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Title: Life in the Fast Lane: Road Crossing Behavior of Mule Deer in a Wildland-Urban Interface

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Executive Summary

In 2009, approximately 260,000 animal-vehicle collisions were reported in the United States, resulting in 12,000 human injuries and 173 human fatalities. Research has focused on identifying factors associated with high densities of animal-vehicle collisions, including variables such as traffic speed and volume, road design, topographic features, vegetative cover, and local deer or elk (*Cervus elaphus*) abundance. The purposes of this study were to document how often and where mule deer (*Odocoileus hemionus*) crossed roads in a western United States wildland-urban interface area, and to relate deer road-crossing behavior to deer-vehicle collision locations. Seven adult mule deer (four males [M] and three females [F]) were captured and collared with GPS-enabled collars during December 2001 and January 2002. Five of the seven deployed collars were recovered.

None of the roads in the study area appeared to act as a substantial barrier to deer passage. Deer home ranges straddled highways and primary, secondary, and tertiary arterial roads. Deer crossed all types of roads. The average number of times deer crossed road during 24 hours of monitoring ranged from 2.1 to 7.0. Deer in the Los Alamos townsite avoided crossing roads during day and before sunset.

Deer-vehicle accidents occurred at 350 percent of the level expected after sunset. All other time periods had fewer accidents than expected. The distribution of accidents across time periods was not similar to the distribution of road crossings across time periods for any deer. Within Los Alamos County there was a clear trend for deer-vehicle collisions to occur on roads with speed limits > 35 mph. Deer in the townsite frequently crossed roads with lower speed limits; therefore, the reason for the paucity of accidents along these roads was evidently the ability of drivers to detect deer (or the ability of deer to detect vehicles) and respond before an accident occurred. There was a significant but not strong correlation between the density of accidents and the density of road crossings. This was probably related to the high number of deer crossings of tertiary arterial roads, where accidents were not likely to occur.

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Introduction

During 2009, approximately 260,000 animal-vehicle collisions were reported in the United States, with 12,000 human injuries and 173 human fatalities (National Highway Traffic Safety Administration 2011). The animals involved in police-reported collisions are predominantly deer (*Odocoileus* spp.) (Centers for Disease Control 2004, Williams and Wells 2005). Research has focused on identifying factors associated with high densities of animal-vehicle collisions, including variables such as traffic speed and volume, road design, topographic features, vegetative cover, and local deer or elk (*Cervus elaphus*) abundance (Finder et al. 1999, Biggs et al. 2004, Bissonette and Kassar 2008, Farrell and Tappe 2008, McShea et al. 2008, Danks and Porter 2010).

Specific types of attractive habitats such as forest cover and riparian corridors for deer (Finder et al. 1999) and riparian meadows for elk (Dodd et al. 2007) have been associated with locations experiencing higher rates of animal-vehicle collisions. Effects of road design, traffic volume and traffic speed on animal-vehicle collision rates have been inconsistent among study areas (Biggs et al. 2004, McShea et al. 2008, Bissonette and Kassar 2008). Danks and Porter (2010) found odds of a location having a moose-vehicle collision on low-traffic-volume roads increased by 57 percent for each additional 500 vehicles/day, peaking at around 2500 average annual daily traffic (AADT). Odds of a collision also increased 35 percent for each additional 5 miles per hour (mph) increase in the speed limit.

Road characteristics such as number of lanes and traffic volume influence the level of road avoidance by deer or elk (Dodd et al. 2007, Ager et al. 2003, Alexander and Waters 2000, Gagnon et al. 2007). Deer and elk may or may not habituate to road-related disturbances (Dodd et al. 2007, Tull and Krausman 2007, Sawyer et al. 2006). Waring et al. (1991) and D'Angelo et al. (2006) conducted focal point sampling of white-tailed deer along roadways. D'Angelo et al. (2006) reported that in only approximately six percent of potential deer-vehicle interactions did deer behave in ways that would increase the probability of a collision. Waring et al. (1991) found that deer tended to cross roads in the absence of vehicles.

The presence of animals on a roadway is a necessary condition for an animal-vehicle collision to occur. However, the degree of correspondence between when and where animals cross roads and when and where animal-vehicle collisions occur is not well understood. The purposes of this study were to document how often and where mule deer (*Odocoileus hemionus*) crossed roads in a western United States wildland-urban interface area, and to relate deer road-crossing behavior to deer-vehicle collision locations.

Study Area

The town of Los Alamos is located in Los Alamos County on the Pajarito Plateau in north-central New Mexico, United States, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (Figure 1). In 2000 Los Alamos had 11,909 residents and 5,463 housing units (U. S. Census Bureau 2002). South of the town is the Los Alamos National Laboratory (LANL), administrated by the Department of Energy, National Nuclear Security Administration (DOE/NNSA) Los Alamos Site Office (LASO). LANL employs approximately 13,000 people. Land surrounding the Los Alamos townsite and LANL is largely undeveloped. Land north, west, and south is administered by the United States Forest Service (Santa Fe National Forest), National Park Service (Bandelier National Monument), and the General Services Administration. The Pueblo de San Ildefonso borders LANL to the east.

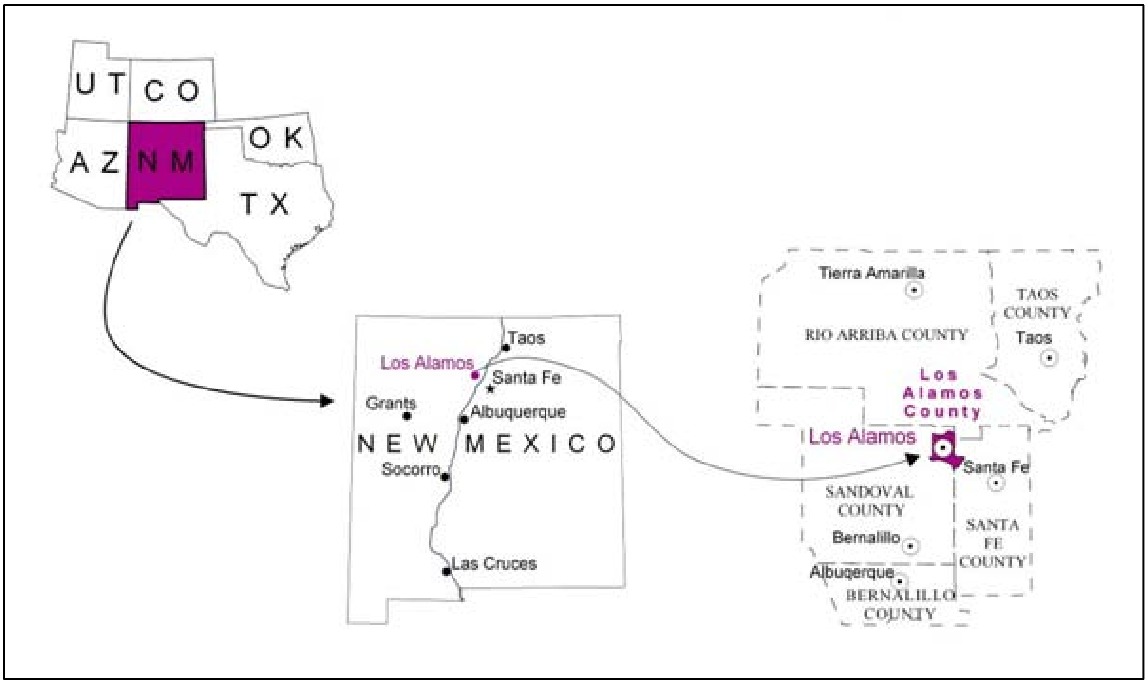

Figure 1. Map showing the location of Los Alamos County, New Mexico, in the southwestern United States.

The Pajarito Plateau is an approximately 900-foot (ft) layer of solidified volcanic ash located along the eastern edge of the Jemez Mountains (Powers 2005). The plateau ranges from 6,200 ft to approximately 8,000 ft in elevation. The Rio Grande has incised a deep gorge, White Rock Canyon, along the eastern edge of the Plateau. A dozen deep canyons trending west to east cut the Plateau into long, sloping mesas. A few of these canyons provide undeveloped, topographically complex forested areas within the Los Alamos townsite (Figure 2). Almost all developed areas are on the tops of mesas.

In 1999, two dominant forest types occupied the majority of undeveloped portions of Los Alamos County: piñon-juniper (*Pinus edulis – Juniperus monosperma*) woodlands and ponderosa pine (*Pinus ponderosa*) forest. Other vegetative cover types included mixed conifer forests on the north-facing slopes of canyons and juniper woodlands at lower elevations near the Rio Grande. Areas within the county previously affected by wildland fire or cleared for agriculture contained grasslands or oak (*Quercus* spp.) shrublands. Since 1999, extreme drought and wildfires have changed the extent and condition of much of the forest, range, and soils. Bark beetle outbreaks killed more than 90 percent of the piñon trees greater than 10 ft tall, as well as many mature trees in ponderosa pine and mixed conifer forest types (Allen 2007). Natural vegetative communities are currently in a state of flux.

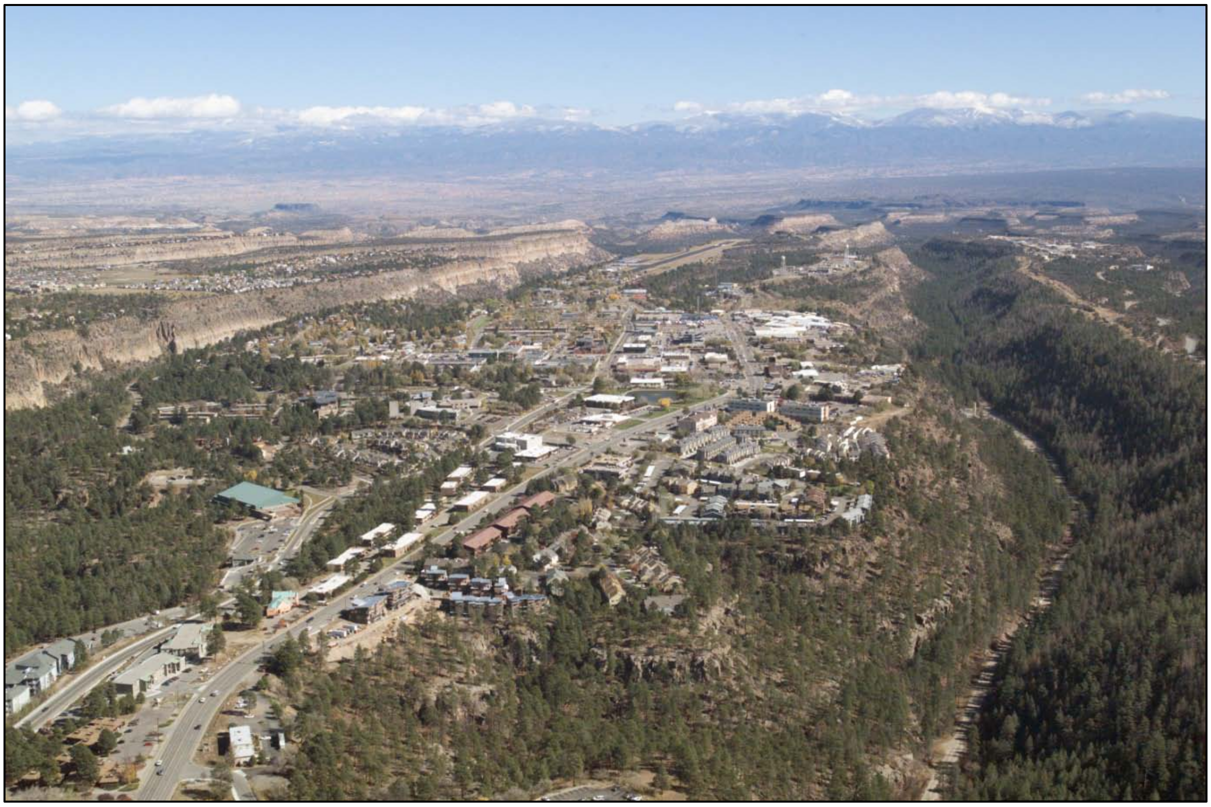

Figure 2. View of downtown Los Alamos, looking east over the Pajarito Plateau towards the Sangre de Christo Mountains.

Analysis of 2001 satellite imagery documented the following five most abundant cover types on LANL property: piñon-juniper, 39.4 percent; ponderosa pine, 18.8 percent; urban-sparse-bare rock, 13.0 percent; shrublands, 11.2 percent; and grasslands, 10.0 percent (McKown et al. 2003).

Development in Los Alamos County is limited by steep slopes and by the need for security and safety buffers for work at LANL. Neither Bandelier National Monument nor LANL allow hunting, farming, grazing, or off-road recreational vehicular access on their properties. Hunting is prohibited within the townsite of Los Alamos, although it is allowed in the National Forest lands west and north of town. Timber harvest in the area is limited to forest fuel management activities. Los Alamos County is inhabited by many of the large herbivore and carnivore species found throughout the western United States, including mule deer, elk, mountain lion (*Puma concolor*), black bear (*Ursus americanus*), bobcat (*Lynx rufus*) and coyote (*Canis latrans*).

Methods

Biologists trapped mule deer on LANL property using drop nets in December 2001 and January 2002. Adult deer were physically restrained and blindfolded while fitted with Lotek® Global Positioning System (GPS) store-on-board collars. The collars were programmed to acquire locations at 15-minute intervals for four-hour-long periods six days of every week. The four-hour-long periods were staggered each day so that at the end of every week an entire 24-hour period had been monitored. Each collar was programmed with the same location acquisition schedule. Locational data was stored in the collars, so collars had to be retrieved to collect the data. Collars were attached with explosive remote release mechanisms and cotton spacers to allow recovery.

Once collars were recovered, data were downloaded and differentially corrected and a locational error was applied to the GPS positional data to give an estimate of accuracy. A general locational error (error radius) was calculated for differential corrected GPS positions and GPS non-corrected positions. The general location error was calculated by comparing Lotek® GPS radio collar positions (corrected and non-corrected) taken at known locations to the actual surveyed location coordinates. The following equation was used to calculate locational error,

$$LE = (sx^2 + sy^2)^{1/2}$$

where sx and sy were distance in feet from the actual position. The locational errors calculated were then averaged from several different locations to derive a general locational error that could be applied to data downloaded from GPS radio collars deployed on deer.

Data were analyzed in a Geographical Information System (GIS). We visually examined each four-hour sequence of locations on a GIS system with mapped roads and buildings. To determine when and where road crossings occurred, we only used locations separated by less than 20 minutes and looked for evidence of a travel path crossing the road. Road crossings were not recorded if the deer could have traveled around the road, if a road crossing was indicated by only one location that was within 12 m (the general locational error radius) of the road, or if the location showing a road crossing was not consistent with the travel path as mapped by the other locations in the four-hour sequence (e.g., possibly an incorrect location). Only paved roads were considered in this analysis.

Road were classified as tertiary arterial paved roads, secondary arterial paved roads, primary arterial paved roads (2-lane and 4-lane), paved 2-lane highways, and restricted access roads (roads on LANL property with no public access) by the County of Los Alamos. Tertiary arterial paved roads provide access to and from residences, and tend to have the lowest traffic volumes and speeds. Speed limits for tertiary arterial paved roads in Los Alamos were 25 miles per hour (mph). Secondary arterial roads provide access and traffic circulation within residential neighborhoods and commercial and industrial areas (≥ 1,500 annual average daily traffic [AADT]). Speed limits for secondary arterial paved roads ranged from 35 to 45 mph. Primary arterial paved roads (2-lane and 4-lane) provide long-distance intercity and cross town traffic routes with relatively high speeds (≥ 7,500 AADT). Speed limits for primary arterial paved roads ranged from 35 to 55 mph. Paved highways are numbered roads in the New Mexico State Highway system, have relatively high speeds, and, in Los Alamos County, cross both developed and undeveloped areas. Speed limits for paved highways ranged from 40 to 55 mph.

Each day was divided into the following time categories based on astronomical twilight: before sunrise, after sunrise, bright day, before sunset, after sunset, and night. Astronomical twilight is defined to begin in the morning, and end in the evening, when the center is of the sun is geometrically 18 degrees below the horizon. Before sunrise was defined as the beginning of astronomical twilight to sunrise; after sunrise was the same length of time as before sunrise each day, but directly following sunrise; day was the period between after sunrise and before sunset; before sunset was a time period of the same length as after sunset, but directly preceding sunset; after sunset was the period from sunset to the end of astronomical twilight; and night was the period between the end of astronomical twilight one day and the beginning of astronomical twilight the next day. The total number of hours in each time category for the months that each deer was monitored was calculated.

To evaluate deer road-crossing behavior relative to deer-vehicle accident locations within Los Alamos County, we used a database of animal-vehicle accidents describing the location, time of day, and involved species for reported accidents from January 7, 1990 to March 2, 2002 (see Biggs et al. [2004] for a more detailed description of the database). There were 99 reported accidents within this time frame that involved deer and had adequate location and time information.

We examined the types of roads that deer crossed, the types of roads where deer-vehicle accidents occurred, and the time of day for deer road-crossings and for accidents. We compared actual road crossings to expected road crossing without any time category preference (numbers of road crossings distributed proportionally to the number of hours in each time categories) using Friedman's test (Conover 1980, Thomas and Taylor 1990) on the values of observed crossings as a percent of expected crossings for each deer in each time period. Chi-square tests were used to determine if accidents were distributed proportionally among time periods, and to compare the distribution of road crossings within time periods to the distribution of accidents within time periods.

Ninety-five percent minimum convex polygon (MCP) home ranges were calculated in ESRI, ArcMap 9.2 using Hawth's Analysis Tools for ArcGIS (Beyer 2004) for each deer radio-collared. Hawth's tool is applied to the selected set of a theme. In order to calculate a 95 percent MCP, a 95 percent selection had to be developed. The selection required identifying the mean center of the locational data for each individual deer and then calculating the distance from each location to the mean center. The selection was based on selecting the closest 95 percent of the positions to the mean center. The mean center was calculated for each set of data corresponding to an individual deer using ESRI, ArcToolbox, Measuring Geographic Distributions, Mean Center tool. The point distance was calculated from the mean center to each GPS position (using ESRI, ArcToolbox, Analysis Tools, Proximity, Point Distance) and the table was permanently sorted by this distance in ascending order. A query was applied selecting 95 percent of the locations with the shortest distance to the mean center and the Minimum Convex Polygon tool within the Hawth's Tools was applied to the selection.

Within the 95 percent MCP home range of the animals monitored in this study, the density of road crossings by each animal and the density of deer-vehicle accidents was calculated using ESRI, ArcMap, Spatial Analyst, Density Tool using the kernel density option and the default search radius (1/30th of the shortest of the width or height of the extent of the spatial reference [ESRI 2007]). The nonparametric Spearman's Rho (SAS Institute Inc 2000) was used to test for a correlation between the density of deer road crossings and the density of deer-vehicle collisions within the 95 percent MCPs. A composite road crossing density grid was also calculated using all data from the deer to generate a single road crossing density grid to use in the correlation analysis. This density grid was converted to a point theme and each point represented the centroid of the corresponding grid cell with the density value as an attribute. Using Zonal Statistics in ESRI, ArcMap, Spatial Analysis, the deer-vehicle collisions density values corresponding to the point locations from the deer road crossings density point layer were generated and the values placed in a table with the corresponding point identifier. The attribute table from the deer road crossing point density layer was joined to the zonal statistics table (with deer-vehicle collisions density values) by the point identifier. The joined tables were exported to a comma-delimited text file. The data were imported into SAS and checked for normality (using Proc Univariate Normal). The data were non-normal and the correlation between the two densities was tested using Proc Corr with the statement option Spearman.

Results

Seven adult mule deer (four males [M] and three females [F]) were captured and collared during December 2001 and January 2002. Five (2 M, 3 F) were captured near the Los Alamos townsite, and two were captured approximately 7.4 km south of the townsite in an undeveloped area near the boundary between LANL and Bandelier National Monument (Figure 3). Five of the seven deployed collars were recovered – three from mortalities (including one road kill), one from use of the explosive release mechanism, and one from tearing of the cotton spacer in the collar. We recovered collars from one male trapped near Bandelier National Monument and from two males and two females trapped near the Los Alamos townsite.

The collars successfully acquired between 93.7 percent and 98.9 percent of attempted locations (Table 1). Deer were monitored for between 40.6 to 54.3 weeks. The deer monitored in this study did not exhibit any long-distance seasonal migratory movements. The 95 percent MCP home range of males averaged 1758 ha, and of females 667 ha (Table 1). The average number of road crossings during 24 hours of monitoring per week ranged from 2.1 to 7.0. Based on a linear extrapolation of the data, we estimated that individual deer crossed roads a mean number of 781 to 2548 times per year (Table 1).

We tested for selection or avoidance of time categories by deer for road crossings relative to their expected use if crossings had been distributed proportionally among time categories. For the four deer located in the Los Alamos townsite, deer selected bright day and before sunset periods for crossing roads significantly less than other time periods (Friedman Test Statistic = 12.429, p = 0.029, 5 df; sd = 8.011, 15 df). The one deer located along the Bandelier National Monument boundary appeared to have a more crepuscular pattern of road crossings than deer in the townsite, however, the crossing times for that deer were not statistically tested.

Accidents did not occur at the levels that would be expected if accidents were distributed proportionally across time periods ($\chi^2 = 21.122$, $p = 0.001$). Accidents occurred at 350 percent of the level expected in the after sunset time period (Table 2). All other time periods had fewer accidents than expected. We compared road crossing times for each deer to accident times in the study. The distribution of accidents across time periods was not similar to the distribution of road crossings across time periods for any deer ($\chi^2 = 17.24$ to 95.23, p = 0.004 to 0.000).

Within Los Alamos County, three times as many accidents occurred on paved highways as on any other road type (Table 3). This type of road was not very available to the monitored deer living in the Los Alamos townsite, although it was frequently crossed by the deer living in the undeveloped area by Bandelier National Monument. The monitored deer living in the Los Alamos townsite crossed tertiary arterial roads more than any other road type. However, only one percent of deer-vehicle collisions occurred on these roads.

Within the 95 percent MCP home range boundaries of the monitored deer, we calculated the density of road crossings and the density of deer-vehicle collisions (Figures 4 and 5). The density of road crossings and the density of accidents were significantly correlated ($P < 0.0001$) with an r value of 0.52.

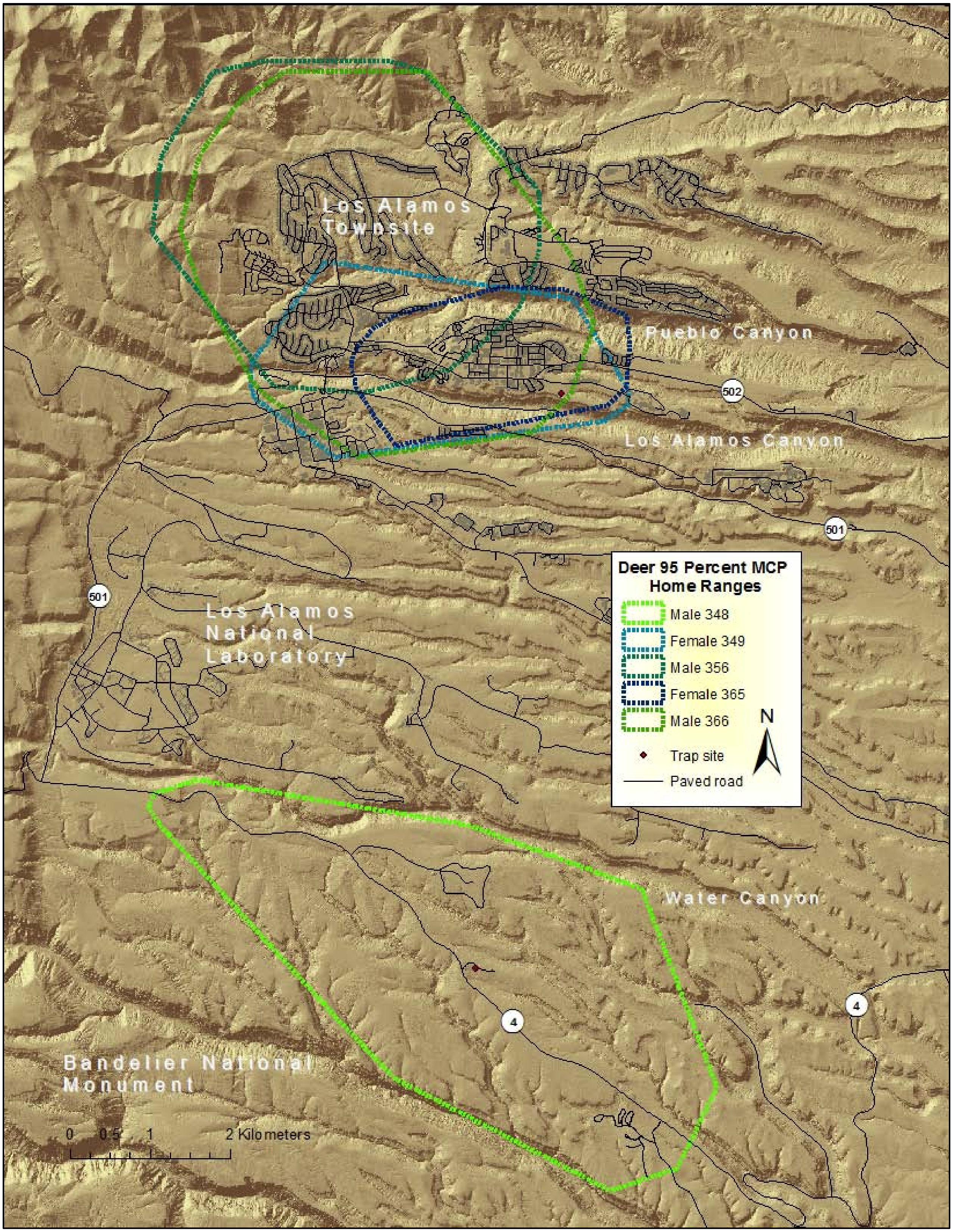

Figure 3. Map of the Los Alamos study area, showing the 95 percent Minimum Convex Polygon home ranges of three male and two female mule deer in relation to area roads and the trapping locations.

Table 1. Date of the first and last GPS location, the number of weeks monitored, the number of programmed attempts of locations, the percent of programmed attempts that were successful in acquiring a location, the number of programmed attempts for which no data exists demonstrating that the GPS unit attempted to acquire the location (number of data records with the same date and time that are repeated), the average number of observed road crossings (xings) during 24 hours of monitoring each week, the estimated number of road crossings per year, and the 95 percent Minimum Convex Polygon (MCP) home range size for individual mule deer collared with GPS collars in Los Alamos County, NM, 2001 – 2003.

Deer Id	Start Date	End Date	No. weeks	No. attempted locations	Percent successful locations	No. missed attempts (no. duplicated attempts)	Average road xings during 24 monitored hrs per week	Extrapolated no. of road xings per year	95 percent MCP home range (ha)
M348	1/25/02	2/4/03	53.6	5158	98.9	0 (6)	2.1	781	1912
F349	12/14/01	10/17/02	43.9	4224	97.1	1 (0)	5.8	2116	821
M356	12/14/01	9/24/02	40.6	3917	97.0	0 (0)	5.3	1911	1543
F365	12/18/01	1/2/03	54.3	5201	93.7	3 (4)	4.6	1683	513
M366	12/21/01	12/5/02	49.9	4745	95.0	0 (55)	7.0	2548	1820

Table 2. The location where each mule deer established their home range (BNM = Bandelier National Monument boundary, Townsite = Los Alamos townsite), the deer identification number, the total number of road crossings observed with telemetry data, the number of observed road crossing occurring in each of six time categories, and the observed road crossings as a percentage of expected road crossings (if road crossings were distributed in all time categories in proportion to their availability) for individual mule deer collared with GPS collars in Los Alamos County, NM, 2001 – 2003. The last row is the number of deer-vehicle accidents in each time category in Los Alamos County from 1990 – 2002, and the observed accidents as a percentage of expected accidents (if accidents were distributed in all time categories in proportion to their availability).

Location Deer ID	Total No. Road Crossings Obs.	Before Sunrise n (percent)	After Sunrise n (percent)	Bright Day n (percent)	Before Sunset n (percent)	After Sunset n (percent)	Night n (percent)
BNM							
M348	115	6 (81)	18 (243)	35 (81)	10 (132)	17 (225)	29 (69)
Townsite							
F349	255	11 (66)	9 (54)	32 (32)	4 (24)	18 (106)	181 (204)
M356	213	41 (294)	27 (194)	10 (12)	0 (0)	24 (168)	111 (151)
F365	251	12 (74)	3 (19)	25 (27)	8 (49)	12 (74)	191 (207)
M366	349	37 (164)	38 (169)	35 (26)	4 (17)	21 (91)	214 (171)
Accidents	99	4 (39)	6 (58)	19 (64)	8 (78)	36 (350)	26 (92)

Table 3. The location where each mule deer established their home range (BNM = Bandelier National Monument boundary, Townsite = Los Alamos townsite), the deer identification number, the total number of road crossings observed with telemetry data, the percent of observed road crossing occurring in each of six road types for individual mule deer collared with GPS collars in Los Alamos County, NM, 2001 – 2003. The last row is the percent of deer-vehicle accidents by road type in Los Alamos County from 1990 – 2002.

Location Deer ID	Total No. Road Crossings	Paved Highway percent	Four-lane Primary Arterial Road percent	Primary Arterial Road percent	Restricted Secondary Arterial Road percent	Secondary Arterial Road percent	Tertiary Arterial Road percent
BNM							
M348	115	62.6	-	-	-	2.6	13.9
Townsite							
F349	255	3.9	11.0	7.8	16.9	22.4	38.0
M356	213	1.4	7.5	0.9	1.4	23.0	65.7
F365	251	0.8	8.8	7.2	2.4	33.5	47.4
M366	349	0.0	3.4	3.2	0.9	20.9	71.6
Accidents	99	59.6	8.1	20.2	0.0	11.1	1.0

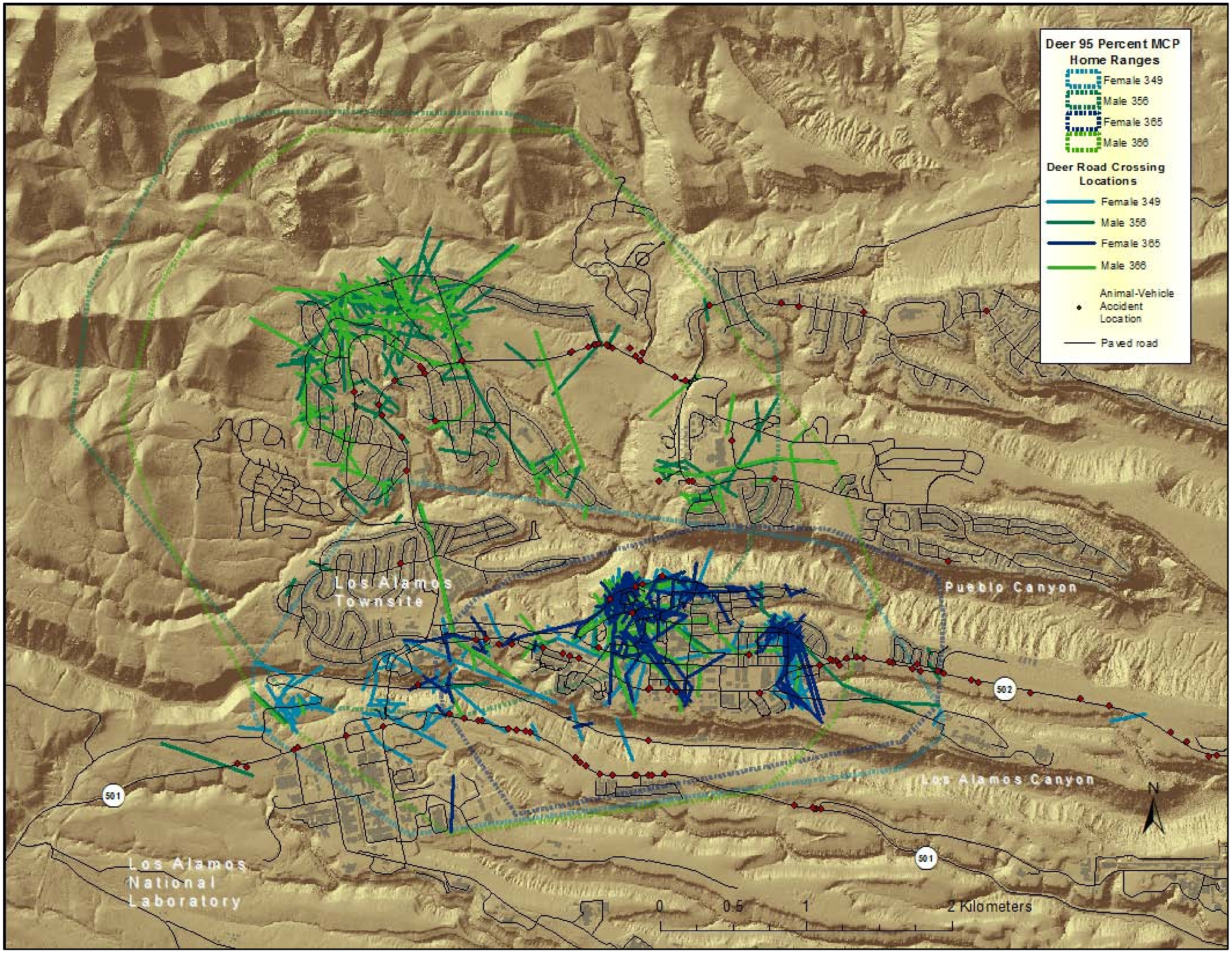

Figure 4. Locations of mule deer road crossings and animal-vehicle accidents around the Los Alamos townsite.

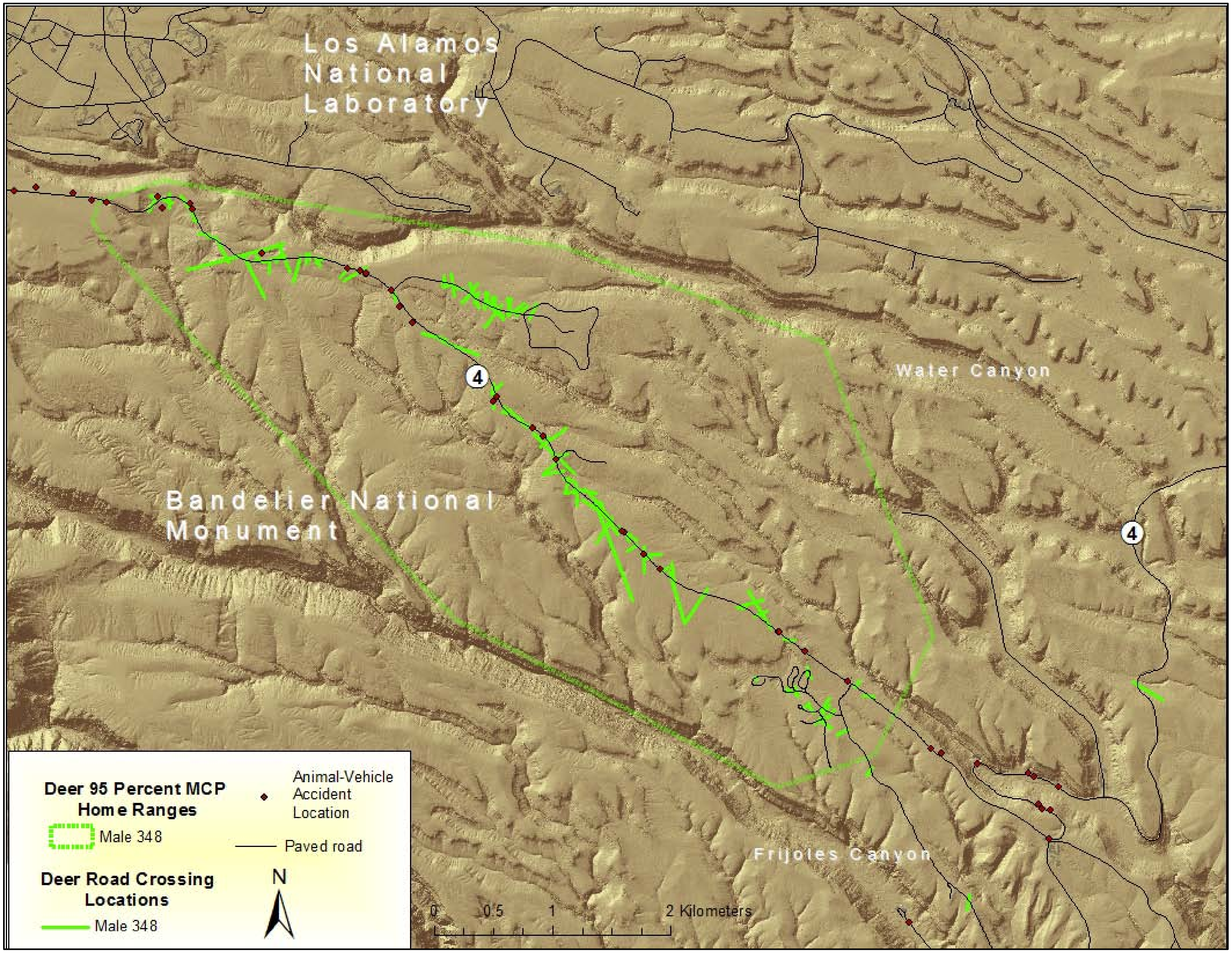

Figure 5. Location of mule deer road crossings and animal-vehicle accidents in an undeveloped portion of the Los Alamos study area.

Discussion

We documented an unexpectedly (to us, anyways) high rate of road crossings by mule deer in the wildland-urban interface. Even the deer living in an undeveloped area of Los Alamos crossed the roads within its home range multiple times per day. Adult mule deer in this area are undoubtedly habituated to roads, and very experienced at crossing them.

None of the roads in the study area appeared to act as a substantial barrier to deer passage. Deer home ranges straddled highways and primary arterial roads, and deer crossed both types of roads. Alexander and Waters (2000) found that the Trans-Canada Highway, at 14,000 AADT, was a substantial barrier to animal movement, but that many more animals crossed a local highway with 3000 AADT. Elk in Arizona crossed a large (6300 – 8700 AADT) highway less frequently than would be expected if movements were random with respect to the highway, but still crossed an average of once every five days (Dodd et al. 2007).

Deer in this study avoided crossing roads during day and before sunset. Deer within the Los Alamos townsite consistently used night more frequently than expected for crossing roads, as suggested by Putnam (1997), while the deer located in undeveloped Los Alamos county used night less frequently than expected and showed an overall more crepuscular pattern of road crossing. Ager et al. (2003) found that elk had a 40 percent probability of being within 200 m of a highway at traffic volumes of less than 100 vehicles/hour, but <20 percent probability at 600 vehicles/hour. In that study, over 97 percent of highway crossings by elk occurred between 1700 and 0800. Gagnon et al. (2007) found that elk used habitat near a large highway primarily when traffic volume was less than 100 vehicles/hour. Deer moving within developed areas of the Los Alamos townsite may prefer crossing roads during nighttime hours to avoid heavier traffic.

Within Los Alamos County there was a clear trend for deer-vehicle collisions to occur on roads with speed limits > 35 mph. Deer in the townsite frequently crossed roads with lower speed limits; the reason for the paucity of accidents along these roads was evidently the ability of drivers to detect deer (or the ability of deer to detect vehicles) and respond before an accident occurred.

There was a significant but not strong correlation between the density of accidents and the density of road crossings. This was probably related to the high number of crossings of tertiary arterial roads, where accidents were not likely to occur. Areas on primary arterial roads with high densities of crossings did correspond to locations with deer-vehicle accidents.

The peak in mule deer-vehicle collisions we observed during the after sunset time period was also noted by Haikonen and Summala (2001) in Finland with moose and white-tailed deer and by Danks and Porter (2010) for moose. The peak in accidents in Los Alamos County was not accompanied by a peak in road-crossing: mule deer road crossing rates after sunset were not significantly different from before or after sunrise. Haikonen and Summala (2001) noted that in the morning, traffic volume increases from nearly empty roads to peak volumes in a very short period of time. However, in the evenings, the decrease in traffic volume is much more gradual. Animals may be more successful in avoiding vehicles under conditions of increasing light and quickly increasing traffic volume than they are under conditions of decreasing light and moderately decreasing traffic volume. Sullivan (2011) found that there is an increased odds that an animal-vehicle collision will occur in darkness as posted speed limits increase. He hypothesized that these increased odds occur because of the short and fixed limit on forward visibility experienced by drivers using low beam headlights.

Biggs et al. (2004) documented an increased number of deer-vehicle collisions in the Los Alamos area during September through November, and an increased number of elk-deer collisions during September through February. Increases in ungulate-vehicle collisions during months with shorter day lengths could be associated with a higher traffic volume in the after sunset time period. Chambers et al. (2010) found that day length was negatively correlated with frequency of road-kills of tammar wallabies in Western Australia.

Acknowledgments

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