EFFECTS OF FENCES ON ROADWAY CROSSINGS AND HOME RANGE DISTRIBUTION OF WHITE-TAILED DEER

by

WILLIAM D. GULSBY

(Under the Direction of Karl V. Miller and Robert J. Warren)

ABSTRACT

Although many deer-vehicle collision (DVC) mitigation devices have been developed and tested, only fencing has proven effective. Because a 2.4-m woven-wire fence and a prototype outrigger fence (i.e., 0.6-m outriggers attached to a 1.2-m wire fence angled at 45º) were 100% effective at preventing crossings by captive white-tailed deer (*Odocoileus virginianus*), we evaluated the efficacy of these designs at preventing crossings by free-ranging deer. From January to April 2009, we fitted 14 adult does with GPS collars, programmed to collect ≥ 24 locations/day. In June 2009, we constructed a 3.2-km fence treatment that included a 1.6-km section of 2.4-m vertical-wire fence and a 1.6-km section of the outrigger fence. We retrieved collars between January and March 2010. We compared home ranges, core areas, fence crossings, and fence circumventions among deer that encountered the outrigger and 2.4-m fences as well as for deer that did not encounter the fence (i.e., controls), before and after fence construction. Although home ranges and core areas changed among seasons, we found no effect of fencing. 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 fences. Fence crossings, however, 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 may be a viable option for reducing DVCs because of its affordability and potential as a one-way barrier. More importantly, we believe this study highlights 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.

INDEX WORDS: deer-vehicle collision, fencing, GPS collars, home range, LoCoH, *Odocoileus virginianus*, outrigger fence, telemetry, white-tailed deer, wildlife-vehicle collision

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by

WILLIAM D. GULSBY

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DISTRIBUTION OF WHITE-TAILED DEER

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WILLIAM D. GULSBY

Major Professors: Karl V. Miller
Robert J. Warren

Committee: John P. Carroll
Nathan P. Nibbelink

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, STUDY AREA, OBJECTIVES, AND THESIS FORMAT

INTRODUCTION

The combination of abundant white-tailed deer (*Odocoileus virginianus*) populations, an expanding roadway system, and increased vehicular traffic have led to an increase in deer-vehicle collisions (DVCs) in many areas of the United States (Romin and Bissonette 1996). An estimated 1.5 million DVCs (Conover et al. 1995) account for $1.1 billion in damages each year in the United States alone (State Farm Insurance Company 2009). According to the Insurance Information Institute (2008), the average insurance claim for damage incurred from a DVC is $2,800. When medical costs for bodily injury are included, the average cost increases to $10,000. The Georgia Department of Natural Resources, Wildlife Resources Division estimates that as many as 51,000 DVCs occur each year in Georgia, accounting for 13.5 % of all collisions in the state (Bowers et al. 2005).

Many transportation departments have attempted to alleviate this problem using roadside fencing. Although it is clear that deer cannot cross certain fences, little is known about how these fences affect their behavior. The attention given to this problem is increasing, but consultation between biologists and transportation departments will be critical to the reduction of DVCs in the future. The purpose of this study was to evaluate the efficacy of two types of roadside fencing when deployed in the field and their effects on home ranges and movements of free-ranging deer.

LITERATURE REVIEW

Animal-detection systems, roadway signage, intercept feeding, deer whistles, roadside reflectors, and exclusion fences with or without wildlife crossing structures incorporated into them have all been implemented in an attempt to mitigate DVCs (Huijser et al. 2007). Despite the variety of these mitigation strategies, most fall into three main categories: alteration of driver behavior, alteration of deer behavior, or exclusion of deer from the road. Devices designed to alter driver behavior, such as roadway signage placed in areas with a high frequency of DVCs, initially increase driver awareness but motorists quickly revert to their standard driving practices after becoming habituated to them (Putnam et al. 2004). Devices designed to alter deer behavior, such as roadside reflectors or deer whistles, often do not account for the way deer perceive their environment. Recently, D'Angelo (2007) examined the physiological and morphological characteristics of white-tailed deer visual and auditory systems in an attempt to better understand their perception of deer whistles and roadside reflectors. Then these devices were tested in the field and found to be ineffective at preventing deer from entering roadways (D'Angelo et al. 2007, Valitzski et al. 2009).

Exclusion of deer from the roadway using roadside fencing is perhaps the most frequently utilized and studied DVC mitigation technique. Although the construction costs of deer-proof fencing are high, it is the most economical and effective option when human tolerance of deer damage is low, as is the case in areas with a high incidence of DVCs (Bashore et al. 1985, Bryant et al. 1993, Craven and Hygnstrom 1994, DeNicola et al. 2000, VerCauteren et al. 2006). Huijser et al. (2007) estimated the cost of DVC-mitigation fencing to be \$3,760/km/yr with a benefit (e.g., collisions prevented as a result of the fencing) of \$32,728/km/yr.

Woven-wire fencing ≥ 2.4-m in height is generally regarded as effective for preventing crossings by large ungulates (Fitzwater 1972, Falk et al. 1978, Bashore and Bellis 1982, Ward 1982, Sauer 1984, Bryant et al. 1993, Craven and Hygnstrom 1994, Seamans 2001, Kaneene et al. 2002, VerCauteren et al. 2006), and has been shown to decrease DVCs by 60-93% (Ludwig and Bremicker 1981).

The Georgia Department of Transportation (GDOT) currently uses a “game fence” in DVC-prone areas. This fence is 2.74-m tall with three distinct sections (GDOT, personal communication). The lowest section is 22.9 cm of woven wire with 7.6-cm vertical spacing and a strand of barbed wire running along the ground. The next section, which composes the majority of the fence, is 2.2 m of woven-wire fence with 20.32-cm vertical spacing. The third section is two strands of barbed wire spaced 15.24-cm apart and is located 15.24-cm above the woven wire. Although this fence effectively excludes deer from the roadway, it is quite expensive and no wildlife escape structures are incorporated into its design.

Alternatives to high fences that use less material or less-costly material and provide escape routes for entrapped deer have been proposed and tested. For example, Jones and Longhurst (1958) tested a 0.6-m vertical fence with a 1.8-m outrigger angled at 25º and a 1.2-m vertical fence with a 1.2-m outrigger angled at 45º. In both cases, deer were more likely to attempt to go under the fence when the outrigger was angled towards them. Goddard et al. (2001) found that a 0.9-m vertical fence with a 0.8-m, 90º outrigger effectively prevented crossings by red deer (*Cervus elaphus*). Similarly, Stull (2009) reported that a 1.2-m woven-wire fence with a 0.6-m 50% opaque plastic outrigger angled at 45º may act as a one-way barrier, with a higher degree of efficacy when the outrigger is angled towards the deer.

Knapp et al. (2004) and Huijser et al. (2007) reported that maximum effectiveness of any fence design requires that the fence is properly constructed and maintained, located on both sides of the road, is of sufficient length to extend beyond the home ranges of deer in high-risk areas, and has some way for animals to escape from the right-of-way. Additionally, Ludwig and Bremicker (1981) reported that deer will circumvent roadside fences that are too short, resulting in a reduction in their efficacy. However, barriers are often constructed only at deer crossing "hot-spots" (Utah Department of Transportation 2008). "Hot-spot" treatments have the potential to shift or magnify the number of DVCs in an area by funneling deer to a common crossing point (Owen and Owen 1980, Isleib 1995, Clevenger et al. 2001, VerCauteren et al. 2006, Huijser et al. 2007). For example, one study found that where mitigation fencing was used, wildlife-vehicle collisions were highest within 2 km of the fence ends and tapered off thereafter (Clevenger et al. 2001).

Before DVCs can be effectively reduced, factors influencing deer movements in relation to fencing and highways must be more thoroughly understood (Puglisi et al. 1974). However, researchers often use indirect measures such as carcass counts, track counts, or surveys of deer in the right-of-way to examine these movements and almost no direct evidence currently exists regarding behavioral responses of deer to fences (Puglisi et al. 1974, Carbaugh et al. 1975, Falk et al. 1978, Clevenger et al. 2001). Only Feldhamer et al. (1986) have directly studied deer movements in relation to a highway with mitigation fencing. In this study, deer were captured and radio-collared alongside a roadway where several types of fencing were in place. However, because deer movements were monitored using VHF telemetry, the investigators lacked the fine-scale data needed to quantify individual crossings or circumvention events.

The combination of widespread use of roadside fencing and the lack of knowledge surrounding how deer respond to it could potentially exacerbate deer-vehicle interactions. Therefore, I determined the effects of a prototype outrigger-fence design and a 2.4-m woven-wire fence on home range distribution and movements of free-ranging deer. I also evaluated the efficacy of these fences for preventing deer crossings.

OBJECTIVES

The goals of this project were to determine the efficacy of two types of roadside deer fencing and evaluate their effects on deer home range distribution and movements. My specific objectives were to: (1) determine any changes in deer home ranges that occur as a result of the construction of roadside fences; (2) determine if deer circumvent roadside fences to gain access to portions of their home range from which they are excluded; (3) compare the efficacy of a 2.4-m woven-wire fence to that of a 1.2-m woven-wire fence with an outrigger angled at 45º (Figure 1); (4) determine if the outrigger fence served as a one-way barrier by comparing its efficacy when angled toward versus away from the deer.

STUDY AREA

I conducted my study on the 1,215-ha Berry College Wildlife Refuge (BCWR) within the 11,340-ha Berry College Campus in Floyd County, Georgia (Figure 2). Although the refuge is located in the Ridge and Valley physiographic province (Hodler and Schretter 1986), which has elevations ranging from 172 to 518 m, much of BCWR lies in the Coosa Valley and the elevation is typically ≤ 200 m.

The forested habitat on BCWR consists of tree species common to southern forests, including *Acer rubrum*, *Diospyros virginiana, Ilex opaca, Liquidambar styraciflua, Liriodendron tulipifera, Pinus taeda, Quercus alba, and Q. nigra*. The refuge is also interspersed with some of the last-remaining stands of mountain longleaf pine (*Pinus palustris*).

Hunting is prohibited on the refuge and deer are abundant with an estimated density of 40 deer/km^2 (J. Beardon, Georgia Department of Natural Resources, personal communication). As a result, between 12 and 24 DVCs are reported annually, although the actual number of collisions is likely higher (Berry College Police Department, unpublished data).

The campus is divided into the main campus and the mountain campus. Both campuses are characterized by buildings and facilities interspersed with pastures, woodlots, and manicured lawns. They are connected by a 4.8-km, straight stretch of road known as Lavender Mountain Road (LMR). LMR is a two-lane blacktop road with a speed limit ranging from 40-64-km/hr. Running parallel to LMR is a power-line right-of-way known as the Viking Trail (VT). The area surrounding LMR and the VT is forested and consists of pine stands (*Pinus taeda* and *Pinus palustris*) and mixed forest dominated by oaks (*Quercus* spp.), hickories (*Carya* spp.), and pines (*Pinus* spp.). LMR and the VT are separated by a strip of mixed forest, of similar composition, that ranges from 30-125 m wide. I selected the VT as the construction site for the DVC-mitigation fencing because of its openness, flatness, linear orientation, and similarity to a common situation where a roadway travels through a wooded area harboring an abundant deer population.

THESIS FORMAT

My thesis is presented in manuscript format. Chapter 1 is an introduction and a literature review of previous studies addressing similar research topics. Chapter 2 is the manuscript chapter that will be submitted to a peer-reviewed scientific journal for publication. It describes the efficacy of two types of roadside fencing for preventing deer crossing and their effects on home ranges and movements of white-tailed deer. Chapter 3 presents conclusions and the management implications of the findings of my study.

LITERATURE CITED

ArcGIS Online. 2010. World Imagery. ArcGIS Resource Center. Last updated June 2010. < http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9> (accessed July 2, 2010).

Bashore, T.L., and E.D. Bellis. 1982. Deer on Pennsylvania airfields: problems and means of control. Wildlife Society Bulletin 10:386-388.

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

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.

Bryant, L.D., J. Thomas, and M. Rowland. 1993. Techniques to construct New Zealand elk-proof fence. La Grande (OR): USDA Forest Service Pacific Northwest Research Station. General Technical Report No. PNW-GTR-313.

Carbaugh, B., J.P. Vaughan, E.D. Bellis, and H.B. 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.

Craven, S.R., and S.E. Hygnstrom. 1994. Deer. Pages D25-40 *in* S.E. Hygnstrom, R.M. Timm, and G.E. Larson, editors. Prevention and control of wildlife damage. University of Nebraska Cooperative Extension, Lincoln, Nebraska, USA.

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

D'Angelo, G.J., A.R. DeChiccis, D.A. Osborn, G.R. Gallagher, R.J. Warren, and K.V. Miller. 2007. Hearing range of white-tailed deer as determined by auditory brain stem response. Journal of Wildlife Management 71:1238-1242

DeNicola, A.J., K.C. VerCauteren, P.D. Curtis, and S.E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments. Cornell University Cooperative Extension, Ithaca, New York, USA.

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

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

Fitzwater, W. D. 1972. Barrier fencing in wildlife management. Proceedings of the Vertebrate Pest Control Conference 5:49–55.

Goddard, P.J., R.W. Summers, A.J. MacDonald, C. Murray, and A.R. Fawcett. 2001. Behavioral responses of red deer to fences of five different designs. Applied Animal Behavioural Science 73:289-298.

Hodler, T.W., and H.A. Schretter. 1986. The atlas of Georgia. University of Georgia, Athens, USA.

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. 2008. <http:// www.iii.org/>. Accessed December 3, 2008.

Isleib, J. 1995. Deer exclusion efforts to reduce crop damage in Michigan and Northeast Wisconsin. Great Plains Wildlife Damage Control Workshop 12:63-69.

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

Kaneene, J.B., C.S. Bruning-Fann, L.M. Granger, R. Miller, and B.A. Porter-Spalding. 2002. Environmental and farm management associated with tuberculosis on cattle farms in northeastern Michigan. Journal of the American Veterinary Medical Association 221:837-842.

Knapp, K.K., X. Yi, T. Oakasa, W. Thimm, E. Hudson, and C. Rathmann. 2004. Deer-vehicle crash countermeasure toolbox: a decision and choice resource. Midwest Regional University Transportation Center, Madison, Wisconsin, USA.

Ludwig, J. and T. Bremicker. 1981. Evaluation of 2.4-meter fences and one-way gates for reducing deer-vehicle collisions. Minnesota Wildlife Resources Quarterly 41:77-88.

Owen, M., and D. Owen. 1980. The fences of death. African Wildlife 35:25-27.

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.

Putman, R.J., J. Langbein, and B.W. Staines. 2004. Deer and road traffic accidents: a review of mitigation measures: costs and cost-effectiveness. Report for the Deer Commission for Scotland.

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

Sauer, P. R. 1984. Physical characteristics. Pages 73-90 *in* L.K. Halls, editor. White-tailed deer: ecology and management. Stackpole Books, Harrisburg, Pennsylvania, USA.

Seamans, T.W. 2001. A review of deer control devices intended for use on airports. Bird Strike Committee Proceedings 21.

State Farm Insurance Company. 2009. <http://www.statefarm.com/>. Accessed October 7, 2009.

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

Utah Department of Transportation Environmental Services & Wildlife & Domestic Animal Accident Quality Improvement Team. 2008. UDOT Wildlife and Domestic Animal Accident Toolkit. Report No. UT-08.07.

Valitzski, S.A., G.J. D'Angelo, G.R. Gallagher, D.A. Osborn, K.V. Miller, and R.J. Warren. 2009. Deer responses to sounds from a vehicle-mounted sound-production system. Journal of Wildlife Management 73:1072-1076.

VerCauteren K.C., M.J. Lavelle, and S. Hygnstrom. 2006. Fences and deer-damage management: a review of designs and efficacy. Wildlife Society Bulletin 34:191-200.

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

Figure 1.1. The 2.4-m woven-wire fence treatment (left) and outrigger fence treatment (right) constructed on Berry College, Floyd County, Georgia.

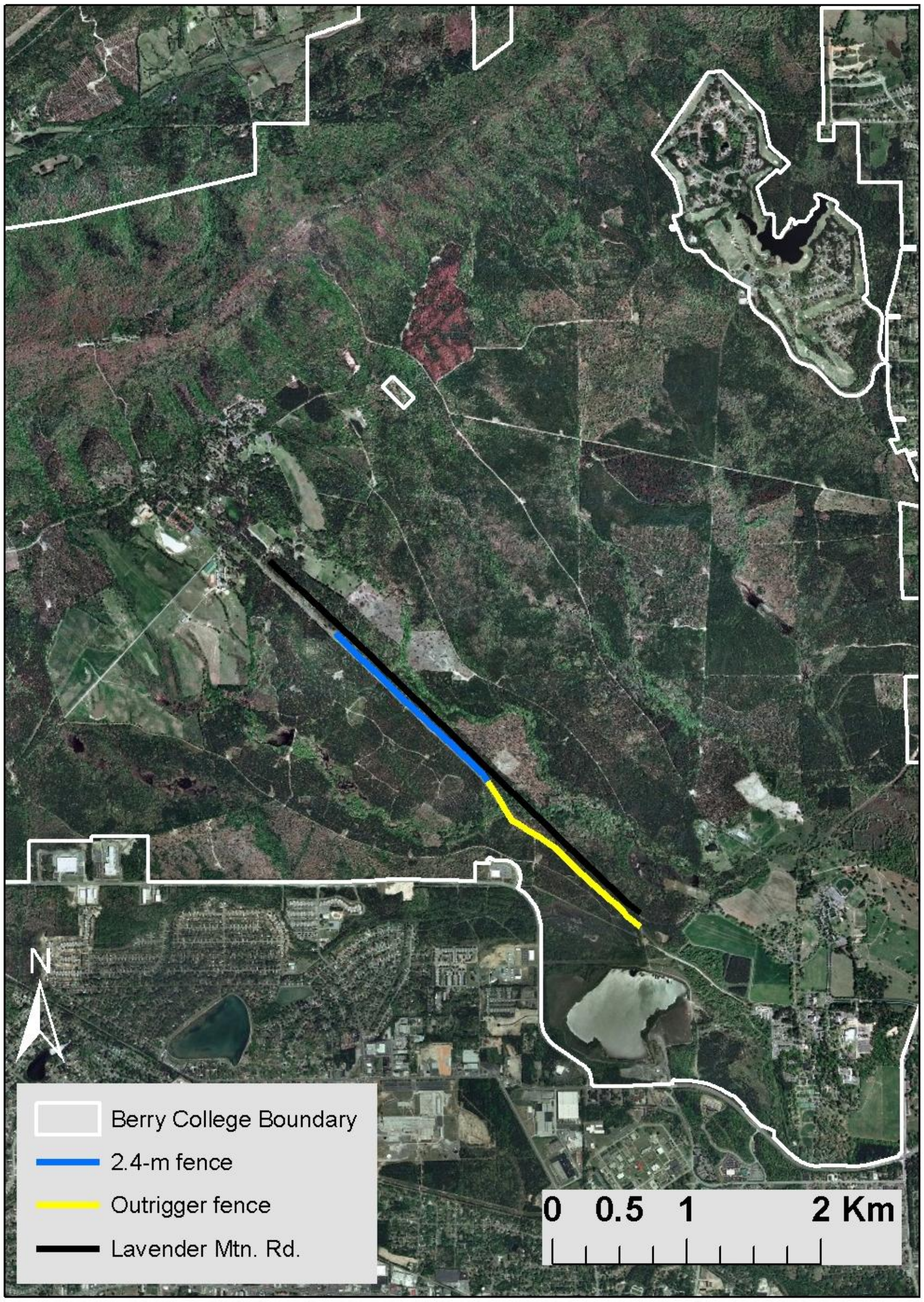

Figure 1.2. A 1-m resolution imagery map from the ArcGIS Resource Center (ArcGIS Online 2010) of Berry College, Floyd County, Georgia and the 1.6-km fence treatments.

CHAPTER 2

EFFECTS OF FENCES ON ROADWAY CROSSINGS AND HOME RANGE DISTRIBUTION OF WHITE-TAILED DEER

ABSTRACT

Although many deer-vehicle collision (DVC) mitigation devices have been developed and tested, only fencing has proven effective. Because a 2.4-m woven-wire fence and a prototype outrigger fence (i.e., 0.6-m outriggers attached to a 1.2-m wire fence angled at 45º) were 100% effective at preventing crossings by captive white-tailed deer (*Odocoileus virginianus*), we evaluated the efficacy of these designs at preventing crossings by free-ranging deer. From January to April 2009, we fitted 14 adult does with GPS collars, programmed to collect ≥ 24 locations/day. In June 2009, we constructed a 3.2-km fence treatment that included a 1.6-km section of 2.4-m vertical-wire fence and a 1.6-km section of the outrigger fence. We retrieved collars between January and March 2010. We compared home ranges, core areas, fence crossings, and fence circumventions among deer that encountered the outrigger and 2.4-m fences as well as for deer that did not encounter the fence (i.e., controls), before and after fence construction. Although home ranges and core areas changed among seasons, we found no effect of fencing. 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 fences. Fence crossings, however, 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 may be a viable option for reducing DVCs because of its affordability and potential as a one-way barrier. More importantly, we believe this study highlights 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.

INDEX WORDS: deer-vehicle collision, fencing, GPS collars, home range, *Odocoileus virginianus*, outrigger, outrigger fence, telemetry, white-tailed deer, wildlife-vehicle collision

INTRODUCTION

The combination of abundant white-tailed deer (*Odocoileus virginianus*) populations, an expanding roadway system, and increased vehicular traffic have led to an increase in deer-vehicle collisions (DVCs) in many areas of the United States (Romin and Bissonette 1996). An estimated 1.5 million DVCs (Conover et al. 1995) account for $1.1 billion in damages each year in the United States alone (State Farm Insurance Company 2009). According to the Insurance Information Institute (2008), the average insurance claim for damage incurred from a DVC is $2,800. When medical costs for bodily injury are included, the average cost increases to $10,000. The Georgia Department of Natural Resources, Wildlife Resources Division estimates that as many as 51,000 DVCs occur each year in Georgia, accounting for 13.5% of all collisions in the state (Bowers et al. 2005).

Most devices designed to mitigate DVCs have failed to account for the way deer perceive their environment (i.e., vision and hearing), or these devices are marketed without data verifying their efficacy. Devices and strategies promoted to reduce DVCs include, but are not limited to animal-detection systems, deer whistles, exclusion fences, herd reduction, intercept feeding, roadway lighting, roadside reflectors, roadway signage, and wildlife underpasses/overpasses. Of these techniques, exclusion fencing is perhaps the most frequently utilized and studied. Although the construction costs of deer-proof fencing are high, it is the most economical and effective option when deer-damage tolerance is low, as is the case in areas with high incidence of DVCs (Bashore et al. 1985, Bryant et al. 1993, Craven and Hygnstrom 1994, DeNicola et al. 2000, VerCauteren et al. 2006). Huijser et al. (2007) estimated the cost of DVC-mitigation fencing to be $3,760/km/yr with a benefit (e.g., collisions prevented as a result of the fencing) of $32,728/km/yr.

Woven-wire fencing ≥ 2.4-m in height is generally regarded as effective in preventing deer crossings (Fitzwater 1972, Falk et al. 1978, Bashore and Bellis 1982, Ward 1982, Sauer 1984, Bryant et al. 1993, Craven and Hygnstrom 1994, Seamans 2001, Kaneene et al. 2002, VerCauteren et al. 2006). However, maximum effectiveness of any fence design requires that the fence is properly constructed and maintained, located on both sides of the road, is of sufficient length to extend beyond the home ranges of deer in high-risk areas, and has some way for animals to escape from the right-of-way (Knapp et al. 2004, Huijser et al. 2007).

Successful deer exclusion also can be attained with alternative fencing designs or modifications to a reduced-height, woven-wire fence. For example, Jones and Longhurst (1958) tested a 0.6-m vertical fence with a 1.8-m outrigger angled at 25º and a 1.2-m vertical fence with a 1.2-m outrigger angled at 45º. In both cases, deer were more likely to attempt to go under the fence when the outrigger was angled towards them. Similarly, Stull (2009) found that a 1.2-m woven-wire fence with a 0.6-m 50% opaque plastic outrigger angled at 45º acted as a one-way barrier, with a higher degree of efficacy when the outrigger was angled towards the deer.

Trials conducted on captive deer allow direct observation of crossing events and control of extraneous variables, but fail to account for potential biological and ecological effects on movements of free-ranging deer. For example, a deer that is excluded from a portion of its home range may concentrate its activity in another area or circumvent the barrier, thereby potentially increasing DVCs elsewhere (Owen and Owen 1980, Isleib 1995, Clevenger et al. 2001, VerCauteren et al. 2006). Roadside trials can reveal these responses of deer to barriers, but typically using indirect measures such as carcass counts, track counts, or surveys of deer in the right-of-way (Puglisi et al. 1974, Carbaugh et al. 1975, Falk et al. 1978, Clevenger et al. 2001). To our knowledge, only Feldhamer et al. (1986) have studied deer movements in relation to DVC-mitigation fencing. However, because deer movements in this study were monitored using VHF telemetry, the investigators lacked the fine-scale data needed to quantify individual crossings or circumvention events.

The combination of widespread use of roadside fencing and the lack of knowledge surrounding how deer respond to these fences could potentially exacerbate deer-vehicle interactions. Herein, we report on a study of a prototype fencing design, compare its efficacy to a commonly used fence design, and determine their effects on home range distribution and movements of free-ranging deer.

STUDY AREA

We conducted our study on the Berry College Wildlife Refuge (BCWR) within the 11,340-ha Berry College Campus in northwestern Georgia, USA. The 1,215-ha refuge is located in the Ridge and Valley physiographic province (Hodler and Schretter 1986) with elevations ranging from 172 to 518 m. Hunting is prohibited on the refuge and deer are abundant with an estimated density of 40 deer/km^2 (J. Beardon, Georgia Department of Natural Resources, personal communication). As a result, between 12 and 24 DVCs are reported annually, although the actual number of collisions is likely higher (Berry College Police Department, unpublished data).

The campus is divided into the main campus and the mountain campus. Both campuses are characterized by buildings and facilities interspersed with pastures, woodlots, and manicured lawns. They are connected by a 4.8-km, straight, road known as Lavender Mountain Road (LMR). LMR is a two-lane blacktop road with a speed limit ranging from 40-64-km/hr. Running parallel to LMR is a power-line right-of-way known as the Viking Trail (VT). The area surrounding LMR and the VT is forested and consists of pine stands (*Pinus taeda* and *Pinus palustris*) and mixed forest dominated by oaks (*Quercus* spp.), hickories (*Carya* spp.), and pines (*Pinus* spp.). LMR and the VT are separated by a strip of mixed forest that ranges from 30-125-m wide. We selected the VT as the construction site for the DVC-mitigation fencing because of its openness, flatness, linear orientation, and similarity to a common situation where a roadway travels through a wooded area harboring an abundant deer population.

METHODS

From January to April 2009, we fitted 14 adult female deer (≥ 1.5 years old) with GPS collars. We deployed 10 Televilt Tellus®, 5H1D (Televilt/TVP Positioniong AB, Lindesberg, Sweden) and 4 Lotek 3300L (Lotek Engineering, Ontario, Canada) collars. Deer were captured using a combination of free-darting and rocket nets. When free-darting, we used 2-ml transmitter darts (Pneu-dart Inc., Williamsport, PA) to intramuscularly inject a Telazol® (Fort Dodge Animal Health, Fort Dodge, IA)/xylazine hydrochloride (Congaree Veterinary Pharmacy, Cayce, SC) (300 mg/400 mg) mixture to immobilize deer. We immobilized deer captured in rocket nets with an intramuscular Telazol®/xylazine hydrochloride (100 mg/320 mg) injection. Dosages were calculated assuming an average weight of 45 kg. During immobilization, we monitored vital signs, treated minor injuries, lubricated eyes, and blindfolded each deer. After 90 minutes, we administered a 100-mg injection (50 mg [IV] + 50 mg [IM]) of yohimbine hydrochloride (Antagonil®, Wildlife Laboratories, Fort Collins, CO) to reverse the effects of the immobilization agents. All deer were monitored until ambulatory. Animal handling procedures were approved by the University of Georgia Institutional Animal Care and Use Committee (#A2007-10127-0).

We programmed the GPS collars to collect and store GPS locations, in the form of X, Y coordinates, on their nonvolatile memory. Lotek collars were programmed to collect 48 locations/day at equal intervals throughout the study period. Due to battery-life limitations, we programmed the Televilt collars to collect 48 locations/day at equal intervals from 1 January to 30 June (immediately before and after fence construction) and 24 locations/day at equal intervals from 1 July to 31 December. For all statistical comparisons between collar brands, we filtered data to ensure equal sampling frequencies. Collars were equipped with mortality sensors, programmed to emit a double-pulse VHF beacon after 8 hours of inactivity. We monitored animals once per week using VHF-telemetry equipment to ensure they were alive and that collars were functioning properly. If a mortality signal was detected, the collar was retrieved immediately using radio telemetry. At the end of the study, activation of a remote-release mechanism caused functioning collars to fall from the animal. The release mechanisms failed on 9 collars, so we retrieved these collars via lethal means (gunshot). Upon collar retrieval, we used the Televilt Tellus TPM Project Manager software (Televilt/TVP Positioning AB, Lindesberg, Sweden) and the Lotek GPS 3000 Host Application (Lotek Wireless Inc., Newmarket, Ontario, Canada) to download data. To decrease the probability of erroneous points in the datasets, any points representing non-fixes, impossible locations, and locations with dilution of precision values > 6, were filtered out. After data censoring, we imported GPS fixes for each deer into ArcMap 9.3 (Environmental Systems Research Institute, Inc., Redlands, CA) and projected them in Universal Transverse Mercator (UTM) North American Datum (NAD) 1983 Zone 17 North (meters).

Construction of the 3.2-km fence treatment along the VT began on 18 May 2009 and was completed on 10 June 2009. The fence included a 1.6-km section of 2.4-m Solidlock® Fixed Knot 12.5g Game Fence (Bekaert Corporation, Marietta, GA) to which was attached a 1.6-km section of the outrigger fence. The outrigger fence consisted of 1.2-m Solidlock® Fixed Knot 12.5g Game Fence (Bekaert Corporation, Marietta, GA) with 0.6-m long outriggers (Hearne Steel Company, Hearne, TX) attached to the top, angled at 45º away from the road. Five strands of white Bayco® Finish Line wire (Ag-liner, Inc., Mars, PA) were threaded into pre-cut slots spaced 12.5-cm apart on the outriggers. Total construction costs were $9,356/km ($9.36/m) and $7,370/km ($7.37/m) for the 2.4-m and outrigger fences, respectively.

Deer were assigned to outrigger (n=4) or 2.4-m (n=4) treatment groups according to the fence that their home range overlapped. These groups were independent, as no deer encountered both the outrigger and 2.4-m fences. A control group (n=6) was composed of deer that encountered neither fence. We structured the datasets into 3 time blocks based on when the fence was constructed. The pre-treatment period lasted from the time deer were collared until the day before fence construction was initiated. The first post-treatment period (post-treatment 1), which was designed to assess the immediate effects of the fencing treatments on deer home ranges, lasted from the day after fence construction was completed until 11 September 2009. The second post-treatment period (post-treatment 2) lasted from 12 September 2009 until collar recovery. Sample sizes for the third treatment period were reduced to 3 and 2 for the outrigger and 2.4-m treatments, respectively, due to premature collar failure (n=2) and natural mortality (n=1).

We selected only top-hour fixes to estimate home ranges and core areas using the Adehabitat Package (Calenge 2006) for the R software version 2.10.1 (R Development Core Team 2009). We calculated home ranges and core areas, for each deer and treatment period, using 90% and 50% adaptive-local convex hull (*a*-LoCoH) methods, respectively. We used the maximum distance between any 2 points in the data set as the starting point for *a* (Getz et al. 2007), then examined plots of the area covered by a particular utilization distribution against a wide range of values of *a*. When the plot of the estimated area leveled off, we assumed all spurious holes were covered and selected this value of *a* (Getz and Wilmers 2004, Ryan et al. 2006).

We used "Mean Center" in ArcToolbox (Environmental Research Systems Institute, Inc., Redlands, CA) to calculate the mean center of fixes for each deer during each treatment period. We then measured the distance between the mean of center points for each deer from pre-treatment to post-treatment 1 and from post-treatment 1 to post-treatment 2.

To determine barrier efficacy, we quantified crossing events by scrutinizing the daily movement paths of each deer before and after fence construction. We used several criteria to differentiate actual crossing events from spurious (i.e., the result of GPS-location error) ones. When a deer's movement path crossed the fence, we classified the event as a successful crossing as follows: (1) for the 1-hr sampling frequency, ≥ 2 sequential locations had to occur on the opposite side of the fence, farther than 20 m away from the fence; (2) for the 30-min sampling frequency, ≥ 3 sequential locations had to occur on the opposite side of the fence, farther than 20 m away. An event was classified as circumvention only when a distinct movement path going around either end of the fence was observed. We recorded the date and time of each crossing and circumvention event for both fence treatments and recorded the direction of crossing (i.e., outrigger toward vs. away) for the outrigger fence. To account for the unevenness in pre- versus post-construction periods, we calculated the average number of crossing events per sample day (crossings/day) for each deer before and after fence construction by dividing the total number of crossing events by the number of sample days in each treatment period. We used repeated measures ANOVA to compare the efficacies of the outrigger toward, outrigger away and the 2.4-m treatments.

We also analyzed the data to determine the distribution of each deer's point locations around the fences, for each treatment period. We used "Multiple Ring Buffer" in ArcToolbox (Environmental Research Systems Institute, Inc., Redlands, CA) to create linear buffer regions, 50-m in width, starting directly adjacent to each fence treatment and radiating out to 650-m, on either side of the fence. We then joined these buffer polygons to the point layer of each deer for each treatment period, and divided the sum of points occurring in each buffer region by the total number of points contained in the entire multiple-ring buffer to calculate the proportion of points occurring in each buffer region.

RESULTS

Deer encountering the 2.4-m treatment (n=4) crossed the fence area 124 times before fence construction, and only 2 times after fence construction (98% reduction) (Table 1). One deer (#20) was responsible for both of the documented 2.4-m fence crossings. She crossed the barrier, remained on the opposite side for 2-hrs, then crossed again. On average, deer crossed the 2.4-m fence 0.337 times/day (Range 0.09 – 0.51, SE = 0.09) before construction and 0.002 times/day (Range 0 – 0.002, SE = 0.002) after construction (Table 1).

Outrigger efficacy did not differ when angled toward (outrigger toward) versus away (outrigger away) from the deer ($F_{1,6}$ = 1.46, P = 0.27); therefore, we pooled outrigger crossing data for comparison with the 2.4-m treatment group. Deer encountering the outrigger treatment (n=4) crossed the fence area 228 times before, and 22 times after fence construction (90% reduction) (Table 1). On average, deer crossed the outrigger fence 1.02 times/day (Range 0.54 – 1.50, SE = 0.26) and 0.05 times/day (Range 0.005 – 0.155, SE = 0.035) before versus after construction, respectively (Table 1).

The average number of crossings/day for both treatment groups decreased post-treatment ($F_{1,6}$ = 20.10, P = 0.004), but the 2.4-m treatment was more effective than the outrigger treatment ($F_{1,6}$ = 7.96, P = 0.03).

Post-fence construction, we documented 50 and 54 circumvention events for the 2.4-m and outrigger treatments, respectively. One deer (#20), whose home range extended beyond the fence during post-treatment 2 was responsible for all of the 2.4-m circumvention events (Figure 1). Three of 4 deer (#s 1, 10, and 19) were responsible for the 54 recorded outrigger circumvention events. Twenty-six (48%) occurred during post-treatment 1 and 28 (52%) occurred during post-treatment 2. All 3 of these deer had post-treatment home ranges that extended beyond the end of the fence (Figure 2).

The deer whose post-construction home range did not encompass the end of the outrigger fence (#16) accounted for 10 (45%) of the 22 total outrigger crossing events. Eight of these crossings occurred within a 1.5-month period following fence construction, and 2 occurred on 22 October 2009. On 8 December 2009, a flood event downed a 50-m section of the outrigger fence. On 12 December 2009, Deer #16 began breaching the fence through this gap and continued to do so, almost daily, until her collar was recovered on 4 February 2010 (Figure 3).

Home range and core area sizes decreased from pre-treatment to post-treatment 1, and increased again during post-treatment 2. There were no differences in home range or core area sizes among 2.4-m, outrigger, or control groups (Table 2). There was no effect of treatment or treatment period on the mean of center points for each deer (Table 3).

Although deer encountering the 2.4-m fence spent the majority of their time on one side of the fence area, there were a small proportion of points, for each deer, that did occur on the opposite side prior to fence construction (Figure 4). However, post-construction the proportion of points on the opposite side declined to nearly 0 for all deer except #20, which accessed the other side by circumventing the fence during post-treatment 2 (Figure 4). Two deer (#s 12 and 13) encountering the 2.4-m treatment showed an increase in the proportion of points in the 50-m buffer region after fence construction (Figure 4). Relative to the 2.4-m deer, the distributions of deer encountering the outrigger fence were more centered along the fence prior to construction (Figure 5). Although there was a decrease in the proportion of points on one side of the fence after construction, the decline wasn't notable in 3 (#s 1, 10, and 19) of 4 outrigger deer, because they frequently circumvented the barrier (Figure 5). Three (#s 1, 16, and 19) of 4 deer encountering the outrigger treatment showed an increase in the proportion of points in the 50-m buffer region after fence construction (Figure 5).

DISCUSSION

Our data on the efficacy of the 2.4-m woven-wire fence agree with previous reports that fencing ≥ 2.4-m in height is effective at preventing deer crossings (Fitzwater 1972, Falk et al. 1978, Bashore and Bellis 1982, Ward 1982, Sauer 1984, Bryant et al. 1993, Craven and Hygnstrom 1994, Seamans 2001, Kaneene et al. 2002, VerCauteren et al. 2006).

In addition to the 90% reduction in crossings, we made multiple observations that suggest the outrigger fence was an effective deterrent. We observed multiple instances of deer circumventing to the outrigger-toward side of the fence and repeatedly traveling its length for one to several days, apparently trying to regain access to the other side (Figure 6). Once the deer circumvented back, no similar "pacing" behavior was observed. We also noticed the appearance of a 0.6-m wide deer path along the outrigger-toward side of the fence shortly after its construction, suggesting that many deer exhibited this same behavior. Because no similar path was seen along the 2.4-m fence, we believe that this behavior was elicited only by the outrigger fence. Stull (2009) also observed similar behavior in captive deer when they approached the outrigger-toward side of this fence design. Finally, Deer #16, which was the only deer encountering the outrigger treatment that didn't circumvent, began exploiting the gap left by the December 2009 flood on a daily basis shortly after it was knocked down (Figure 3). Prior to this time, this deer was essentially excluded from the opposite side of the outrigger fence.

Unlike Stull (2009), we found no difference in the efficacy of the outrigger fence in the outrigger-toward versus away direction. Because the outrigger fence was located 30-125 m from the road, and due to the presence of cover between deer and the road, we suspect that deer were not pressured to cross the fence when they were positioned between it and the road. In most situations where DVC-mitigation fencing is used, it is placed on both sides of the road and closer to the roadway. Deer trapped between the road and fences in those situations may be more motivated to cross than in our study.

For those deer whose home ranges did not encompass the fence end, both fence types were effective. However, 3 of 4 deer encountering the outrigger fence, and 1 of 4 deer encountering the 2.4-m fence had home ranges that came close to or encompassed the end of the fence (Figures 1 and 2). As a result, the deer maintained use of their entire home range. Additionally, our finding that 5 of 8 deer showed an increase in the proportion of their point locations just adjacent to the fence highlights the danger of implementing DVC-mitigation fencing without structures that allow safe crossing or escape from the roadway (Figures 4 and 5). This finding is in agreement with those of Ludwig and Bremicker (1981) who reported that barrier efficacy is reduced when fences are of insufficient length, as deer will circumvent the endings. In situations, such as this, where fencing is not of sufficient length to extend beyond home ranges of deer in high-risk areas, crossings are concentrated at the end of the fence, thereby moving or exacerbating existing hot-spots (Knapp et al. 2004, Huijser et al. 2007).

Across groups, mean pre-treatment home range size was 44 ha and the mean long axis of home ranges was 1,164 m in length. However, Rogers (1996) found that home ranges of adult does in northwestern Georgia were, on average, 6 times larger than what we observed. If long axis length increases proportionally to home range size, up to 7 km of fencing would be necessary to prevent circumvention by these deer. Furthermore, because home ranges of adult bucks are typically larger than those of adult does, extension of fences beyond the home ranges of all deer in a high-risk area is difficult, if not impossible. Thus, where DVC-mitigation fencing is used as a hot-spot treatment, fences likely should end at natural barriers to deer movements (i.e., heavy development or bodies of water), or the fence endings must incorporate some means (e.g., wildlife overpasses or underpasses) of facilitating crossings by deer so as to avoid vehicular traffic.

Less substantial fences, such as the outrigger fence, are typically more effective when motivation to cross is low (Goddard et al. 2001). In our study, motivation to cross remained low because deer maintained use of their entire home range via circumvention. The incorporation of devices such as highway overpasses or underpasses into fence designs allows deer full use of their home range while keeping them out of the roadway. This suggests that the outrigger fence design may be effective in situations where crossings structures are in place.

Both fencing designs were of sufficient efficacy to allow examination of their effects on deer home ranges and movements. However, if our fence treatments were of sufficient length to prevent circumvention, more crossings may have occurred. Therefore, we suggest that further testing be done to assess the performance of longer stretches of outrigger fences with and without crossing structures (e.g., wildlife overpasses or underpasses) incorporated into them.

MANAGEMENT IMPLICATIONS

Our results emphasize that deer behavior is equally important as barrier efficacy when attempting to mitigate DVCs. Even fences that are highly effective may relocate, exacerbate, or fail to reduce DVCs if they are of insufficient length. Alternately, less substantial fences may be adequate if they extend beyond deer home ranges and have crossing structures incorporated into their design. Although these structures often are expensive, they may become economically feasible when combined with a less expensive fence such as the outrigger design tested herein. Finally, we recommend the use of localized data on deer home range sizes to determine the minimum length of fencing needed to prevent circumvention in high-risk areas.

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LITERATURE CITED

Bashore, T.L., and E.D. Bellis. 1982. Deer on Pennsylvania airfields: problems and means of control. Wildlife Society Bulletin 10:386-388.

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

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.

Bryant, L.D., J. Thomas, and M. Rowland. 1993. Techniques to construct New Zealand elk-proof fence. La Grande (OR): USDA Forest Service Pacific Northwest Research Station. General Technical Report No. PNW-GTR-313.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modeling. 197:516-519.

Carbaugh, B., J.P. Vaughan, E.D. Bellis, and H.B. 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.

Craven, S.R., and S.E. Hygnstrom. 1994. Deer. Pages D25-40 *in* S.E. Hygnstrom, R.M. Timm, and G.E. Larson, editors. Prevention and control of wildlife damage. University of Nebraska Cooperative Extension, Lincoln, Nebraska, USA.

DeNicola, A.J., K.C. VerCauteren, P.D. Curtis, and S.E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments. Cornell University Cooperative Extension, Ithaca, New York, USA.

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

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

Fitzwater, W. D. 1972. Barrier fencing in wildlife management. Proceedings of the Vertebrate Pest Control Conference 5:49–55.

Getz, W.M., S. Fortmann-Roe, P.C. Cross, A.J. Lyons, S.J. Ryan, and C.C. Wilmers. 2007. LoCoH: nonparametric kernel methods for constructing home ranges and utilization distributions. PLoS ONE 2:e207.

Getz, W.M., and C.C. Wilmers. 2004. A local nearest-neighbor convex-hull construction of home ranges and utilization distributions. Ecography 27:489-505.

Goddard, P.J., R.W. Summers, A.J. MacDonald, C. Murray, and A.R. Fawcett. 2001. Behavioral responses of red deer to fences of five different designs. Applied Animal Behavioural Science 73:289-298.

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, USA.

Hodler, T.W., and H.A. Schretter. 1986. The atlas of Georgia. University of Georgia, Athens, USA.

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. 2008. <http:// www.iii.org/>. Accessed December 3, 2008.

Isleib, J. 1995. Deer exclusion efforts to reduce crop damage in Michigan and northeast Wisconsin. Great Plains Wildlife Damage Control Workshop 12:63-69.

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

Kaneene, J.B., C.S. Bruning-Fann, L.M. Granger, R. Miller, and B.A. Porter-Spalding. 2002. Environmental and farm management associated with tuberculosis on cattle farms in northeastern Michigan. Journal of the American Veterinary Medical Association 221:837-842.

Knapp, K.K., X. Yi, T. Oakasa, W. Thimm, E. Hudson, and C. Rathmann. 2004. Deer-vehicle crash countermeasure toolbox: a decision and choice resource. Midwest Regional University Transportation Center, Madison, Wisconsin, USA.

Ludwig, J. and T. Bremicker. 1981. Evaluation of 2.4-meter fences and one-way gates for reducing deer-vehicle collisions. Minnesota Wildlife Resources Quarterly 41:77-88.

Owen, M., and D. Owen. 1980. The fences of death. African Wildlife 35:25-27.

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. 2009. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rogers, C.L. 1996. Utilization of cedar glades by white-tailed deer at Chickamauga Battlefield Park. M.S. Thesis, University of Georgia, Athens, USA.

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

Ryan, S.J., C. Knechtel, and W.M. Getz. 2006. Range and habitat selection of African buffalo in South Africa. Journal of Wildlife Management 70:764-776.

Sauer, P. R. 1984. Physical characteristics. Pages 73-90 *in* L.K. Halls, editor. White-tailed deer: ecology and management. Stackpole Books, Harrisburg, Pennsylvania, USA.

Seamans, T.W. 2001. A review of deer control devices intended for use on airports. Bird Strike Committee Proceedings 21.

State Farm Insurance Company. 2009. <http://www.statefarm.com/>. Accessed October 7, 2009.

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

VerCauteren K.C., M.J. Lavelle, and S. Hygnstrom. 2006. Fences and deer-damage management: a review of designs and efficacy. Wildlife Society Bulletin 34:191-200.

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

Table 2.1 Total number of fence crossings and average number of fence crossings per day, before and after fence construction, by deer encountering a 2.4-m woven-wire fence (n=4) and an outrigger (n=4) fence on Berry College Wildlife Refuge in northwestern GA.

	Fence crossings			Crossings/day		
Treatment	**Pre**	**Post**	**% Reduction**	**Pre (SE)**	**Post (SE)**	**% Reduction (SE)**
Outrigger toward	110	11	90	0.327 (0.086)	0.037 (0.020)	91 (4)
Outrigger away	118	11	91	0.533 (0.142)	0.045 (0.025)	90 (6)
Outrigger pooled	228	22	90	1.018 (0.257)	0.053 (0.035)	92 (6)
2.4 m	124	2	98	0.337 (0.091)	0.002 (0.002)	98 (2)

Table 2.2 Mean 90% home range and 50% core area size, before and after fence construction, for deer encountering a 2.4-m woven-wire fence (n=4), outrigger fence (n=4), and no fence (controls) (n=6) on Berry College Wildlife Refuge in northwestern GA.

	Pre-treatment		**Post-treatment 1**		**Post-treatment 2**	
	N	**Mean (SE)**	**N**	**Mean (SE)**	**N**	**Mean (SE)**
90% *a*-LoCoH home range (ha)						
2.4 m	4	62 (7)	4	29 (2)	2	82 (62)
Outrigger	4	41 (14)	4	24 (5)	3	46 (7)
Control	6	34 (7)	6	23 (3)	5	51 (9)
50% *a*-LoCoH core area (ha)						
2.4 m	4	17 (1)	4	8 (0.3)	2	28 (21)
Outrigger	4	12 (4)	4	6 (1)	3	13 (2)
Control	6	9 (2)	6	6(0.7)	5	11 (2)

Table 2.3 Mean distance between the mean center of all point locations, from pre-treatment to post-treatment 1 and from post-treatment 1 to post-treatment 2, for deer encountering a 2.4-m woven-wire fence (n=4), outrigger fence (n=4), and no fence (controls) (n=6) on Berry College Wildlife Refuge in northwestern GA.

	Pre- to Post-1		Post-1 to Post-2	
	N	**Mean (SE)**	**N**	**Mean (SE)**
Distance between mean center of points (m)				
2.4-m	4	181.3 (62.1)	2	180.0 (139.0)
Outrigger	4	317.8 (152.0)	3	209.3 (68.7)
Control	6	153.0 (28.1)	5	281.6 (64.2)

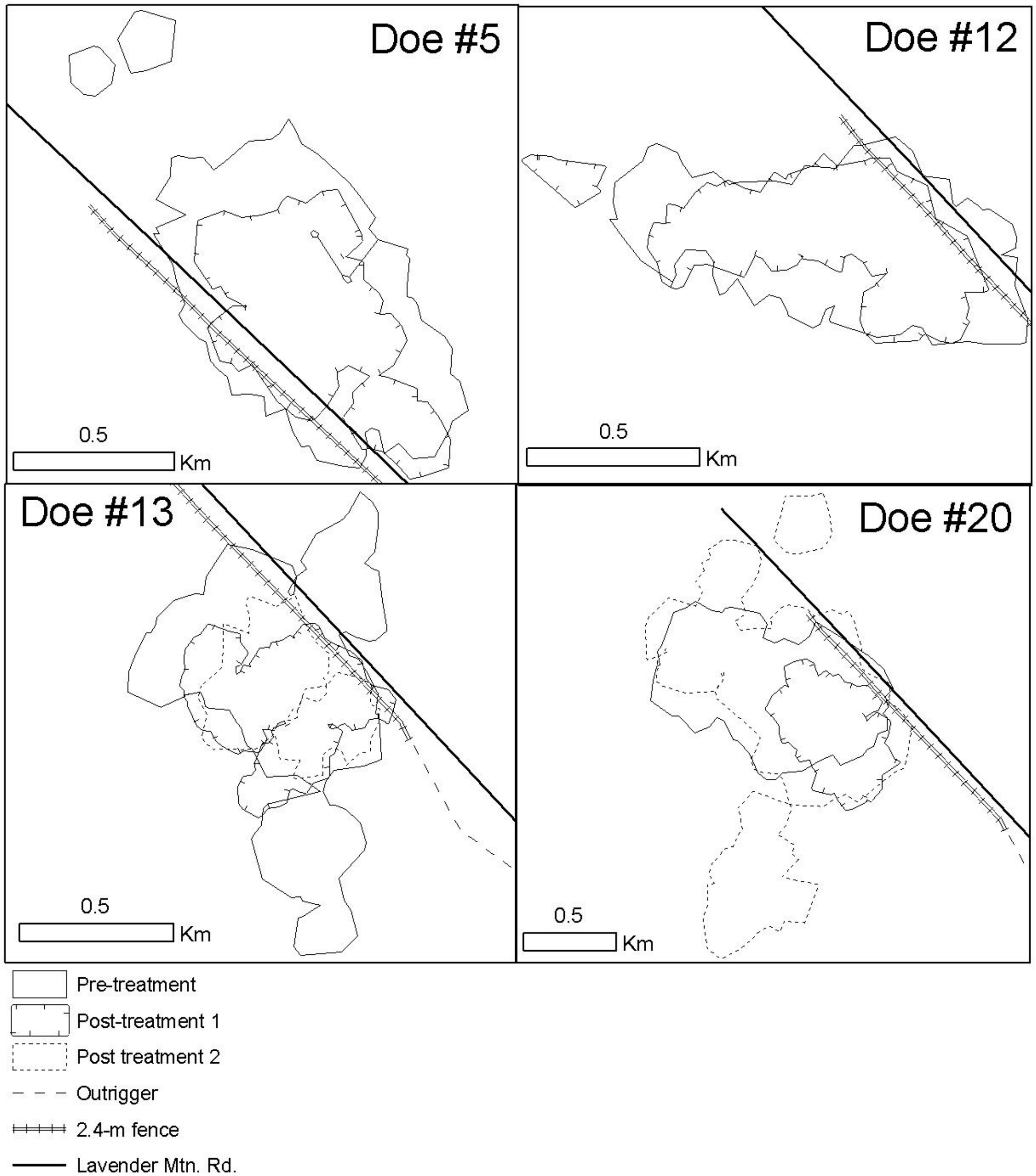

Figure 2.1 90% home ranges and 50% core areas, for deer encountering a 2.4-m woven-wire fence on Berry College Wildlife Refuge in northwestern GA. Pre-treatment was from the time the deer was collared until fence construction began on 17 May 2009, post-treatment 1 was from the time fence construction was completed on 10 June 2009 until 11 September 2009, and post-treatment 2 was from 12 September 2009 until collar recovery in early 2010.

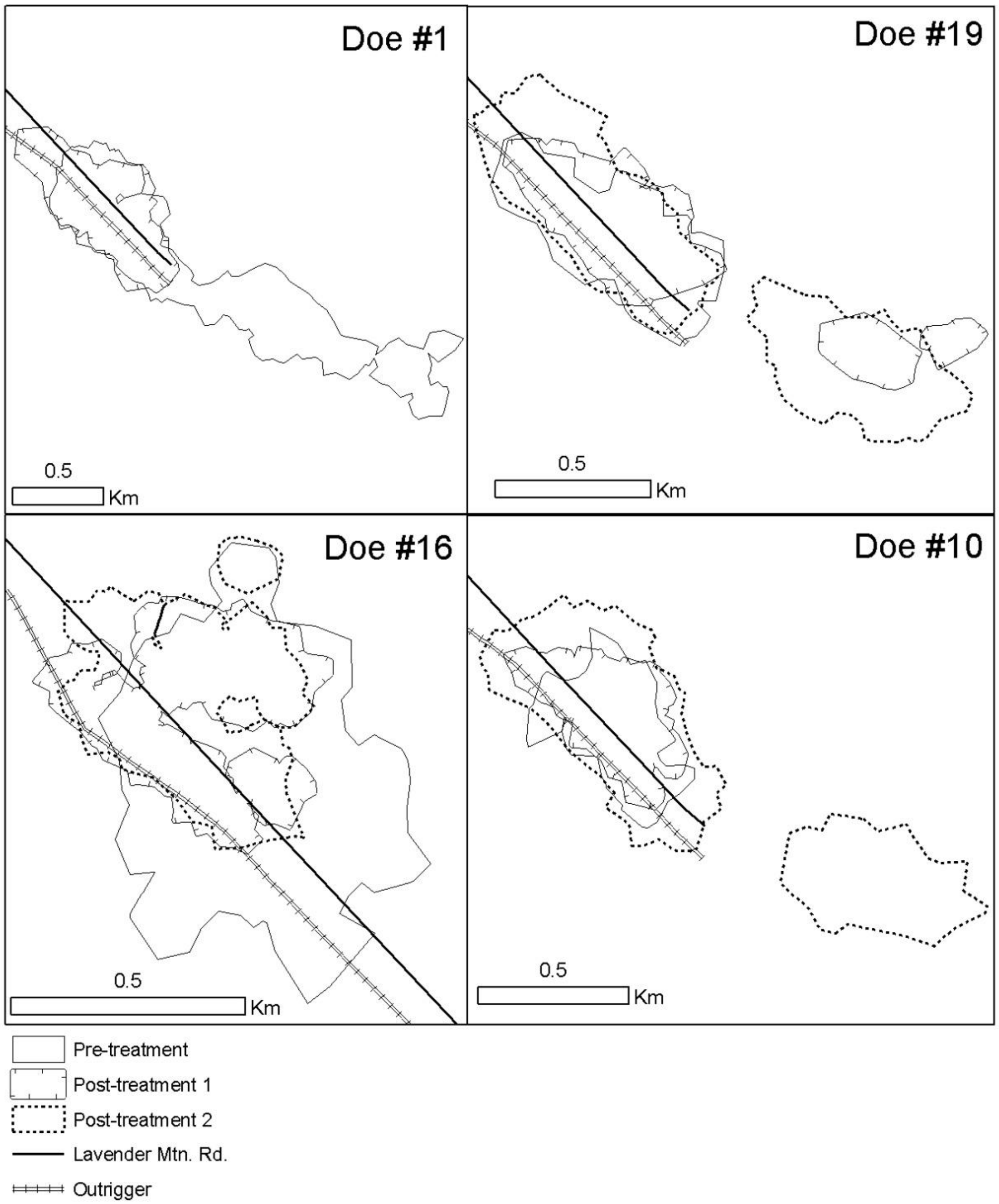

Figure 2.2 90% home ranges and 50% core areas, for deer encountering an outrigger fence on Berry College Wildlife Refuge in northwestern GA. Pre-treatment was from the time the deer was collared until fence construction began on 17 May 2009, post-treatment 1 was from the time fence construction was completed on 10 June 2009 until 11 September 2009, and post-treatment 2 was from 12 September 2009 until collar recovery in early 2010.

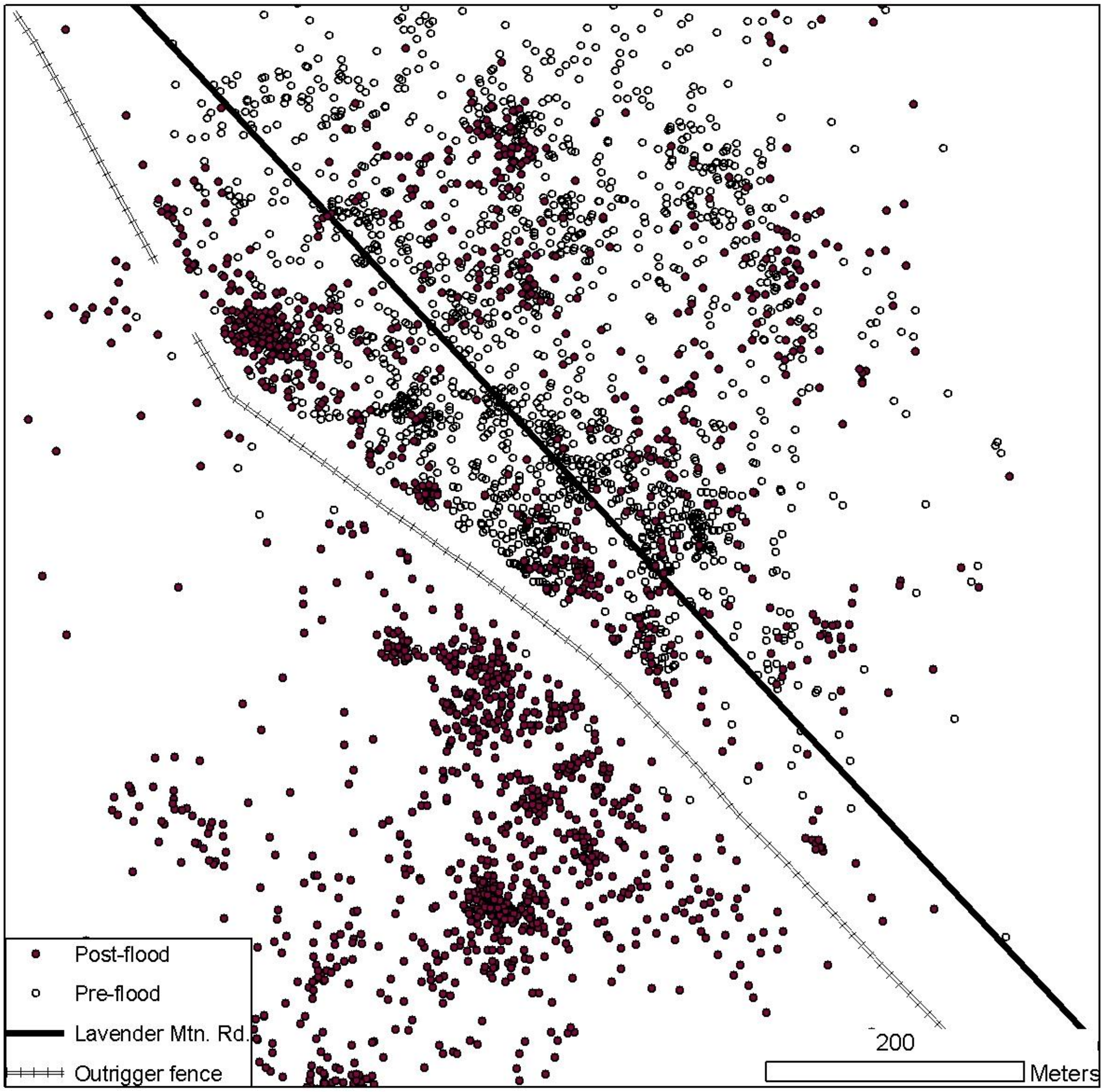

Figure 2.3 GPS point locations for Doe #16 before and after a flood event on 8 December 2009 that left a 50-m gap in an outrigger fence on Berry College Wildlife Refuge in northwestern GA. Points within a 20-m buffer on either side of the fence are not included.

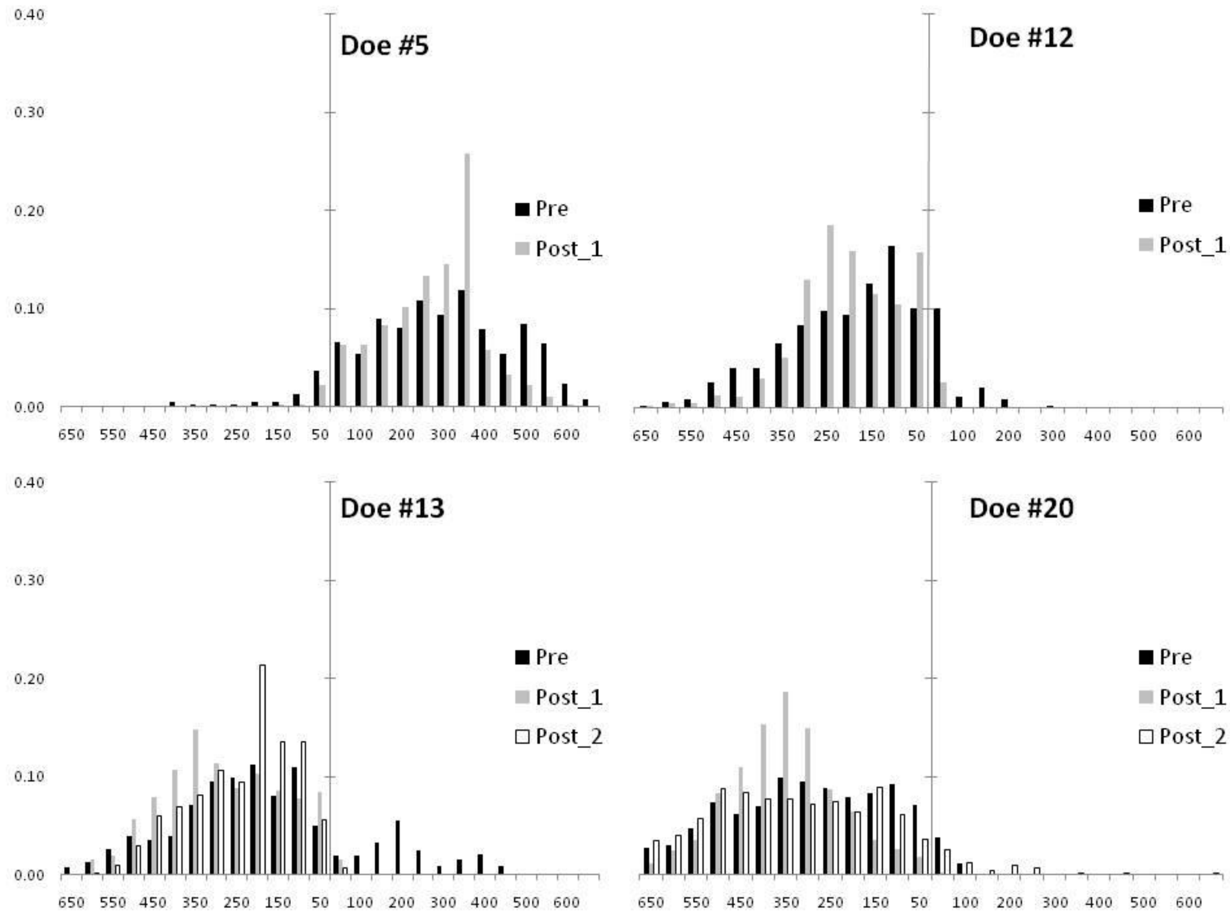

Figure 2.4 Distributions of point locations around a 2.4-m woven-wire fence on Berry College Wildlife Refuge in northwestern GA. Pre-treatment was from the time the deer was collared until fence construction began on 17 May 2009, post-treatment 1 was from the time fence construction was completed on 10 June 2009 until 11 September 2009, and post-treatment 2 was from 12 September 2009 until collar recovery in early 2010. The fence is represented by the vertical axis with the southwestern side to the left of it.

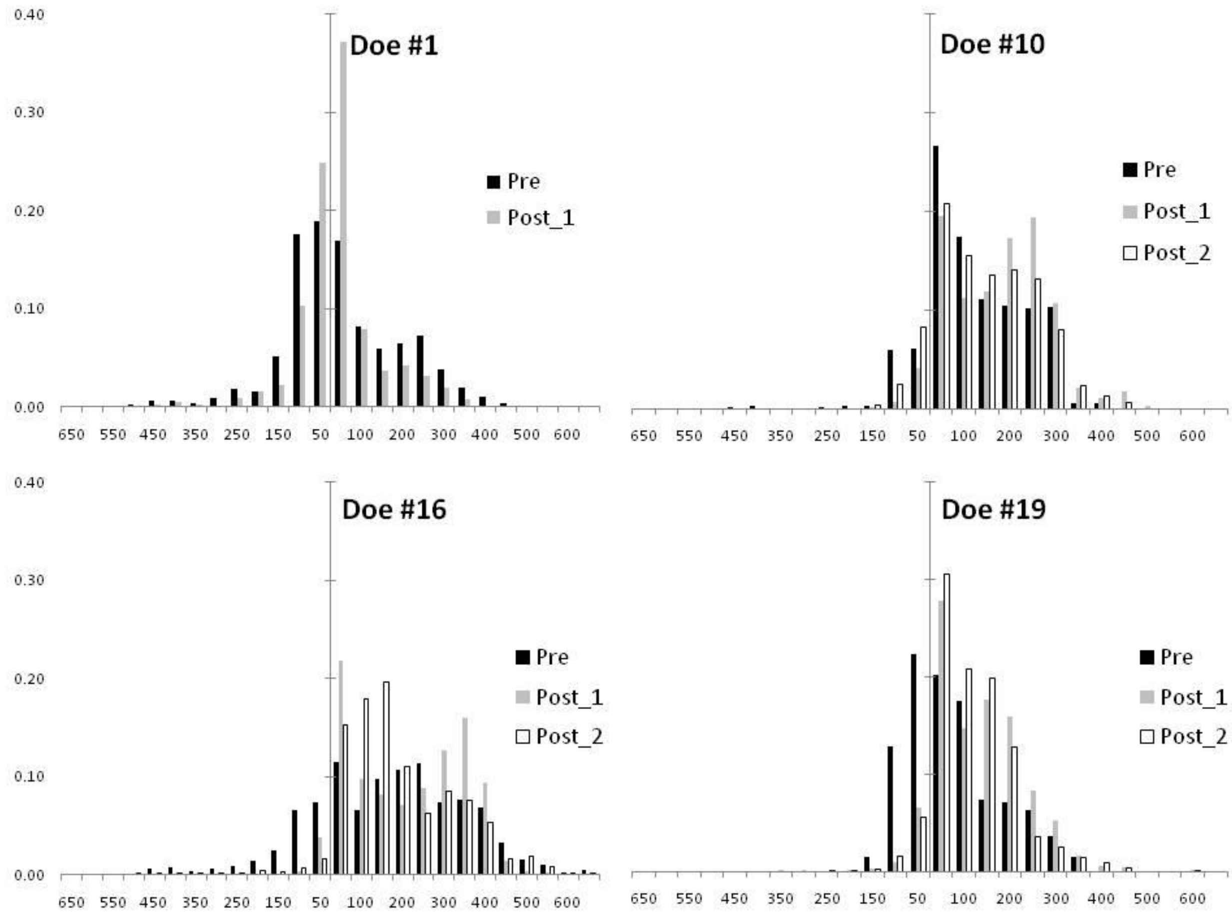

Figure 2.5 Distributions of point locations around an outrigger fence on Berry College Wildlife Refuge in northwestern GA. Pre-treatment was from the time the deer was collared until fence construction began on 17 May 2009, post-treatment 1 was from the time fence construction was completed on 10 June 2009 until 11 September 2009, and post-treatment 2 was from 12 September 2009 until collar recovery in early 2010. The fence is represented by the vertical axis with the southwestern side (outrigger toward) to the left of it.

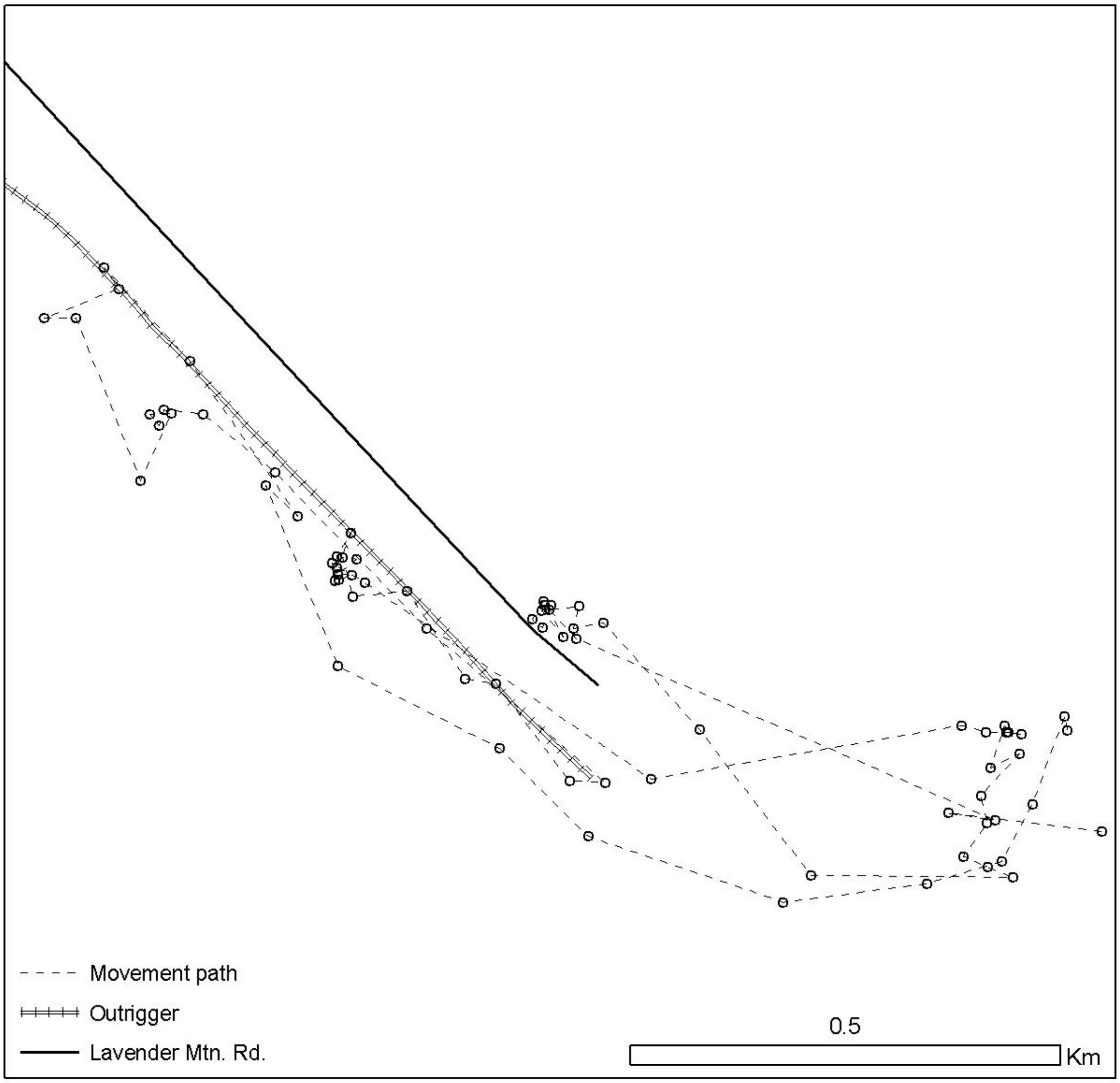

Figure 2.6 A 48-hr movement path showing Doe #19 circumventing an outrigger fence twice on Berry College Wildlife refuge in northwestern GA.

CHAPTER 3

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Collisions between white-tailed deer and vehicles have been one of the most prevalent and costly types of wildlife-human conflicts for several decades. Despite near extirpation at the turn of the 20th century, deer herds across the United States reached what were likely all-time highs just prior to the turn of the 21st century. Herd sizes in many states are now being brought back to normal levels due to an improved understanding of deer management. However, the concomitant occurrence of increasing human populations and vehicular traffic, increasingly fragmented forests, and decreased hunting access in urban and suburban areas likely means that DVCs will remain problematic.

As a result, state transportation departments are increasingly using deer-proof fencing to exclude deer from roadways. However, traditional deer-proof fencing is often too expensive for use over long distances and these fences can entrap deer in the roadway, thereby exacerbating DVCs. Therefore, I evaluated the efficacy of a traditional deer-proof high fence and a more cost-effective outrigger fence that was previously shown to act as a one-way barrier to deer. In addition, I examined the effects of these fences on deer movements and home range distributions using high-frequency sampling rates with GPS collars.

Interestingly, my results suggest that less-substantial fences, such as the outrigger fence, may be as effective as traditional high fences at preventing deer crossings. However, I found that 3 of 4 deer encountering the outrigger fence continued to access their entire home range after fence construction, via circumventing the end. Because fence-crossing motivation likely is positively correlated with the degree to which roadside fencing excludes deer from their former home range, motivation to cross the fence was probably low for these deer. The only deer that encountered the outrigger fence but did not circumvent it was responsible for the majority of outrigger-fence crossings. These findings suggest that less-substantial, more-economical fences may exclude deer from roadways if they are allowed access to their entire home range by some mechanism. This access can be allowed using wildlife overpasses or underpasses designed to allow deer to cross the roadway safely.

Our results emphasize that deer behavior is equally important as barrier efficacy when attempting to mitigate DVCs. Even fences that are highly effective may relocate, exacerbate, or fail to reduce DVCs if they are of insufficient length. Alternately, less substantial fences may be adequate if they extend beyond deer home ranges and have crossing structures incorporated into their design. Although these structures often are expensive, they may become economically feasible when combined with a less expensive fence such as the outrigger design tested herein. Finally, we recommend the use of localized data on deer home range sizes to determine the minimum length of fencing needed to prevent circumvention in high-risk areas.

Because my study focused on the efficacy and effects of these fencing types on adult does on one study site, extension of my study results to adult bucks or different sites must be done with caution. Home ranges of adult bucks are typically much larger than those of adult does, and extension of fencing beyond the ends of their home ranges would be even more difficult. Likewise, others have reported much larger home ranges for adult does than those of the adult does in my study.

A great number of studies have addressed the problem of DVCs. The authors of these studies have acknowledged the need to understand the effects of roadway fencing on deer, yet my study is the first to examine these interactions using GPS collars. We urge that similar research be done to assess this interaction on different geographic areas and in a variety of situations.

APPENDIX A

HOME RANGES OF TREATMENT AND CONTROL DEER AT BERRY COLLEGE, FLOYD COUNTY, GEORGIA BEFORE AND AFTER FENCE CONSTRUCTION

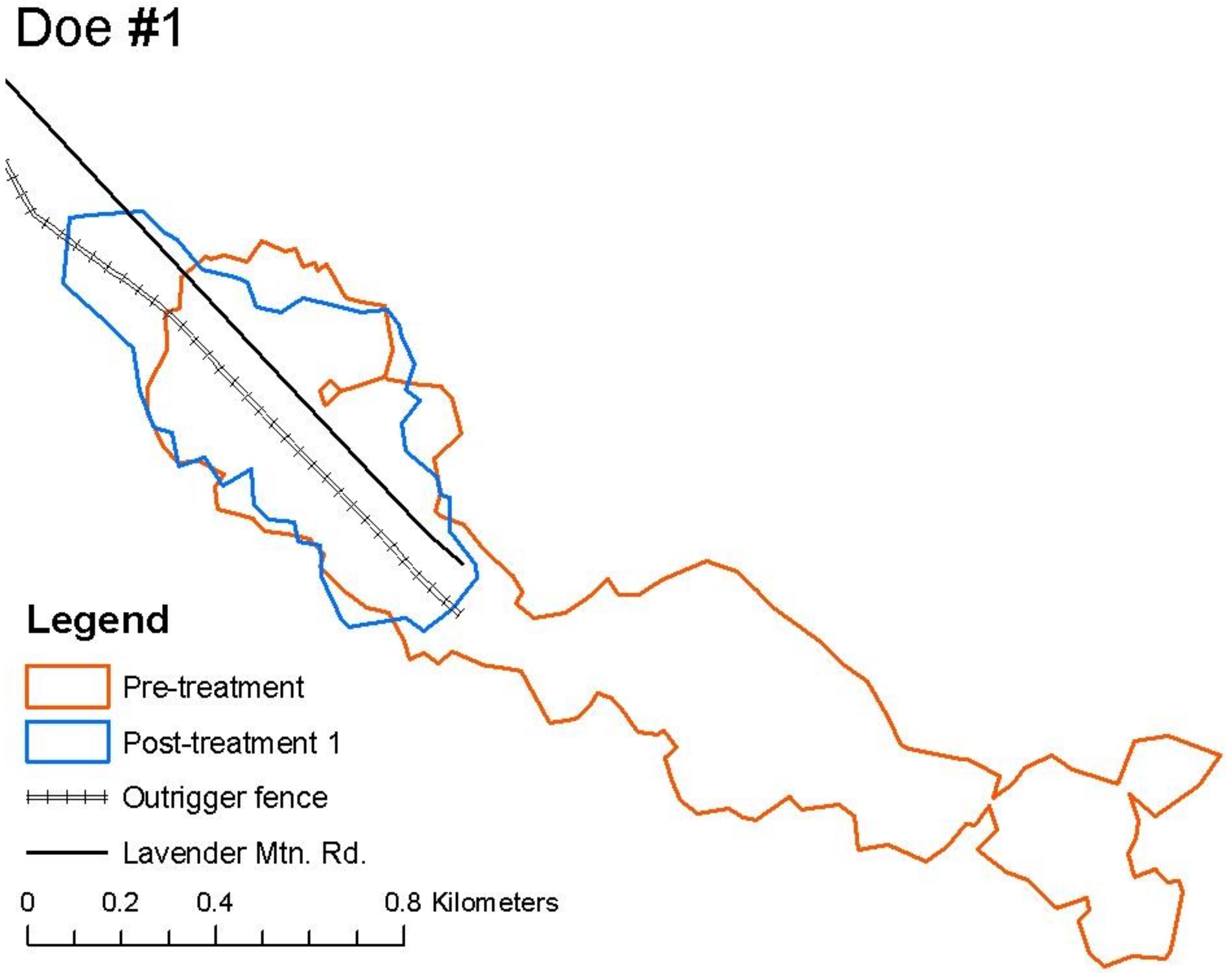

Figure 1. 90% *a*-LoCoH home ranges of outrigger treatment Doe #1 during pre-treatment and post-treatment 1 periods at Berry College Wildlife Refuge.

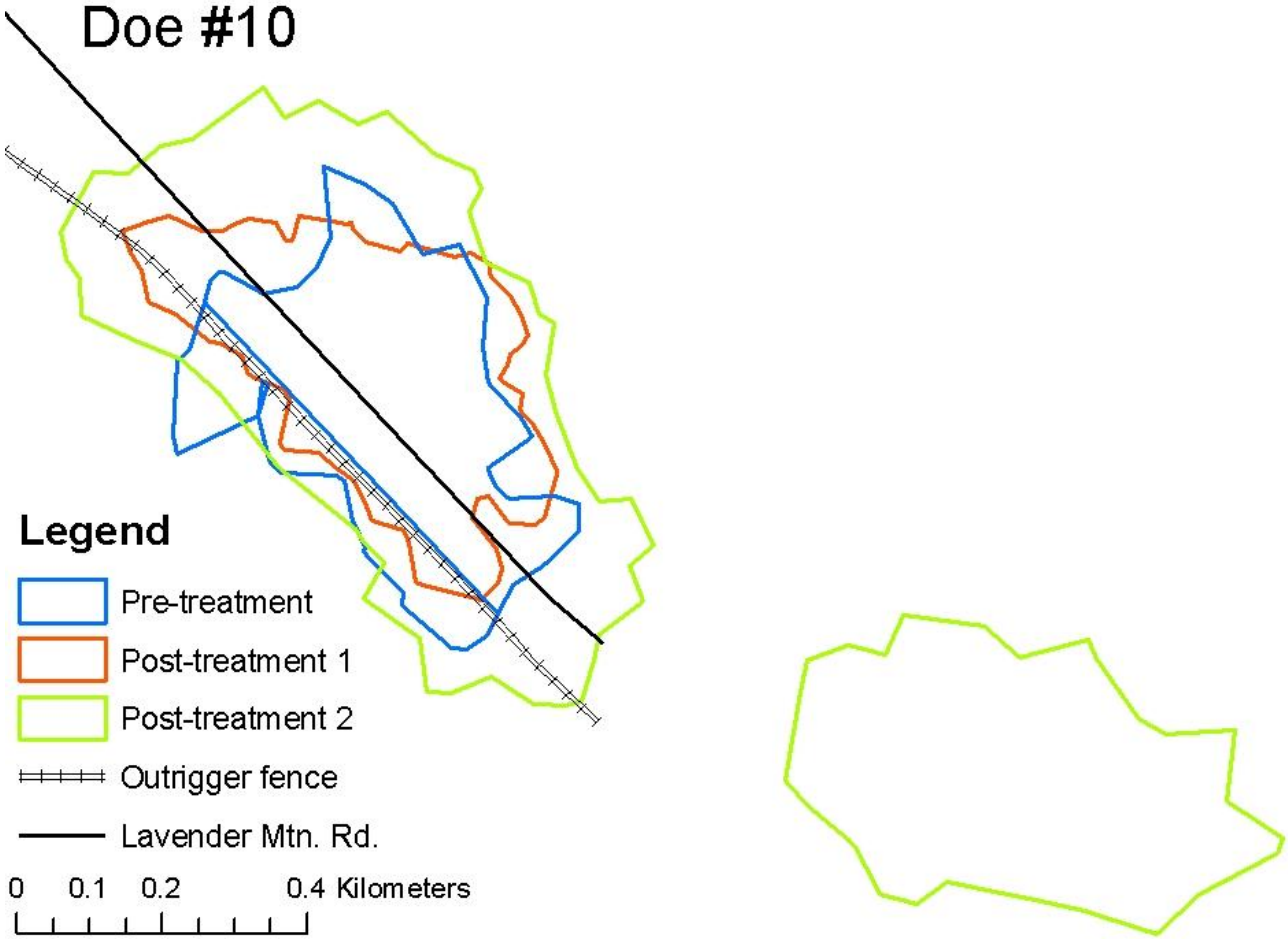

Figure 2. 90% *a*-LoCoH home ranges of outrigger treatment Doe #10 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

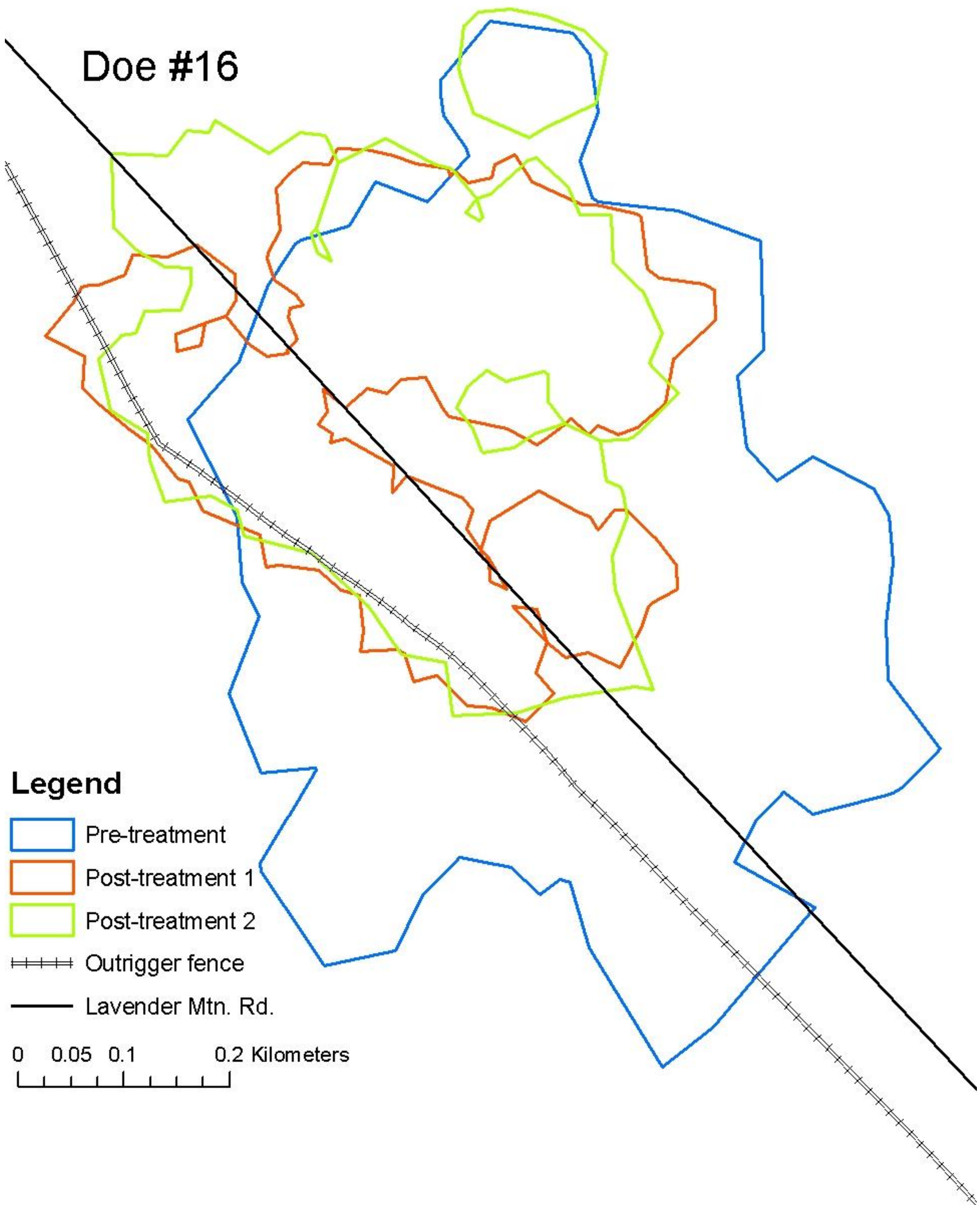

Figure 3. 90% *a*-LoCoH home ranges of outrigger treatment Doe #16 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

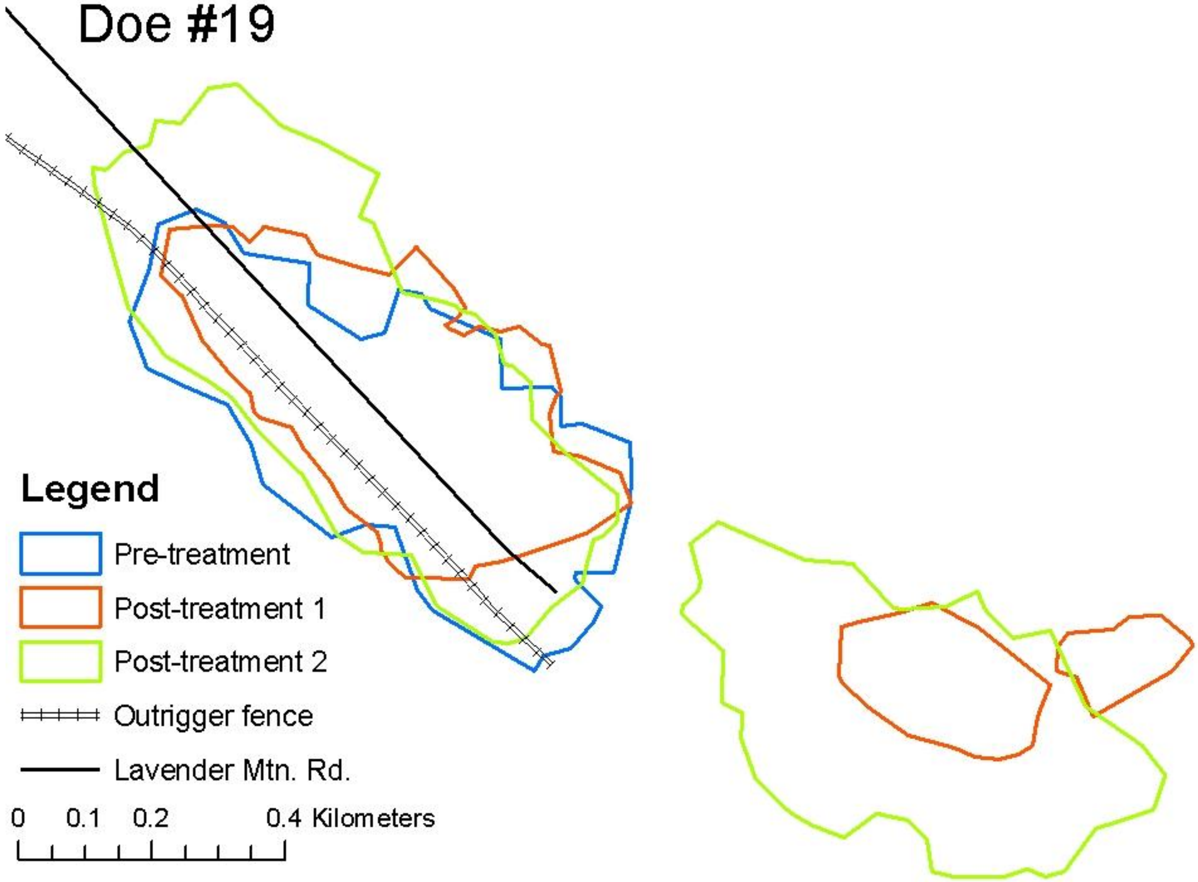

Figure 4. 90% *a*-LoCoH home ranges of outrigger treatment Doe #19 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

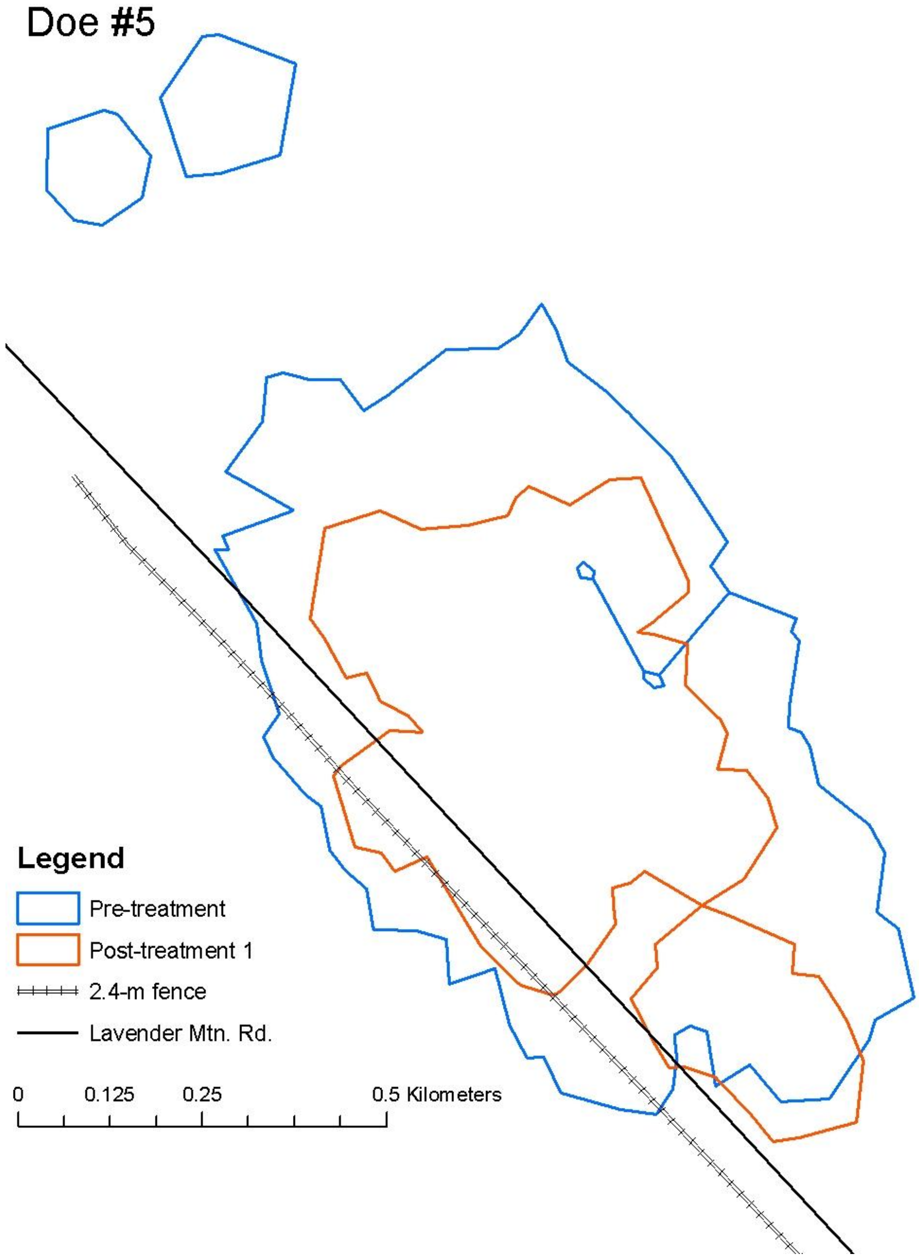

Figure 5. 90% *a*-LoCoH home ranges of 2.4-m treatment Doe #5 during pre-treatment and post-treatment 1 periods at Berry College Wildlife Refuge.

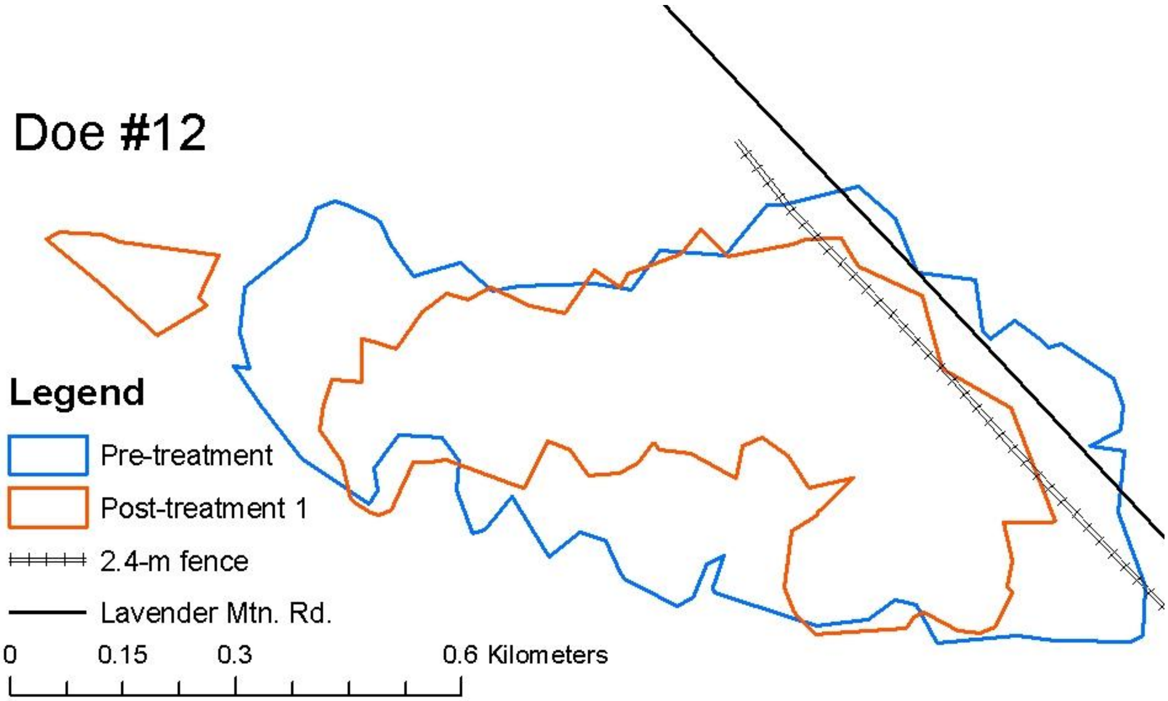

Figure 6. 90% *a*-LoCoH home ranges of 2.4-m treatment Doe #12 during pre-treatment and post-treatment 1 periods at Berry College Wildlife Refuge.

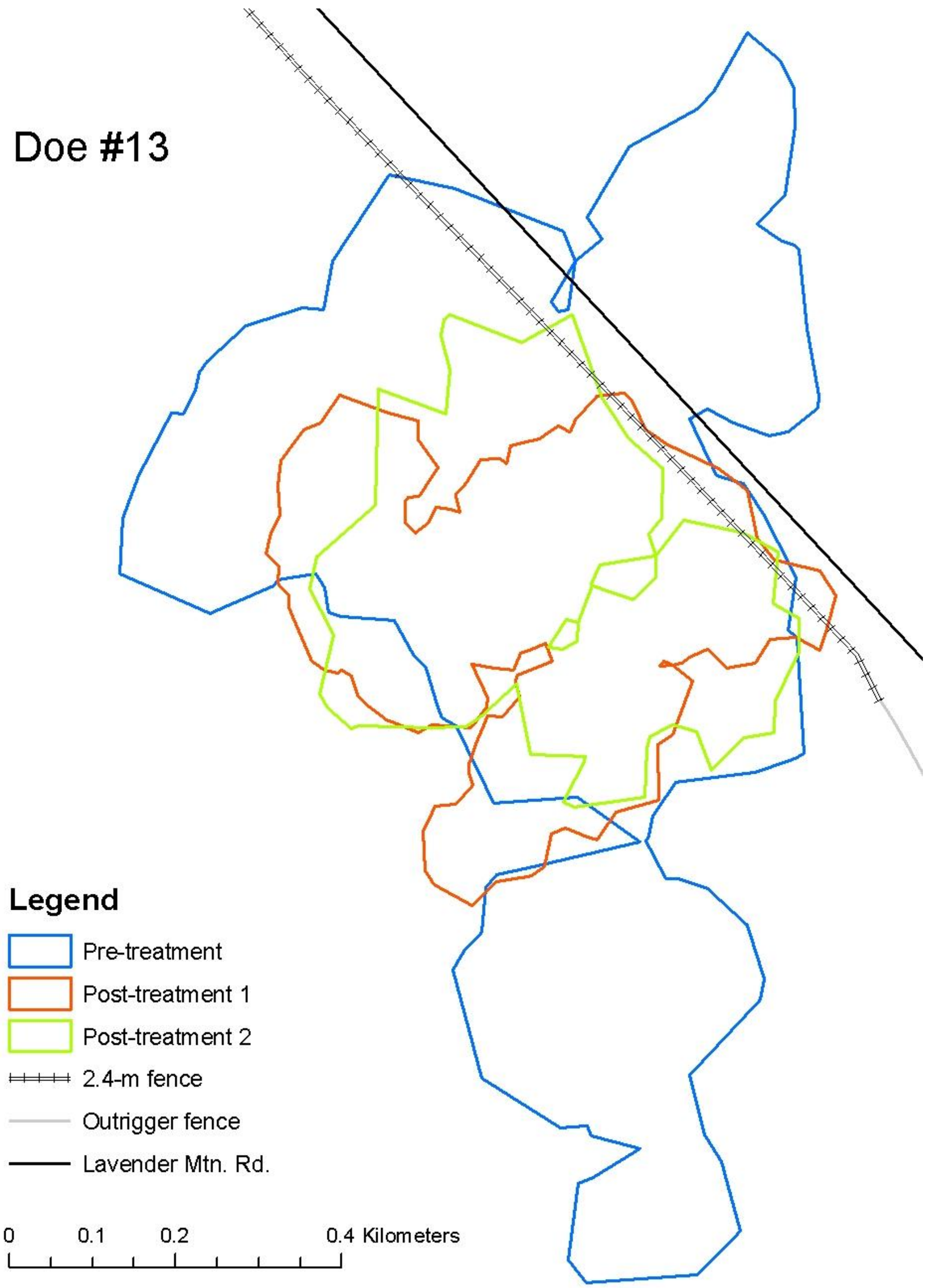

Figure 7. 90% *a*-LoCoH home ranges of 2.4-m treatment Doe #13 during pre-treatment and post-treatment 1 periods at Berry College Wildlife Refuge.

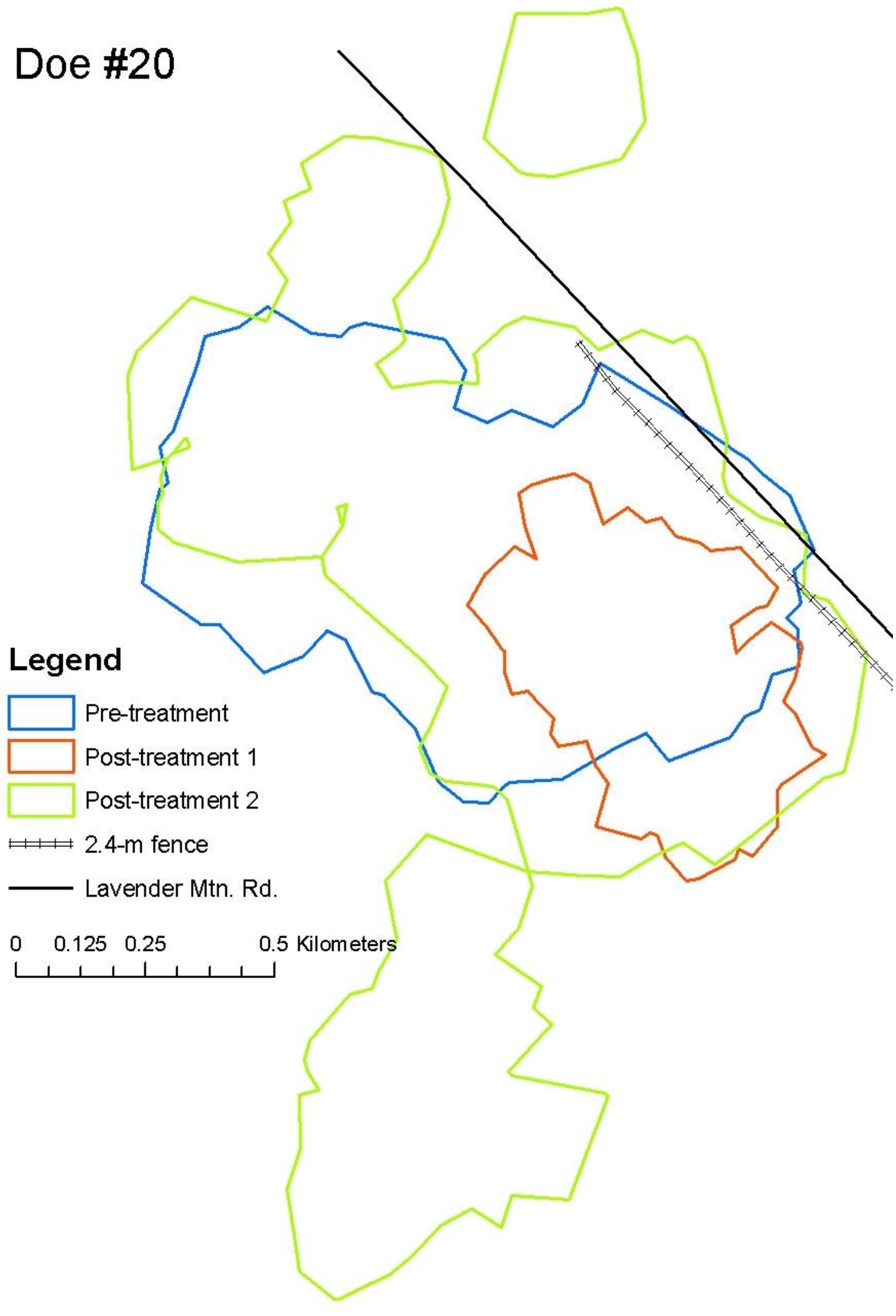

Figure 8. 90% *a*-LoCoH home ranges of 2.4-m treatment Doe #20 during pre-treatment and post-treatment 1 periods at Berry College Wildlife Refuge.

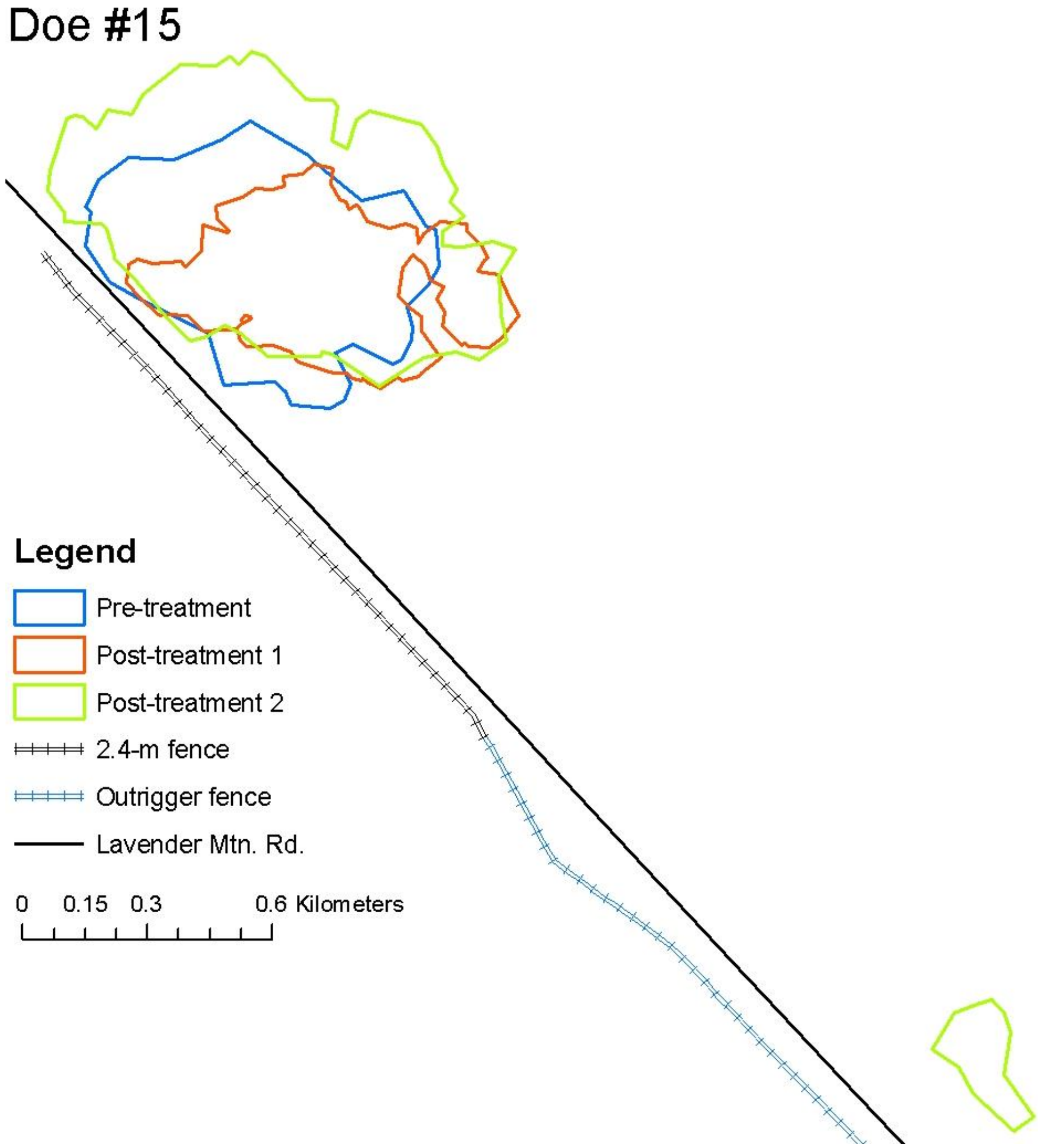

Figure 9. 90% *a*-LoCoH home ranges of control Doe #15 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

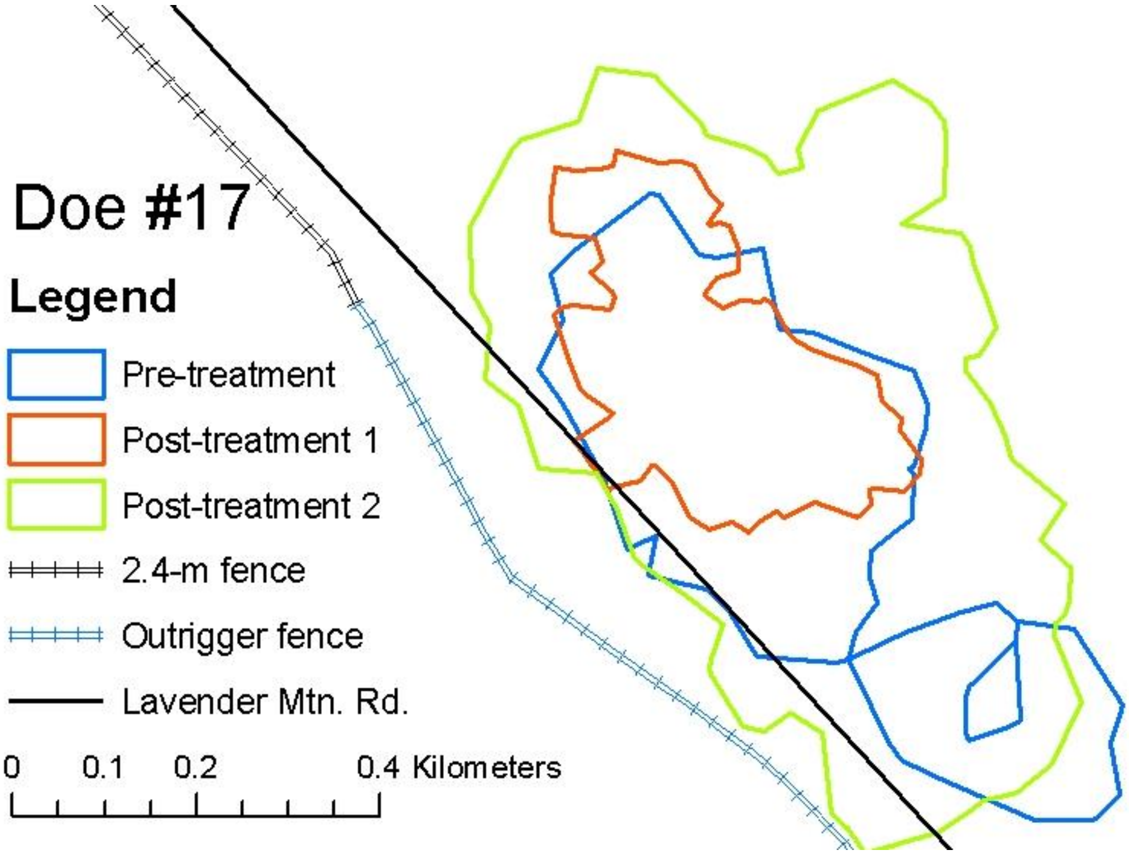

Figure 10. 90% *a*-LoCoH home ranges of control Doe #17 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

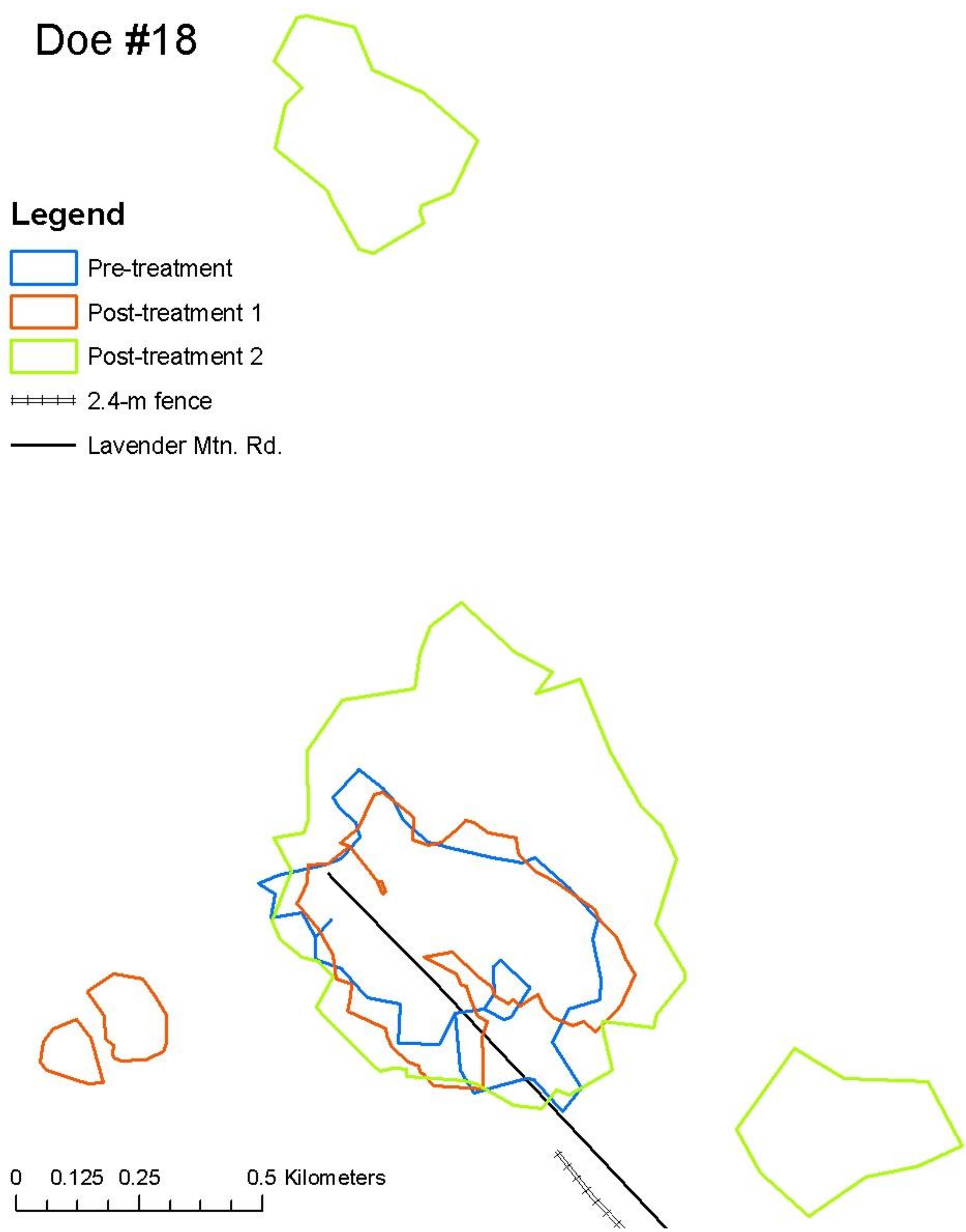

Figure 11. 90% *a*-LoCoH home ranges of control Doe #18 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

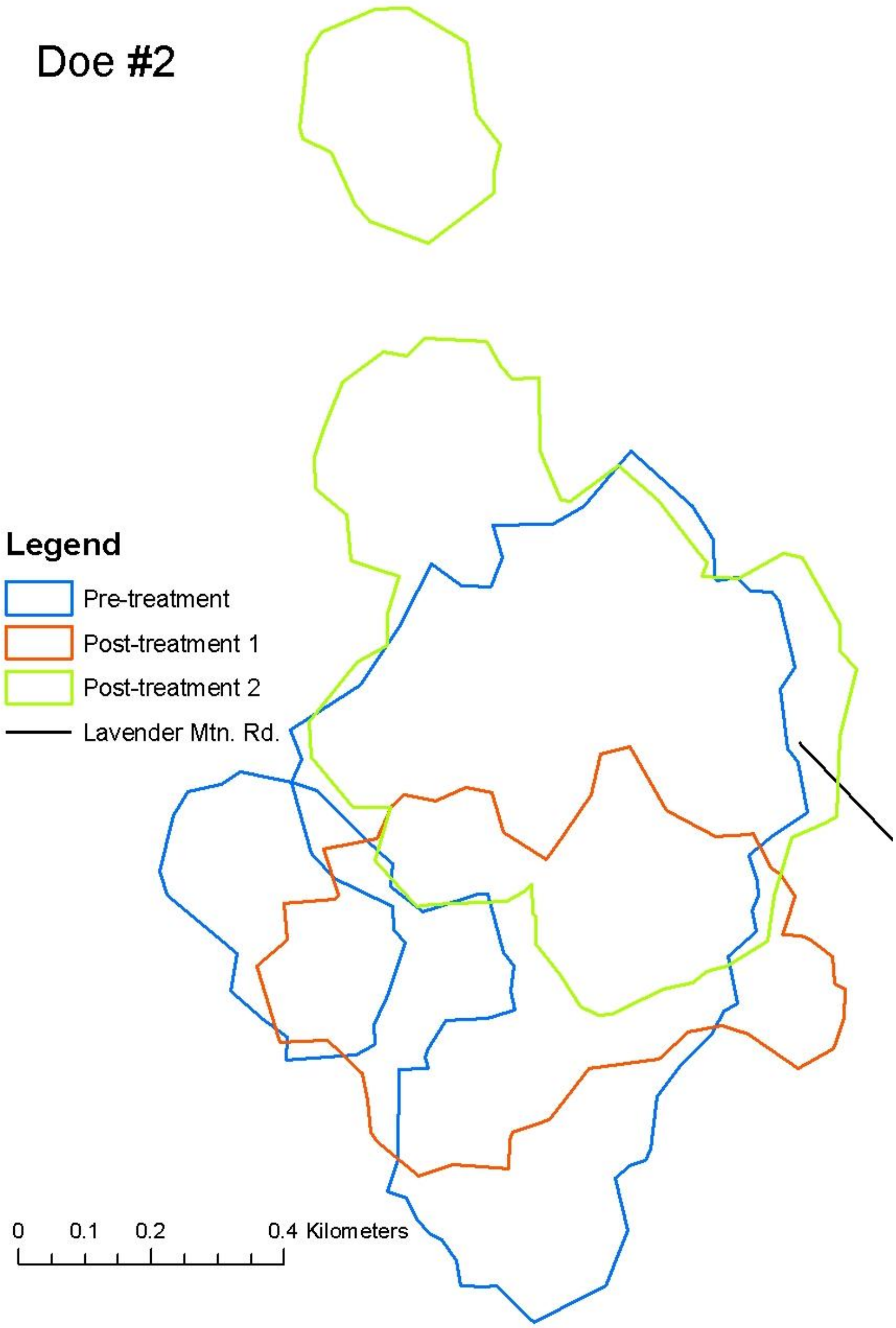

Figure 12. 90% *a*-LoCoH home ranges of control Doe #2 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

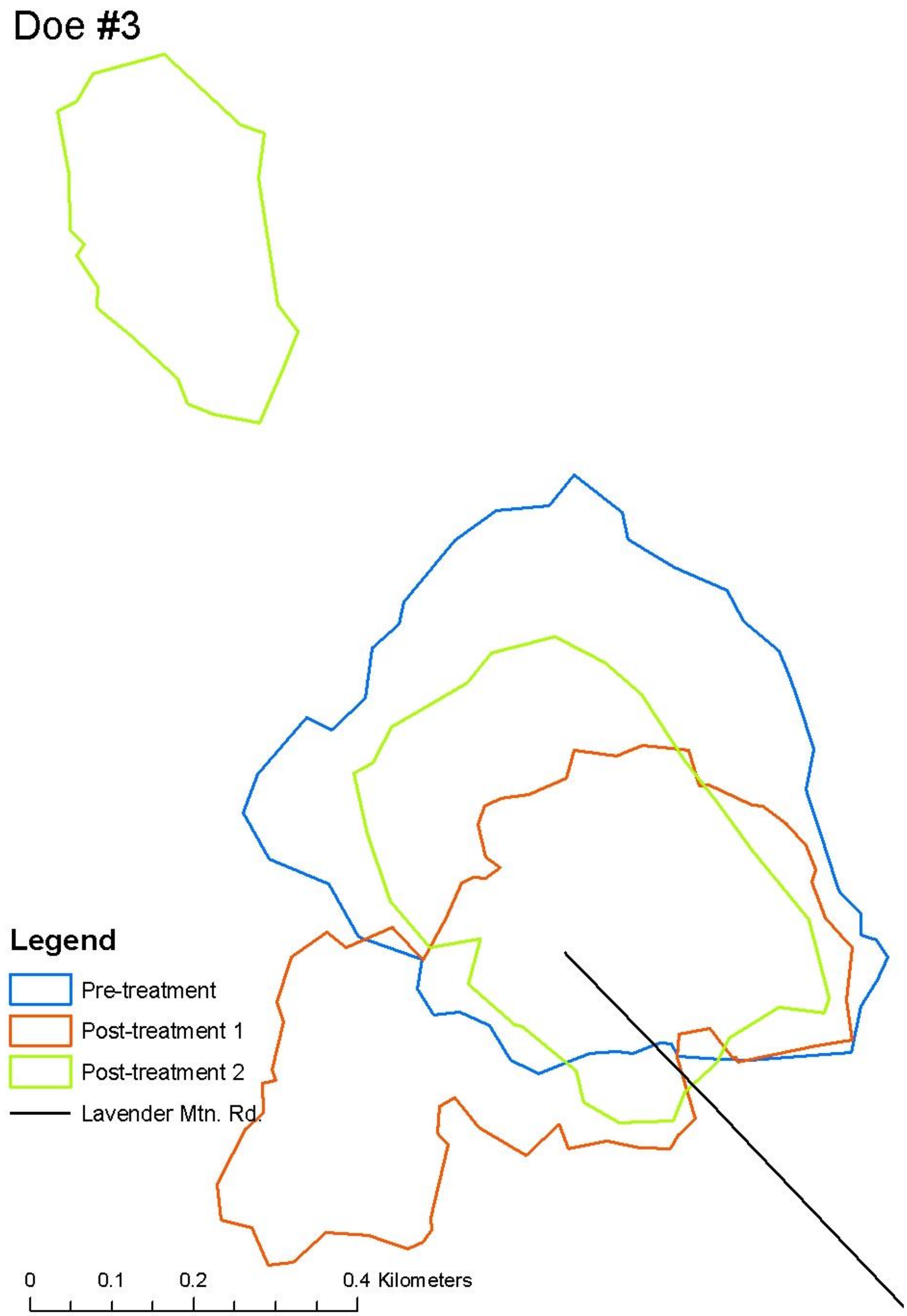

Figure 13. 90% *a*-LoCoH home ranges of control Doe #3 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

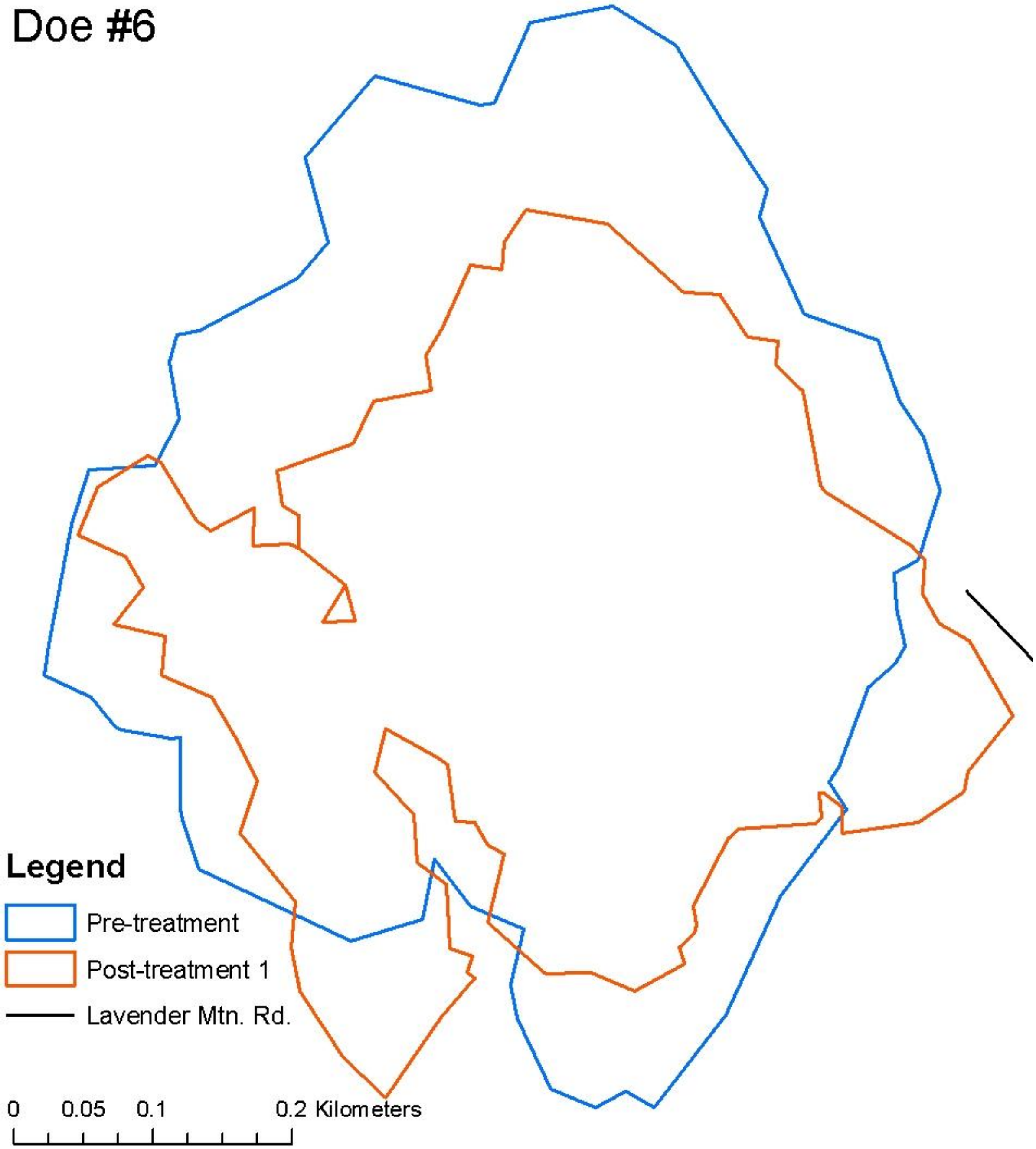

Figure 14. 90% *a*-LoCoH home ranges of control Doe #6 during pre-treatment, post-treatment 1, and post-treatment 2 periods at Berry College Wildlife Refuge.

APPENDIX B

COSTS AND DIAGRAMS OF OUTRIGGER AND 2.4-M WOVEN-WIRE FENCE TREATMENTS CONSTRUCTED AT BERRY COLLEGE, FLOYD COUNTY, GEORGIA

Table 1. Construction cost per meter of outrigger fence and 2.4-m woven-wire fence treatments constructed on Berry College, Floyd County, Georgia.

	Materials	Labor	Total
Cost of construction ($/m)			
2.4-m	$5.88	$3.48	$9.36
Outrigger	$6.75	$0.62	$7.37

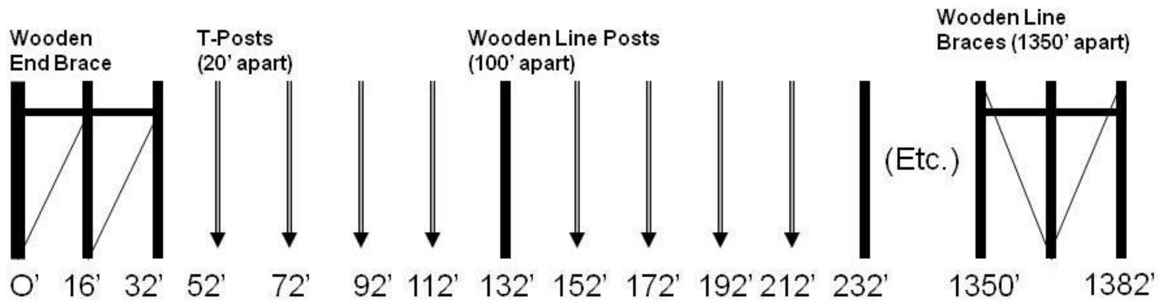

Figure 1. Diagram of 2.4-m and outrigger support post spacing for the 3.2-km fence treatment constructed on Berry College, Floyd County, Georgia. Spacing units are in feet.