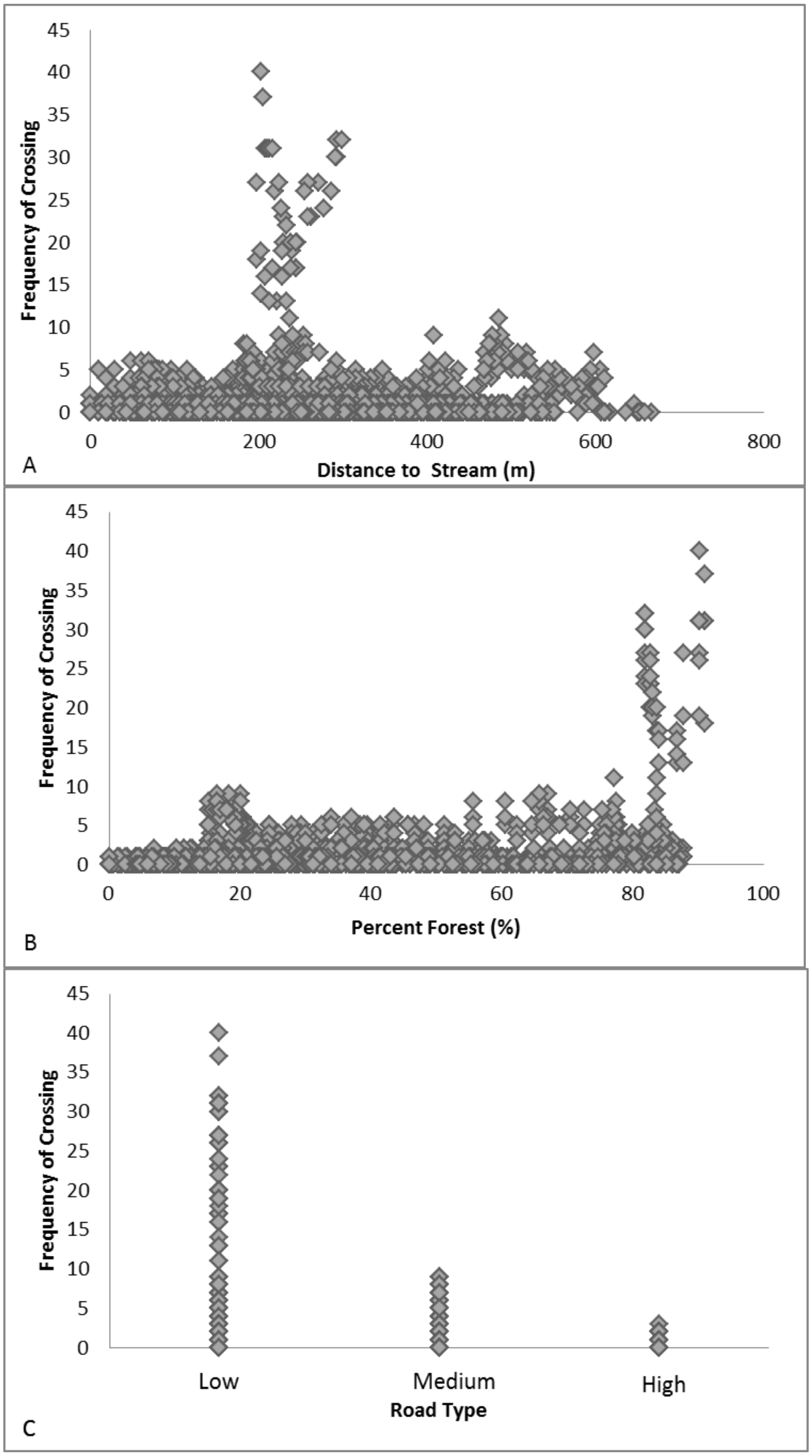

Figure 3. Landscape values associated with each observed crossing frequency, (A) the distance from stream (m), (B) The percentage of the forested landscape, and (C) the road type. Landscape values are associated to white-tailed deer crossing locations on a study area in Morgan County, Georgia during 2012-2014.

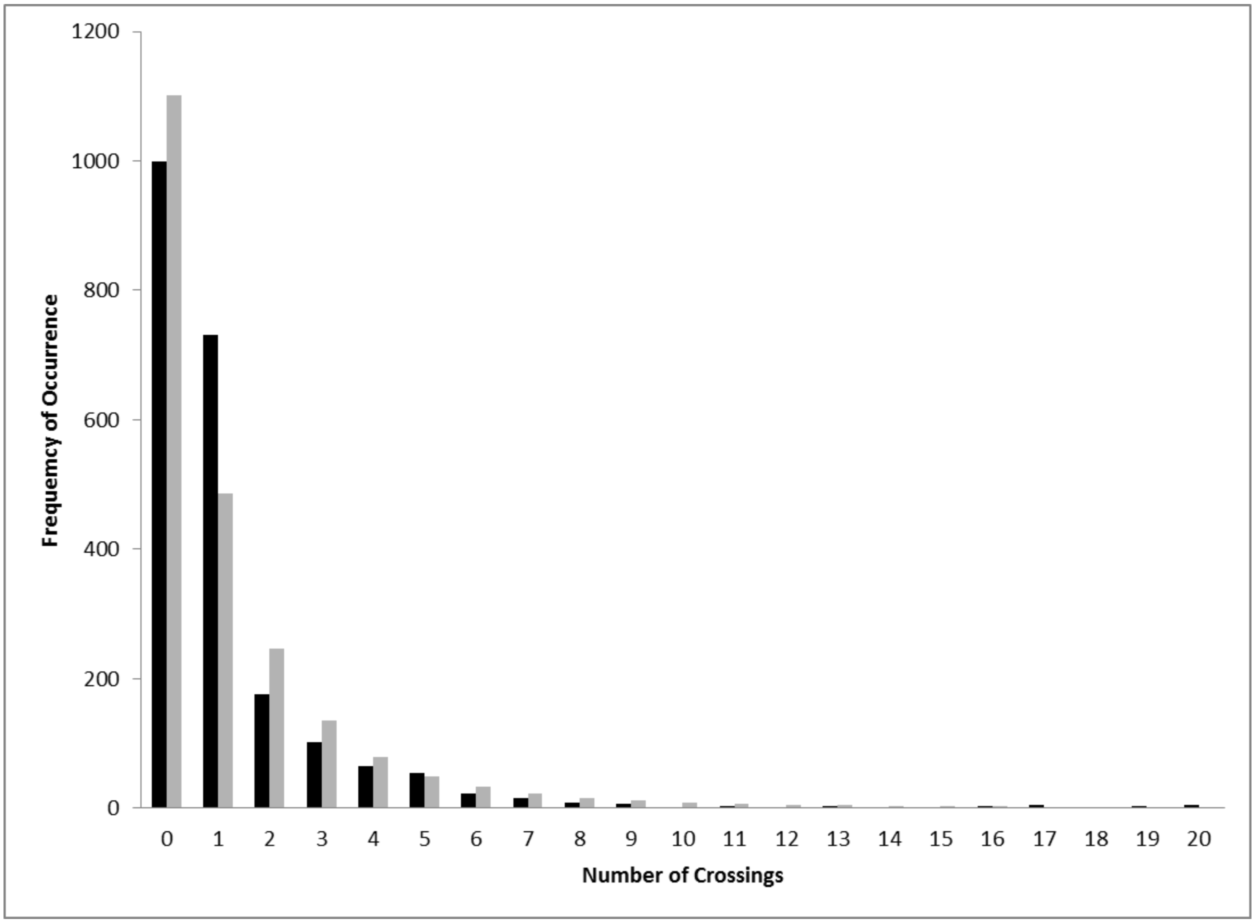

Figure 4. The frequency of occurrence for the number of crossings that roadway sampling points experienced with observed crossing frequencies (Black) and the modeled expected values per sampling location (Gray). Crossings were conducted by white-tailed deer on a study area in Morgan County, Georgia during 2012-2014.

OPERATIONAL FIELD TRIAL OF A RETROFITTED FENCE TO MITIGATE DEER-VEHICLE COLLISIONS

ABSTRACT

Roadside fencing is often used to mitigate deer-vehicle collisions (DVCs) by excluding deer from the road or by directing them to road crossing structures. Previous research indicates that an experimental 1.2-m woven wire fence outfitted with a 45^o outrigger strung with several strands of wire was approximately 21% less expensive than a 2.4 m fence, and appeared to serve as a one-way barrier. We monitored highway right-of-way (ROW) usage of 3 GPS-instrumented adult female deer before and after we repaired and retrofitted a 1.2-m, woven-wire, ROW fence with 45.7-cm steel outrigger arms angled at 45^o and strung with 4 strands of high-tensile wire. Also, we surveyed the highway approximately once per week for road-killed deer (RKD), and trail cameras were placed in large culverts passing under the highway to monitor animal activity. For 2 deer located at fence ends, ROW usage did not change ($P > 0.05$) the year after the outrigger fence was completed compared to the previous year. For Deer #13, located in the middle of the study area, ROW use was significantly reduced post-treatment ($P < 0.05$). Five RKD were found in the study area after the outrigger fence was completed compared to zero during the year before. Three deer were photographed using the large culverts passing under the highway during pre-treatment periods, but zero deer were photographed using the culverts post-treatment. The cost of retrofitting was approximately \$17,181/km. We conclude that the outrigger design is suited best for new construction in open areas, and that a 2.4-m fence may be a more practical fencing option, with a caveat that gaps under a fence are the biggest weakness in exclusion fence design.

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) pose a safety risk to motorists when they interact with roads. Each year, >1 million deer-vehicle collisions (DVCs) contribute to approximately 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). Approximately 50,000 DVCs occur annually in Georgia, accounting for nearly 14% of vehicle collisions reported state-wide (Bowers et. al 2005), and Georgia is among the top 10 states in the United States for numbers of annual DVCs (State Farm Insurance Company 2011). Unless effective DVC mitigation techniques are developed, future increases in deer populations, road networks, and traffic, will likely lead to increased DVCs.

Ungulate-proof fencing used in combination with roadway underpasses or overpasses has proven effective for DVC mitigation (Hedlund et al. 2004, Ellingwood et al. 2009). Despite their success, the initial costs of construction are high. Gulsby et al. (2011) reported the construction costs for a 2.4-m fence to be \$9,356/km and Huijser et al. (2007) reported a minimum cost of about \$2,801 per meter for the construction of an underpass depending on the size and type.

Approximately 13% of Georgia's counties accounted for 55% of DVCs reported to law enforcement agencies (Bowers et al. 2005). In other studies, relatively short sections of highway were responsible for high numbers of DVCs (Bellis and Graves 1971, Bashore et al. 1985, Hubbard et al. 2000, Clevenger et al. 2001). Concentrated DVCs suggest mitigation efforts can be focused in high-risk areas to maximize the physical and economic benefits of mitigation devices (Hubbard et al. 2000).

Overhanging fences have been effective at excluding deer and sheep (*Ovis sp.*) from areas where grazing was not desired (Jones and Longhurst 1958), and at keeping deer out off a major highway in Pennsylvania (Falk et al. 1978). Georgia researchers found that a 1.2-m woven-wire fence with a 0.6-m outrigger angled at 45^o was effective at reducing deer crossings when the outrigger was facing toward the deer, but was less effective when facing away (Stull et al. 2011). A similar design reduced deer crossings along a power-line right-of-way (ROW) by 90% and was 21% cheaper to construct than a 2.4-m woven-wire fence (Gulsby et al. 2011). Predicated on the results of these previous studies, we retrofitted an existing 1.2-m highway ROW fence with 45^o outrigger arms strung with 4 strands of high tensile wire to exclude deer from an interstate highway in northcentral Georgia. We monitored deer movements and usage of the ROW before and after the outriggers were installed to evaluate fence efficacy. Costs associated with construction and maintenance were also calculated.

STUDY AREA

Our study area included the land adjacent to a 4-km section of U.S. Interstate 20 (I-20) extending from Exit 114 to Bethany Road near Madison, GA, USA. Mean traffic on I-20 was approximately 25,000 vehicles per day and the posted speed limit was 70 mph. A 1.2-m woven-wire fence located 30.5 cm inside the ROW boundary seperated private property from the I-20 ROW. The plant community inside the ROW consisted of grasses (*Schedonorus arundinaceus*, *Cynodon dactylon*, *Andropogon* spp., *Setaria* 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.). Landscape habitat features included agricultural fields, planted pines, mixed pine-hardwoods, and pasture on both sides of the highway. These associated habitat features represented most of the major habitat types that occur along roadways throughout much of Georgia.

METHODS

Deer Capture and 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. Using 3 ml transmitter darts (Pneu-dart Inc., Williamsport, Pennsylvania, USA), we immobilized deer with an intramuscular injection of Telazol® (500 mg; tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and AnaSed® (450 mg; 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 (≥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 per week, and to emit a mortality beacon after 6 hours of no movement. After 80 minutes, deer received a 300 mg injection (150 mg [IV] + 150 mg [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 October 2014 we monitored survival of each deer via VHF telemetry on a weekly basis. We remotely downloaded GPS data from each deer's collar every 4 to 6 months. We calculated mean collar error ($\bar{x}$ = 24.2 m) by placing one collar at each of two surveyed GPS test sites at the University of Georgia, Athens, GA, USA (n = 252 points).

Right-of-Way Fence Repair, Modification, and Monitoring

The 1.2 m woven-wire fence, built by Georgia Department of Transportation (GDOT) in 1979, had received little maintenance since construction, and sections of the ROW fence were collapsed by fallen trees or overgrown by vegetation prior to outrigger installation. In addition, many of the original wooden posts were rotted or broken. The proposed repair and modification of the ROW fence as the experimental treatment for our research project required an environmental assessment be conducted and approved by GDOT. The environmental assessment was completed and approved on 22 October 2013. Work on reparing and modifying the ROW fence began on 13 January 2014 and was completed on 22 March 2014. Therefore, by April 2014 the ROW fence was fully repaired and had been outfitted with 45.7-cm steel outrigger arms (Cox Fence Fittings, Mesquite, Texas, USA; Figure 1) strung with four evenly spaced strands of high-tensile smooth wire by a fencing contractor (Athens Fence, Athens, Georgia, USA; Figure 2). The outrigger wires were pulled only as tight as needed to straighten the wire. From May – October, 2014 the fence was surveyed once per month for damage and potential breach locations. Minor damage and potential breaches were repaired during the survey with hand tools and local resources (i.e., sticks, rocks, logs, etc.). Major damages were repaired as soon as possible. For repair sites, we recorded the date, location, man hours, a brief description of the damage or potential breach, and other relevant notes.

Two culverts passing under I-20 were monitored with no-flash infrared triggered cameras (Reconyx, Inc., Holmen, Wisconsin, USA) placed approximately in the middle of each culvert chamber mounted as high as possible on the concrete wall with an adjustable wall and ceiling mount (Reconyx, Inc., Holmen, Wisconsin, USA). The easternmost culvert consisted of one chamber measuring 1.8 m height, 1.8 m width, and 96.3 m length giving an openness index (OI) (Height x Width/Length) of 0.03. The westernmost culvert was composed of 3 chambers, each measuring 1.8 m height, 2.4 m width, and 31.7 m length giving an OI of 0.14 for each chamber. The cameras were angled slightly downward, and pointed toward the northern opening. Each camera was programmed to take 2 photos per trigger event with no delay between trigger events to maximize the chances of photographing animals passing through. They were also password protected to deter theft. Images for each species observed were counted.

The I-20 ROW was surveyed for road-killed deer (RKD) approximately once per week for the entirety of the study. Location of the RKD was recorded, as well as sex and age if they could be determined.

Spatial and Temporal Analysis

Locations from GPS-instrumented deer were imported into ArcGIS 10.2 and impossible locations were removed. Locations that occurred within the ROW beyond the mean error of the GPS collars (24 m) were used to determine fence efficacy. We used Student's T-tests to compare differences ($\alpha = 0.05$) in the number of monthly locations beyond the 24-m error buffer between pre-treatment years (i.e., before the ROW fence was repaired and retrofitted with outriggers) and post-treatment years (i.e., after ROW fence repair and retrofitting).

Because the fence was intended to deny deer access to the ROW, only post-treatment fence crossing events and circumventions were used to evaluate the efficacy of the fence. When a deer's movement path crossed the fence, we classified the event as a crossing if ≥ 2 sequential hourly locations occurred on the opposite side of the fence. Sequential locations that were >1 hour apart were not considered to be fence crossings. When a distinct movement path around the fence end was observed, it was considered a circumvention. Date and time of each crossing and circumvention were recorded as well as the direction of crossing (i.e., into ROW vs out of ROW; Gulsby et al. 2011). Crossing locations (i.e., the intersection of the movement path and the fence) were marked to serve as reference points to visually compare crossing locations and repair sites.

RESULTS

We captured 32 adult deer (20 males, 12 females). Due to delays associated with ROW fence repair/retrofitting, only 3 adult female deer (#13, #47, and #85) were available for post-treatment evaluation.

Deer #47 (Figure 3) was located at the eastern end of the study area. We collected 3 years of location data from this deer. The mean number of monthly locations within the ROW that were beyond the 24-m error buffer during pre-treatment year 1 (May – October 2012) ($\bar{x} \pm$ SE; 10.8 ± 1.2) was less than ($P = 0.01$) during pre-treatment year 2 (May – October 2013; 24.5 ± 4.4) or the year post-treatment ($P = 0.05$; May – October 2014; 34.3 ± 10.72). The mean number of monthly locations within the ROW during pre-treatment year 2 did not differ ($P > 0.05$) from the post-treatment year. After construction of the fence, Deer #47 crossed into the ROW 57 times and crossed out of the ROW 48 times (Number of crossings into and out of the ROW are not equal because some sequential locations were >1 hour apart were, therefore, not considered to be fence crossings.). This deer also circumvented the fence end 26 times.

Deer #85 (Figure 4) was located at the western end of the study area. The mean number of monthly pre-treatment (May – June 2013) locations within the ROW beyond the 24-m error buffer (15.0 ± 10.0) was not different ($P > 0.05$) from post-treatment (May – June 2014; 225.0 ± 191.0). Post-treatment, she crossed into the ROW 9 times, and out of the ROW 11 times. Although she had the opportunity to circumvent fence ends, a definite circumvention was not observed. Movement data suggested that Deer #85 had selected the ROW for parturition during spring of 2013 and 2014 (Stickles 2014). During June 2014, 416 of her 544 (76%) locations occurred within the ROW beyond the 24-m error buffer. She was eventually struck by a vehicle on 24 June 2014 and died between the I-20 westbound lane and the westbound Exit 114 off-ramp.

Deer #13 (Figure 5) was located near the center of the study area. We collected 3 years of location data from this deer. The mean number of monthly locations within the ROW that were beyond the 24-m error buffer during pre-treatment year 1 (June – October 2012) (19.0 ± 6.3) was less than ($P = 0.03$) the number during pre-treatment year 2 (June – October 2013; 56.8 ± 12.3), but was greater than ($P = 0.05$) the number post-treatment (June – October 2014; 4.4 ± 1.4). The mean number of monthly locations within the ROW during pre-treatment year 2 was significantly greater than ($P < 0.01$) during post-treatment. Deer #13 crossed into the ROW 17 times and crossed out of the ROW 15 times during the post-treatment period.

Despite the low sample size and sex bias, the fact that we observed fence crossings and circumventions is significant, considering that the fence was intended to prevent or reduce access to the ROW for all deer.

The total cost of parts and labor, including the environmental assessment, for retrofitting the ROW fence was approximately $137,448 ($17,181/km; Table 1). The cost of maintenance was estimated at $36.58/km/year. Although the ROW fence was located in a wooded area where trees and limbs damaged the fence from above, the most common repairs were small gaps (≤ 18 cm in size) under the fence.

Clusters of crossing locations near fence gaps suggested that deer used them to access the ROW (Figures 6 and 7). Other crossing locations appeared to occur at seemingly random locations or clustered in areas where no fault in the fence design was identified.

Despite weekly surveys for RKD, no RKD were observed on I-20 from Exit 114 to Bethany Road during the pre-treatment periods. Five RKD (4 adult females, 1 fawn of unknown sex) were observed during the post-treatment period. Of these, a fawn and an adult female were found dead together.

Of 4,117 photos consisting of 12 identifiable species recorded in culverts passing under I-20, 3 deer accounted for 9 photos during the pre-treatment period; no deer activity in the culverts was captured post-treatment (Table 2). Of the 3 deer, an adult male crossed through the eastern culvert on 25 May 25 2013, and juveniles of unknown sex crossed through the western culvert on 19 June 2013 and 14 August 2013.

DISCUSSION

Over-hanging deer fences have been successful at preventing deer access from areas where they are not desired (Jones and Longhurst 1958, Falk et al. 1978), but retrofitting a highway ROW fence with an outrigger may not be the most practical application of the design. Numerous logistical issues with retrofitting became apparent during our study, many of which may have increased costs compared to new construction. For example, the entire fence needed to be surveyed to accurately estimate necessary materials for repair. Also, before the outrigger was installed, the fence needed to be cleared of debris and repaired. Both of these labor-intensive steps would not be necessary with new construction. Also, the environmental assessment added to fence modification costs. The cost of the environmental assessment alone was approximately $25,080 ($3,135/km of fence). Additionally, the environmental compliance concerns required the contractors to use hand tools in some areas, and threatened fines for noncompliance; these environmental compliance requirements likely influenced contractor bid prices. For fences where an environmental assessment might have been completed prior to the original construction, it is not an efficient use of resources to require another environmental assessment prior to installation of an outrigger.

Despite repairing the fence and adding the outrigger, access to the ROW was not adequately inhibited. Gaps of ≤ 18 cm were smaller than those patched in a Pennsylvania study (Falk et al. 1978) and appeared to allow deer to cross under the fence. The smaller size of deer in Georgia may have allowed them to take advantage of smaller fence gaps. Gaps under a fence or holes in a fence are key points of weakness that were observed in other studies (Jones and Longhurst 1958, Bellis and Graves 1978, Falk et al. 1978, Ward 1982, Gulsby et al. 2011). Eliminating gaps under a fence is often very difficult, especially in drainage areas where fence bottoms are often slightly modified to allow free-flow of water. Further, weather can erode soils and some animals may dig under fences, meaning complete elimination of gaps under a fence is likely not feasible without regular maintenance (Hedlund et al. 2004).

Deer jumping the fence was evidenced by seemingly random crossing locations, or locations clustered in areas where no fault in the fence was observed. In the development of the outrigger design used in this experiment, Georgia researchers noted that deer naïve to jumping fences were less successful at jumping them than deer with fence jumping experience (Stull et al. 2011). In our experiment, there was already a ROW fence present in our study area. Deer that regularly accessed the ROW may have been experienced at jumping fences, and thus may have been less hindered by the over-hanging fence design. However, the fact that crossing-in locations appeared more clustered than crossing-out locations agrees with previous suggestions that the design may be more difficult to cross with the outrigger facing toward the deer versus facing away (Stull et al. 2011). Such characteristics are desirable for providing a one-way escape mechanism.

Frequent circumventions by Deer #47 at the eastern end of the study area illustrate the importance of locating escape mechanisms near fence ends for any fence design. No circumventions by Deer #85 at the western end of the study area may indicate that urbanized areas can deter deer from circumventing fence ends. However, deer have been known to habituate to human activity especially in urban and suburban areas (Bowman 2011).

Fence repairs alone may have inhibited the ability of fawns to escape the ROW, thus increasing DVC risk for their dams. For example, Deer #85 appeared to have used the I-20 ROW for parturition during pre- and post-treatment periods. Minimal use of the I-20 ROW during pre-treatment suggested that either her fawns were able to escape the ROW, or they did not survive that year. Post-treatment, Deer #85 used the ROW almost exclusively during the month of June. During several occasions she escaped the ROW, but returned within a few hours suggesting that she was caring for young. Eventually, her extensive use of the ROW led to her demise. Also, a female deer and fawn found together dead in the study area during the post-treatment period, which may be evidence of a similar scenario.

Although fencing is often used in combination with large crossing structures to direct animal movement, there was no evidence that the outrigger fence increased deer traffic through the large culverts passing under I-20. The frequent use of these structures by coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) may have deterred deer from using them. In Florida, it was observed that an underpass heavily used by panthers (*Puma concolor*) had the least deer activity compared to other crossing structures (Foster and Humphrey 1995). Also, the OI for the culverts in our study area was much smaller than what is traditionally used by white-tailed deer (Brudin 2003, Donaldson 2005). In fact, to the best of our knowledge, our study documented deer using the smallest OI for culverts ever reported for white-tailed deer.

MANAGEMENT IMPLICATIONS

Retrofitting the ROW fence was logistically complicated and costly. Further, despite previous success on naïve deer, an over-hanging fence design may be less effective at deterring deer that are experienced at jumping fences. Therefore, we recommend this design only be used with new construction, with a caveat that the design must eliminate, or at least minimize, gaps under the fence and be maintained regularly. Although damage from trees and limbs was minimal during our monitoring period, deer were quick to take advantage of tree-damaged areas of fence. Therefore, we recommend only using this design in open areas. Finally, because breaches were common, a 2.4-m deer exclusion fence is likely the most practical option for excluding deer from an interstate. However, it is important for such fences to incorporate methods to escape the ROW should deer gain access. An over-hanging fence design may fulfill this need by providing a means for escape for white-tailed deer in some areas.

LITERATURE CITED

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

Bellis, E. D. and H. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. Journal of Wildlife Management 35:232-237.

Bowers, J.W., A. Hammond, K. Kammermeyer, C. Martin, S. McDonald, N. Nicholson, J. Robbins, T. Touchstone, and G. Waters. 2005. Georgia's deer management plan 2005-2014. Georgia Department of Natural Resources, Wildlife Resources Division, Game Management Section, Social Circle, Georgia, USA.

Bowman, J.L. 2011. Managing white-tailed deer: exurban, suburban, and urban environments. Pages 599-620 in D.G. Hewitt, editor. Biology and management of white-tailed deer. CRC Press, Boca Raton, USA.

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

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.

Ellingwood, M. R., S. Caturano, Connecticut Department of Environmental Protection, New England Chapter of The Wildlife Society, Northeast Deer Technical Committee. 2009. An evaluation of deer management options.

Falk, N. W., H. Graves, and E. Bellis. 1978. Highway right-of-way fences as deer deterrents. Journal of Wildlife Management 42:646-650.

Foster, M.L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23:95-100

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

Hedlund, J.H., P. Curtis, G. Curtis, and A. Williams. 2004. Methods to reduce traffic crashes involving deer: what works and what does not. Traffic Injury Prevention 5:122-131.

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

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith, and R. Ament. 2007. Wildlife-vehicle collision reduction study. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Insurance Information Institute. 2010. <http://www.iii.org/ >. Accessed 16 Aug 2012.

Jones, M. B. and W. Longhurst. 1958. Overhanging deer fences. Journal of Wildlife Management 22:325-326.

Long, E. S., D. Diefenbach, C. Rosenberry, and B. Wallingford. 2008. Multiple proximate and ultimate causes of natal dispersal in white-tailed deer. Behavioral Ecology 19:1235-1242.

Severinghaus, C.W. 1949. Tooth development and wear as criteria of age in white-tailed deer. Journal of Wildlife Management 13:195-216.

Stickles, J.H. 2014. Using GPS telemetry to assess deer-vehicle collision risk in Georgia. Master's Thesis. University of Georgia, Athens.

Stull, D.W., W. Gulsby, J. Martin, G. D'angelo, G. Gallegher, D. Osborn, R. Warren, and K. Miller. 2011. Comparison of fencing designs for excluding deer from roadways. Human Wildlife Interactions 5:47-57.

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

Table 1. Costs associated with repair, modification, and maintenance of I-20 right-of-way fence from Exit 114 to Bethany Road, Madison, Morgan County, Georgia, USA.

Expense	**Cost**
Fence Construction	
Parts & Labor	$ 112,373
Environmental Survey	$ 25,082
Total	**$ 137,455**
Maintenance[a]	
Parts	$ 61.10
Labor	
Repairs[b]	$ 25.20
Surveys[b,c]	$ 60.00
Total[a]	**$ 146.30**

a - Over a 6-month period (May-October)
b - Assumes hourly wage of $12/hour
c - Survey time likely to vary

Table 2. Number of images of each species photographed crossing through large culverts under I-20 from 22 August 2012 to 18 September 2014.

Species	**Total Images**	**Total Animals**	**Total East Culvert**	**Total West Culvert**
Armadillo	628	628	365	263
Bat	7	7	5	2
Bobcat	514	514	166	348
Coyote	380	414	170	244
Deer	9	9	3	6
Great Blue Heron	94	94	2	92
Opossum	47	51	51	0
Raccoon	2325	2705	1270	1435
Squirrel	3	3	1	2
Unknown	74	74	30	44
Beaver	32	32	0	32
Rabbit	2	2	0	2
Otter	2	3	0	3
Total	**4117**	**4536**	**2063**	**2473**

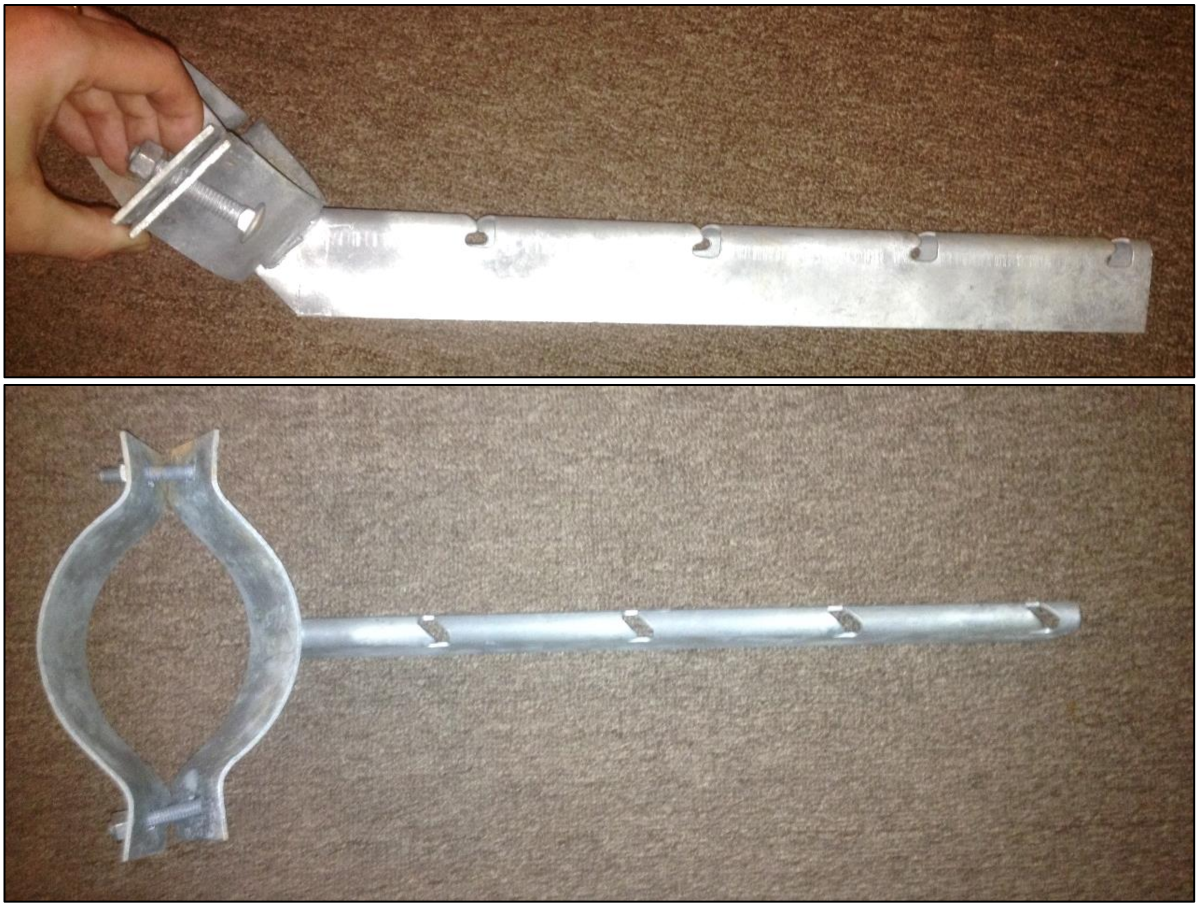

Figure. 1. Side view (top) and top view (bottom) of outrigger arm. Angled wire slots hold high tensile wire in place without tie-downs.

Figure 2. Completed outrigger fence extending from Exit 114 to Bethany Road in Madison, Morgan County, Georgia, USA.

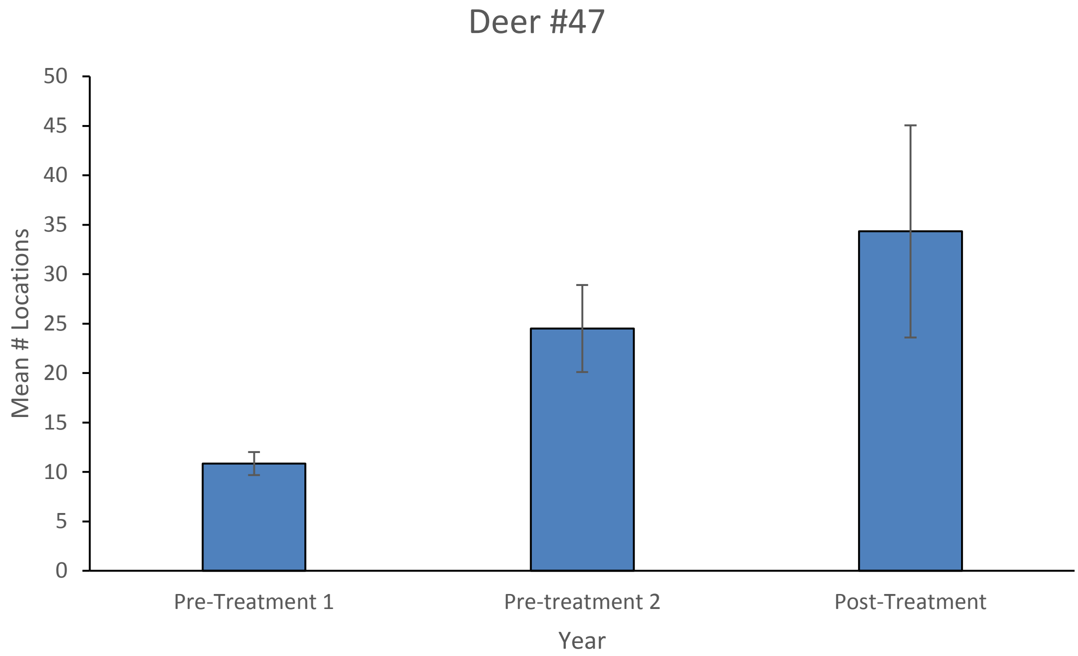

Figure 3. Number of monthly locations ($\bar{x}$ $\underline{+}$ SE) within the I-20 right-of-way (ROW) >24m from the ROW fence for adult female deer #47 during pre-treatment 1 (1 May – 31 October, 2012), pre-treatment 2 (1 May – 31 October, 2013), and post-treatment (1 May – 31 October, 2014) periods.

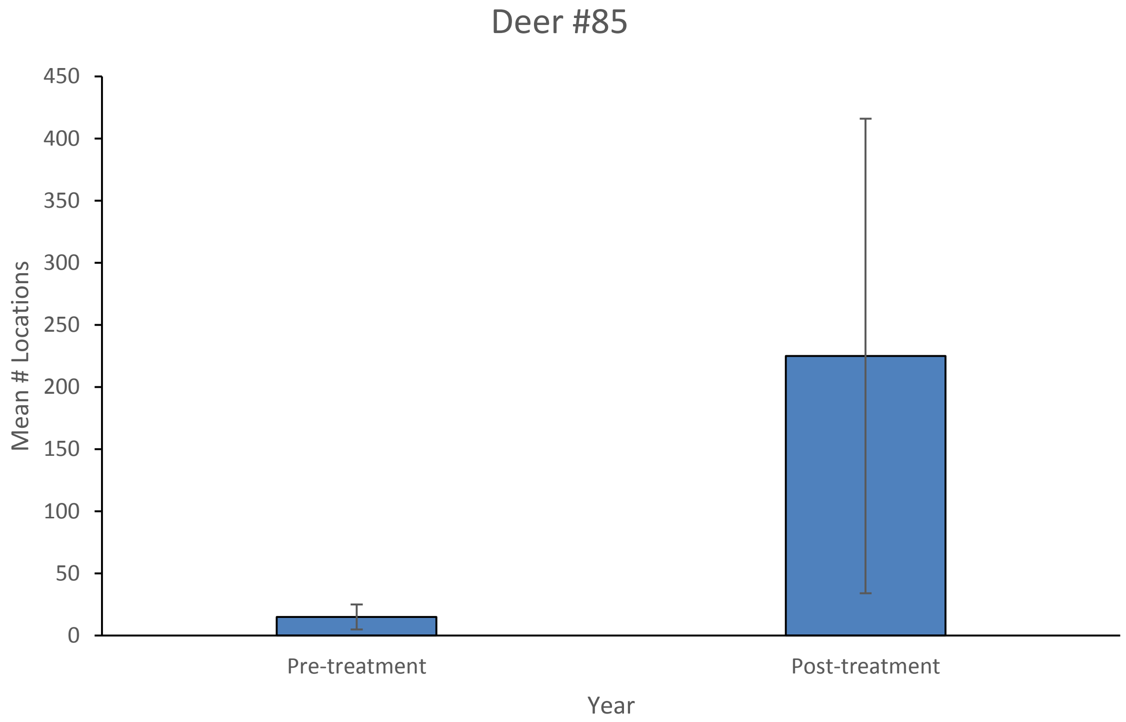

Figure 4. Number of monthly locations ($\bar{x}$ ± SE) within the I-20 right-of-way (ROW) >24m from the ROW fence for adult female deer #85 during pre-treatment (1 May – 24 June, 2013) and post-treatment (1 May – 24 June, 2014) periods.

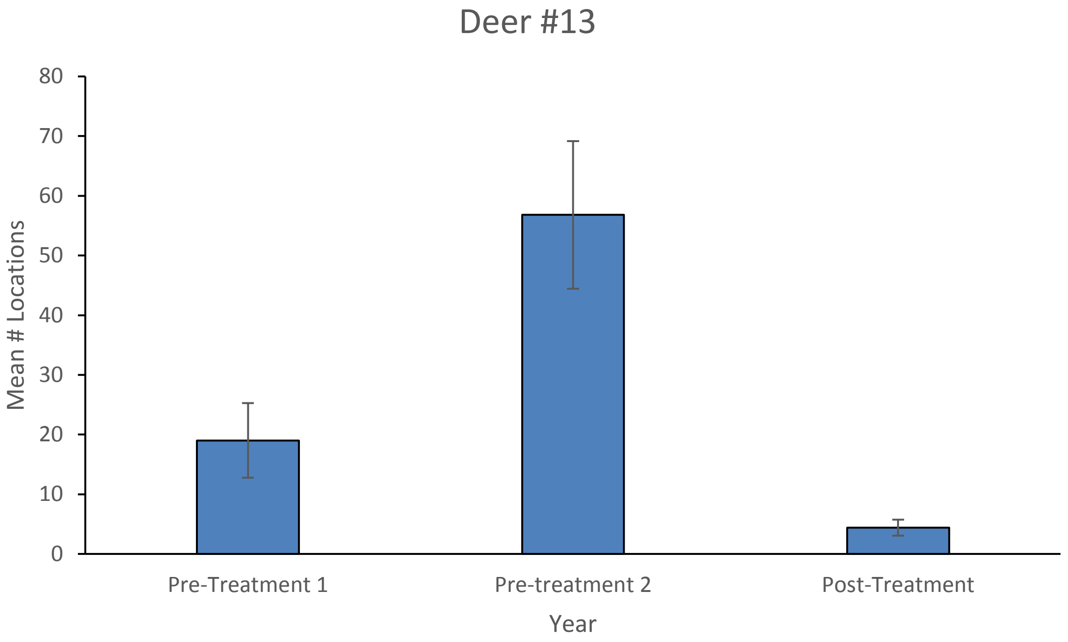

Figure 5. Number of monthly locations ($\bar{x}$ ± SE) within the I-20 right-of-way (ROW) >24m from the ROW fence for adult female deer #47 during pre-treatment 1 (1 June – 31 October, 2012), pre-treatment 2 (1 June – 31 October, 2013) and post-treatment (1 June – 31 October, 2014) periods.

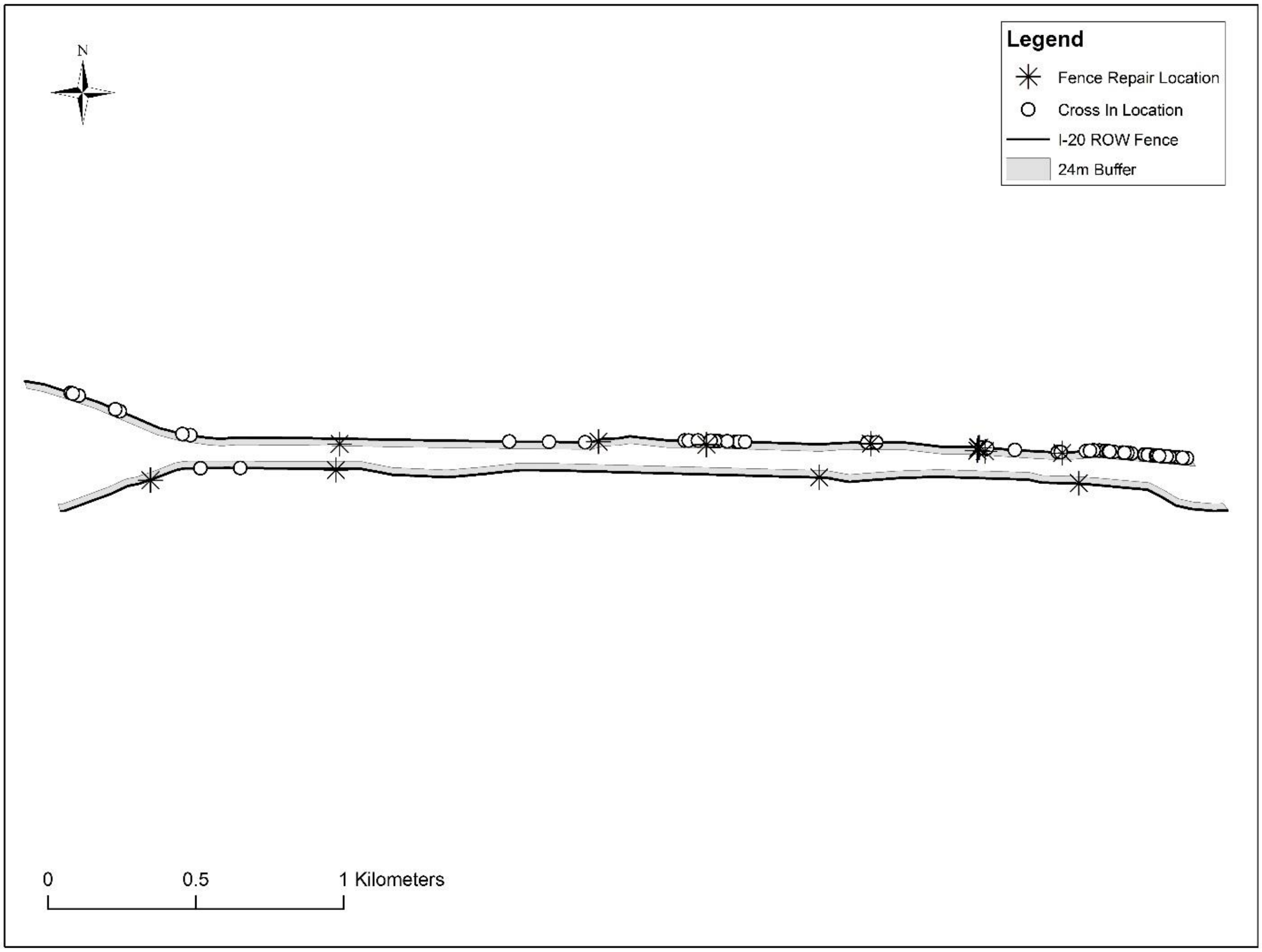

Figure 6. Locations where deer crossed into the I-20 right-of-way were more clustered near repair locations.

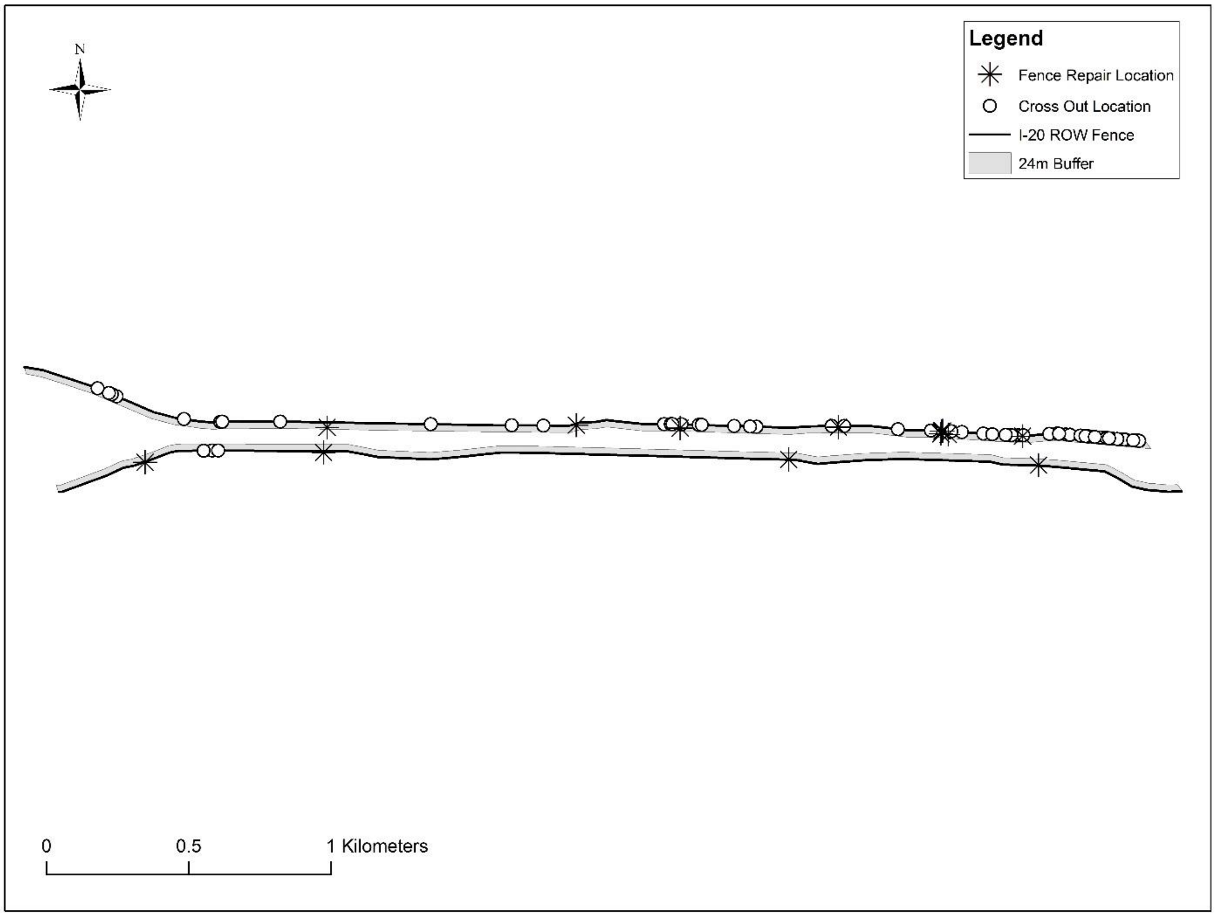

Figure 7. Locations where deer crossed out of the I-20 right-of-way were less clustered near repair locations.