MODELING HABITAT USE AND ROAD BASED DISTURBANCE OF MULE DEER IN NEW MEXICO

by

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Dedicated to family, friends and my community.

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ABSTRACT

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As human activity expands across the globe, disturbance of wildlife by anthropogenic activities such as fragmentation of habitat, and wildlife-human conflicts escalate. The Pueblo of Santa Ana is receiving pressure from road expansion and urban development and is concerned with the impacts of those activities upon wildlife populations. Specifically, mule deer is a species of concern for their Department of Natural Resources (DNR). Mule deer are important economically, culturally, and for recreational purposes. The DNR understands the need for better understanding mule deer ecology to manage for potential conflicts in their interactions with expanding human infrastructure. My objectives were first to model mule deer habitat use in and around the Pueblo of Santa Ana during the summer and winter at different times of the day. My second objective was to understand the relative impacts of different scenarios for road development in the Pueblo of Santa Ana upon the disturbance of mule deer using an Individual Based Modeling (IBM) framework.

Using Geospatial Positioning System telemetry collar data collected on mule deer I used proximity based habitat predictors in a general linear mixed model to create resource selection functions. Generally I found that the season had a greater impact on mule deer habitat use than the time of day. Female and male mule deer select for similar habitat but sexually segregate in their summer distributions. My findings are consistent with results from other locations where mule deer studies have been conducted. In chapter two, I used the Simulation of Disturbance Activities

(SODA) modeling framework to investigate the impact of vehicles on mule deer disturbance response behaviors, alert and fleeing. Using this framework I compared a baseline scenario to road expansion scenarios (DamRoad, ByPass, DeerCrossing) estimating the frequency of disturbance behavior of mule deer for each such scenario. My results show that mule deer were disturbed most in the baseline model. There were no significant differences in the frequency of disturbance for female mule deer across scenarios. Male mule deer did have some significant differences in alert and fleeing behavior across scenarios. My results may be a function of assumptions made in my modeling. Specifically, I assumed that mule deer would shift their areas of activity to new portions of the Pueblo of Santa Ana in response to altered habitat quality caused by new roads. If mule deer did not shift their areas of activity accordingly, my models may provide inaccurate assessments of disturbance patterns.

In conclusion my findings are similar to results from other locations. Specifically, the inferences that roads and road development are important to consider for mule deer management transcends variation associated with the unique characteristics of the Pueblo of Santa Ana mule deer population. Finally, my results suggest that the use of an IBM modeling framework has the potential to provide insights into the disturbance of mule deer by vehicular traffic even if my conclusions were constrained by study design.

CHAPTER 1. INFLUENCE OF SEASON AND TIME OF DAY UPON MULE DEER (ODOCOILEUS HEMIONUS) HABITAT USE IN NEW MEXICO

1.1 Introduction

Habitat describes environmental and ecological characteristics where animals reside, and may provide insights into a species distribution (Morrison 2001). Habitat is often measured as resources that are directly and indirectly used by animals (Morrison 2001) with use varying as a function of season, time of day, abiotic factors, and competition between sympatric species (Johnson et al. 2000). Understanding the fundamental niche of species can identify how animals will respond to spatial and temporal variability (Hebblewhite and Merrill 2008, Northrup et al. 2016*b*). Often, habitat is estimated by comparing resources the animal uses to the total available on the landscape (Johnson et al. 2000, Keating and Cherry 2004). Such resource selection functions based upon a used-available habitat resource framework are an effective way to understand habitat selection (Manly et al. 2002). One important caveat in such studies is that the total area sampled of an animal's distribution on the landscape may lead to different estimates of habitat use in such frameworks (Johnson 1980, Morrison 2001).

Understanding mule deer (*Odocoileus hemionus*) habitat use is important for natural resource managers making management, conservation and development decisions (Webb et al. 2013*b*). Mule deer are important socially and economically across the intermountain west of the United States (Preisler et al. 2006). Mule deer habitat selection studies have been conducted in California, Colorado, Wyoming, and Idaho (Anderson et al. 2012, Lendrum et al. 2012, McKee et al. 2015, Webb et al. 2013). Most of these studies were conducted during the winter season. However, summer resource selection may differ because of varying space use, seasonal preferences related to changing food resources, and reproductive strategies (Nielsen et al. 2003, 2004). Ager et al (2003) found changes in daily cycles of habitat use from spring to summer but did not detect changes in habitat use between daytime periods. Further, they concluded that temporal effects on mule deer resource selection were strongly affiliated with proximity to water sources, vegetation communities, and roads (Ager et al. 2003). Previous studies also have focused on resource selection in habitat containing anthropogenic influences such as energy development (Northrup et al. 2015, 2016*a*), human recreation (Preisler et al. 2006)), and open roads (Marshal et al. 2006, Long et al. 2009, Northrup et al. 2016*b*). Some of these studies documented negative indirect effects of anthropogenic activities on mule deer (Ager et al. 2003, Marshal et al. 2006, Lendrum et al. 2012, McKee et al. 2015, Northrup et al. 2016*a*).

Mule deer habitat studies identified a wide range of important predictors but proximity to roads and water are common important factors. Anthropogenic activity such as roads and traffic are perceived as risky by mule deer (Leblond et al. 2013, Prokopenko et al. 2017). Perceived risks associated with roads include direct effects like mortality due to deer-vehicle collisions (DVC) and indirect effects such as avoidance of roads and traffic (Webb et al. 2013*b*, Northrup et al. 2015, 2016*a*). This risk creates complex management issues. Roads often have the highest level of human activity among anthropogenic disturbances (Leblond et al. 2013). However, the influence of roads on mule deer is not consistently negative. For example, daily and seasonal habitat use for female mule deer in the Starkey Experimental Forest and Range in northeastern Oregon found deer used areas closer to open roads at all times of day (Ager et al. 2003). McKee et al. (2015) reported that female mule deer in the California Mojave National Preserve selected areas near paved roads with high volume traffic during all seasons with strongest selection during the winter. Marshal et al (2006) reported that female mule deer in the Lower Colorado River region of the Sonoran Desert were found further from roads during summer, autumn, and closer to roads in the winter. Similar to roads, water is also an important common predictor of mule deer habitat use (Marshal et al. 2006, Bender et al. 2007, Harris et al. 2015). Female mule deer in the Sonoran Desert were found closer to water catchments in the spring and further from catchments, washes, rivers, and canals during the summer (Marshal et al. 2006). McKee et al (2015) also reported female mule deer selected for areas near water, a limiting resource for mule deer in arid environments during all seasons and significantly more during summer and autumn; however, they did not investigate selection during different times of the day. Depending on the season and time of day, mule deer respond to the same habitat predictors in different ways, creating complex management issues (Ager et al. 2003, Sawyer et al. 2006, McKee et al. 2015, Northrup et al. 2015, Carrollo et al. 2017).

Little is known about habitat resource selection by mule deer in central New Mexico, specifically on the Pueblo of Santa Ana. Characteristics in this area such as an arid environment, resident populations of mule deer, relative low levels of vehicle traffic, and vegetation communities adapted to the unique climate of the region, are different from locations of past studies. Lack of information on mule deer ecology such as resource selection has constrained natural resource management and development decisions on the Pueblo of Santa Ana. The Pueblo of Santa Ana’s Department of Natural Resources (DNR) has been collecting long-term Global Positioning System (GPS) radio collar data on mule deer as part of a larger ungulate monitoring program. The data provide an opportunity to improve our understanding of mule deer ecology in and around this unique and understudied system. Creating separate seasonal and daily resource selection functions for mule deer in and around the Pueblo of Santa Ana has many applications such as creating predictive surface maps to delineate critical habitats and locating areas for water and habitat enhancement projects. Such research also may inform similar efforts by other natural resource managers in this region.

The objective of our study was to create RSF's for female and male mule deer in the summer and winter seasons during the morning, day, evening, and night time periods. Therefore, we hypothesized that seasonal and daily resource selection by mule deer in and around the Pueblo of Santa Ana, New Mexico should exhibit patterns similar to mule deer research from other states. If our hypothesis is true, we predict that seasonal variations of resource selection should be far more important than daily variation and that patterns of mule deer space use should be responsive to features such as water, roads, and habitat cover type.

1.2 Methods

The study area encompasses the Pueblo of Santa Ana Indian Reservation, New Mexico and surrounding lands. It lies within the Lower Basin and Range Physiographic Province, and contains broad desert basins, with discontinuous mountain ranges (Harper 2016). Undulating mesas characterize the area, including lower rolling plains interrupted by hill slopes, dissected by rivers and ephemeral washes. A total estimate of 336 km of ephemeral washes drain into the Rio Jemez and Rio Grande within the Pueblo of Santa Ana's boundaries. The Santa Ana Mesa, above the river bottoms, has the highest elevation at 1,950 m. Lower elevations range between 1,580 m and 1,700 m, and consist of rolling, sand dominated desert surfaces that overlay sandstone and gravel surfaces originating from the Santa Fe Formation (Kelley and Kudo 1978). Several washes dissect the lower plains, which drain the uplands into the Rio Jemez and Rio Grande. Sand deposits stabilized by vegetation are common in the plains, washes, and leeward hillslopes. Vegetation in this area is diverse. The mesa platforms consist of continuous stands of oneseed juniper (*Juniperus monosperma*) savannahs, fragmented by plains grasslands. Rockier mesa slopes contain oneseed juniper woodlands. Slopes leading off the mesa are dominated by oneseed juniper and pinyon pine (*Pinus edulis*) woodlands containing scattered patches of mountain mahogany (*Cercocarpus montanus*), skunkbush sumac (*Rhus trilobata*), and fendlerbush (*Fendlera rupicola*). Lowland plains are diverse as well and consist of a mosaic of shrub and grassland communities. Shrub lands are dominated by broom dalea (*Psorothammus scoparius*), sand sagebrush (Artimesia filifolia), oneseed juniper, dropseed (*Sporobolus* spp.) and galleta (*Pleuraphis jamesii*) grasslands. Riparian vegetation includes native species of Rio Grande cottonwood (*Populus deltoides spp. wislizeni*) forest, coyote willow (*Salix exigua*) shrub lands, and saltgrass (*Disichlis spicata*) flats. Invasive non-native species that occur in riparian vegetation are salt cedar (*Tamarix ramosissima*) and Russian olive (*Eleagnus angustifolia*). The arid high desert watersheds in the study area receive on average 22.50 cm (8.86 in) of rainfall per year, mostly in months of July and August during short intense monsoon rainstorm events (Bernalillo weather station data collected 1924-1982). Winter precipitation averages 6.50 cm (2.56 in) per year mostly during the months of December through February (Harper 2016).

The study area was centered around the 32,045 ha Pueblo of Santa Ana where mule deer were captured and collared (Figure 1.1). We delineated a larger study area for estimating predictive variables by creating a buffer around each observed mule deer location, including locations outside the Pueblo of Santa Ana boundary. The size of this buffer was the average maximum distance between any two points recorded for each animal (Boyce et al. 2003, Webb et al. 2013*b*). We used Arc GIS 10.4, (Environmental Systems Research Institute, Redlands, California) to create a buffer around each observed deer location, and those buffered areas were merged into one polygon delineating the ~400,708 ha extent of the study area. This larger study area includes lands from additional Pueblo Indian Reservations (Sandia, Zia, San Felipe, Jemez, Kewa, and Cochiti), Bureau of Land Management, Forest Service, National Park Service, Valles Caldera National Preserve, state and private lands (Figure 1.1).

The Pueblo of Santa Ana DNR staff captured and collared mule deer within the pueblo boundary. Helicopters (Aerowest and Heliqwest) were used in the capturing of animals. Mule deer were captured using either netguns or dartguns (carfentanil citrate/xylazine hydrochloride loaded darts). Methods used in capturing of animals complied with field methods of the American Society of Mammalogists (Sikes 2016) and the New Mexico Department of Game and Fish. For DNR record keeping, data were collected on body condition and blood samples were collected. In addition, animals were administered a dose of vitamin B, selenium, and penicillin. Captures occurred on the following dates: (22 November, 2010, 23 November, 2010, 25 January, 2011, 25 March, 2012, 26 March, 2012, 25 March, 2015, 8 April, 2015, and 3 December, 2015). A total of 15 mule deer, eight male and seven females, were outfitted with GPS radio collars and ear tags during the capturing process. The collars were programmed to send locations remotely every four hours (schedule found in appendix) for two years. The GPS telemetry collar models used included five D-cell Globalstar GPS collars (North Star Science and Technology), six ATS G2110D Store-on-Board GPS collars (Advanced Telemetry Solutions), and four ATS 2110E Iridium GPS collar (Advanced Telemetry Solutions) types. GPS radiocollars provide X and Y coordinates for deer locations as well as time and date for each set of coordinates.

In order to build a resource selection function (RSF) we categorized vegetation types within the Pueblo of Santa Ana from GIS layers created by Harper and Trafton (2004). For areas outside the Pueblo of Santa Ana we categorized vegetation types from the U.S. Geological Survey's GAP/LANDFIRE National Terrestrial Ecosystems data set (2011). For the portion of our study area within the Pueblo of Santa Ana we reclassified 36 vegetation types from the Harper and

Trafton (2004) GIS layer into 14 categories that best matched vegetation communities on the Pueblo. In addition, we reclassified 12 GAP/LANDFIRE National Terrestrial Ecosystem 2011 vegetation types that occur outside the Pueblo of Santa Ana boundaries into the reclassified 14 categories on the Pueblo. After removing highly correlated covariate types (Pearson correlation coefficients > 0.5), we retained 10 of the 14 habitat categories in our analysis. The habitat variables used in our analyses were arroyo, riparian, juniper woodland-shrub, galleta grassland, juniper-grama grassland, low use dirt roads, high use dirt roads, paved roads, all roads, and water. We used GIS layers for roads outside the Pueblo of Santa Ana boundary that originated from NM RGIS data (Earth Data Analysis Center at The University of New Mexico). For roads within the Pueblo of Santa Ana, we supplemented the NM RGIS data with layers provided by the DNR GIS technician. Potential influence by roads on habitat use was evaluated by categorizing roads into paved, low use dirt road and high use dirt road categories, similarly to roads categorized by Johnson et al. (2000). The category “all roads” combined all road categories into a single coverage. The habitat variable “water” includes wildlife drinkers, water tanks, water catchments, and rivers.

Developing RSF’s requires the collection of location data of fine scale animal habitat use. GPS telemetry collars have become a highly effective means of collecting fine scale location data often used in RSF’s (Ager et al. 2003, Boyce 2006, Marshal et al. 2006, Northrup et al. 2013). For each deer location recorded from GPS collars and corresponding randomly generated available points we used the “Near (Analysis)” tool in ArcGIS (version 10.4) to measure the nearest distance to each of the six cover types and four road types (Northrup et al. 2013). The “distance-to” data were used as predictors in statistical analysis (Conner et al. 2003).

Habitat use typically varies as a function of the time of day, season, and their interaction, therefore, developing unique models of habitat selection within these time windows may improve understanding of mule deer ecology (Boyce 2006, Sawyer et al. 2006). We converted location data to local Mountain Standard Time, for all 15 mule deer. We delineated the summer season from 1 June to 30 September, and winter season from 1 October to 31 May. Within each day, the two hours before and after sunrise were categorized as morning, the two hours before and after sunset were categorized as evening, the time between evening and morning was categorized as night and time between morning and evening categorized as day (Webb et al. 2013). Unique models were estimated from data collected during each time period for the two seasons (Webb et al. 2013*b*). Additional models were created by aggregating morning and evening periods into a crepuscular period and night and day periods into a non-active period.

To characterize available habitat for each individual deer we estimated utilization distributions. These utilization distributions were generated for all possible seasons (summer, winter) and period of day (morning, day, evening, night) using the adaptive local convex hull (a-LoCoH) method (Getz et al. 2007, Lichti and Swihart 2011).

Statistical comparisons between used and available animal locations can provide insights into the effects habitat has upon animal distribution (Manly et al. 2002). For each model, we generated a random selection of available points to compare with used points. Each set of random points were generated from within corresponding seasonal and daily utilization distributions for each deer. Twenty available points were randomly selected for each used point (Lele 2009, Northrup et al. 2013). Logistic regression comparisons in a used-available framework can estimate the probability of use of different habitat or cover types (Manly et al. 2002). These approaches have been used in several other mule deer habitat studies (Boyce 2006, Anderson et al. 2012, Northrup et al. 2013). Accordingly we used a Bernoulli corrected, logistic generalized linear mixed model, to evaluate how our chosen habitat predictors influenced the distribution of mule deer in our system (Manly et al. 2002, Bolker et al. 2009). R packages lme4 (Bates et al. 2015) and MuMIn (Barton 2018) were used to run all models in our analysis in R Studio 3.3.2 (R Core Team 2017). The habitat predictors were modeled as fixed effects, while each individual mule deer was modeled as a random effect, consistent with other RSF models using this approach (McKee et al. 2015, Carrollo et al. 2017). We determined the best models using an information-theoretic framework based upon the difference between calculated Akaike's Information Criterion adjusted for small sample size (AIC_c) values (Burnham and Anderson 2002).We conducted full model averaging for each period of day by season to generate estimates of the relationships between predictor variables and deer use (Bozdogan 2000).

1.3 Results

Seven does were captured and collared during the study. A total 20,214 locations were recorded for all collared does combined. The minimum number of locations recorded for any doe was 1,309 and the maximum number of locations recorded for any doe was 4,321. The mean number of locations recorded per collared doe was 2,888 locations. The number of locations recorded for does during the summer season varied as a function of the time of day. Similar patterns were observed in the number of locations recorded for does during the winter season (Table 1.1).

Eight bucks were captured and collared during the study. A total of 21,304 locations were recorded for all collared bucks combined. The minimum number of locations recorded for any buck was 498 and the maximum number of locations recorded for any buck was 4,880. The mean number of locations recorded per collared buck was 2,663 locations. Similar to does, numbers of locations recorded for bucks varied as a function of the time of day during both summer and winter seasons (Table 1.2).

Season and time of day impacted the adaptive local convex hull estimation of utilization distribution sizes for collared does in our study (Table 1.3). During the summer, morning and day, UD sizes were similar and evening and night sizes were similar. Summer morning and day on average had smaller UD sizes than the evening and night UD sizes. For does during the summer, crepuscular UD sizes were larger than non-active UD sizes. During the winter, UD sizes were larger than the summer sizes for all times of the day. Winter morning had the smallest UD sizes compared to all other times of the day during the winter. Winter day had the largest UD sizes compared to all other times of the day during the winter season. Winter crepuscular UD sizes were smaller compared to the winter non-active UD sizes for does.

Season and time of day affected the adaptive local convex hull estimates of utilization distribution sizes for collared bucks in our study (Table 1.4). During the summer, morning and evening bucks had similar UD sizes, day and night also were similar in sizes. On average during the summer, morning and evening bucks had smaller UD sizes compared to night and day. Summer crepuscular UDs were larger than non-active UD sizes. Winter UD sizes for bucks were larger during all times of the day compared to corresponding times in the summer. During the winter, the morning had the smallest UD sizes compared to all other times of the day. Winter day and evening had similar UD sizes, while winter night had the largest UD sizes on average for bucks during all times of the day. During the winter, bucks had larger non-active UD sizes compared to the crepuscular period.

Results for female and male mule deer resource selection during the summer and winter season at different times of the day are reported in tables and figures below.

1.4 Discussion

Our observation that season influenced habitat selection much more than the time of day for both female and male mule deer in and around the Pueblo of Santa Ana, New Mexico is consistent with studies from other locations. For example, in Oregon, Ager et al. (2003) found a similar pattern when their female mule deer displayed changes in daily cycles of habitat use from spring to summer but did not detect changes in habitat use within daytime periods. An explanation for this phenomenon may be that mule deer habitat selection is more sensitive to seasonal changes associated with the phenology of primary forage species more than diel variation (Boeker et al. 1972, Collins and Urness 1983, Ager et al. 2003, Marshal et al. 2006, McKee et al. 2015).

The “reproductive-strategy hypothesis” states that females should select areas that provide sufficient food, water, and security to raise offspring. Because males do not participate in rearing offspring they are able to forage over a much larger area (Main and Coblentz 1996). Consistent with this hypothesis, male and female mule deer in our study exhibited slight differences in resource selection during each season and at different times of the day, resulting in sexual spatial segregation. Male mule deer are larger than females, and our observations are consistent with other sexually dimorphic ruminants that spatially segregate (Main and Coblentz 1996, Bowyer and Kie 2004). Our spatially explicit maps depicting the probability of mule deer space use of female and male mule deer in our study with 95^{th}, 75^{th}, and 50^{th} predictive surface probabilities demonstrated differences between male and female mule deer space use behavior on the Pueblo of Santa Ana (Fig. 1.4). Past studies on ruminants observed subtle differences in use of habitat associated with sexual segregation (Bowyer et al. 1996). Main and Coblentz (1996) described behavioral differences between male and female mule deer in southeastern Oregon attributed to an adaptation to increase reproductive fitness.

Water is often a limiting resource for mule deer in arid environments (Bleich et al. 2012, Harris et al. 2015). In our results, water was a significant predictor in resource selection for female mule deer during the day and evening. Female mule deer were located significantly farther from water during the summer day and closer to water during the winter day, however farther from water during the winter evening. Our findings are similar to results from the Sonoran desert where female mule deer were located farther from catchments, rivers, and canals during the summer (Marshal et al. 2006). Migratory female mule deer in northeast Nevada also preferred areas near water during the winter when the climate was substantially drier on the winter range than the summer range (Shoemaker et al. 2018). However, McKee et al. (2015) found female mule deer closer to water during all seasons and significantly closer during the summer and autumn. Where water is a limiting resource, it may influence not only habitat selection, but also home range size by mule deer (Marshal et al. 2005, Alcala-Galvan and Krausman 2013). McKee et al. (2015) demonstrated this relation by showing female mule deer utilization distributions contracted during all seasons when supplemental water was provided. Our observation that utilization distributions were smaller for both males and females during the summer is consistent with this general phenomenon because water is more prevalent on the Pueblo of Santa Ana landscape during the summer months. Interestingly, our RSF's only identified water as a significant predictor on the Pueblo of Santa Ana during the daytime. However, the results for our female mule deer, much like those for Marshal et al. (2006), showed habitat selection that differs from restricting space use when water is more available. Our observed pattern for male mule deer selecting locations closer to water during the summer day, and further from water during the winter day is consistent with this phenomenon of restricting space use when water is available.

Roads are known to influence mule deer habitat selection and our results regarding roads were similar to work in other locations (Marshal et al. 2006, Lendrum et al. 2012, McKee et al. 2015). Mule deer in our study area are sympatric with elk. Where mule deer and elk are sympatric, mule deer select habitat to avoid elk (Johnson et al. 2000, Long et al. 2009). Furthermore, it is known that roads negatively affect elk space-use across multiple scales (Prokopenko et al. 2017). Thus, female mule deer in our study may be avoiding elk by selecting for areas near roads during both seasons. Migrating mule deer in the Piceance Basin in northwest Colorado demonstrate similar behavioral responses to elk (Lendrum et al. 2012). A study at the Starky Experimental Range, found mule deer used areas closer to open roads all times of the day (Ager et al. 2003). Similarly, during the summer, our female mule deer significantly selected for areas near paved roads at all times of the day and near high use dirt roads at all times other than night. Our female mule deer were located significantly closer to all roads at night and further in the day during the winter. Female mule deer in the California Mojave National Preserve were found near high use paved roads during all seasons with strongest selection during the winter (McKee et al. 2015). In contrast, our female mule deer were found significantly closer to paved roads at all times during the summer and during the winter evening. In conclusion, our results demonstrate that mule deer in and around the Pueblo of Santa Ana respond to roads consistent with observations across their distribution.

In our results, several different habitat cover types significantly influenced resource selection by mule deer we monitored. Washes or arroyos are both terms used to define areas associated with ephemeral water flows. With an increase in available moisture the plant communities associated with washes and arroyos provide excellent cover and food for mule deer during the spring and summer seasons (Krausman 1998). Our results for the use of arroyos were similar to female mule deer in the Sonoran Desert where deer were observed closer to washes during the summer (Marshal et al. 2006). Both female and male mule deer significantly selected for areas near arroyo habitat during the summer season. Previous studies indicate that although grasslands may provide food seasonally, grassland habitat does not provide enough cover to warrant use by mule deer (Webb et al. 2013*b*). Our results indicate female mule deer were found significantly further from galleta grassland except during the winter day. Male mule deer were also significantly further from galleta grassland during the summer, however were closer during the winter night, similar to migratory female mule deer in northeast Nevada (Shoemaker et al. 2018). Juniper dominated vegetative communities may provide cover that helps with predator avoidance, and thermal regulation for mule deer in our system (Short et al. 1977). Juniper-grama grassland and juniper woodland-shrub vegetative communities occurred most frequently in our system and were significant predictors for mule deer resource selection during most times of the day in the summer and winter. In our study system, female mule deer were found significantly closer to juniper woodland-shrub during all times of the day except during the summer morning. Juniper-grama grassland is a positive significant predictor for female mule deer resource selection during the summer evening, night, and winter morning and day. Riparian habitat in our system contain areas of dense vegetation restricting travel through these areas, and provide increased cover for predators. In addition, mule deer may avoid this habitat given that these areas are likely non-beneficial as a food resource (Marshal et al. 2006). Consistent with studies from across the range for mule deer, our results for the selection of resources such as arroyo, grassland, and juniper communities demonstrates that access to quality forage and cover for thermoregulation and safety from predators are the underlying considerations for mule deer we studied (Webb et al. 2013*a*).

1.5 Management Implications

The landscape level predictive surfaces we developed in this work for mule deer may be relevant in a variety of different ways. These maps may help anticipate, during different times of the year, the critical areas to consider for mule deer management decisions regarding minimization of disturbance, identifying preferred habitat, and delineating areas of concern (i.e. roads, potential development, fences, and travel corridors). Such maps can help identify areas for habitat enhancement projects like the development of water sources when mule deer need them most during the summer and winter on the Pueblo of Santa Ana. During winter aerial surveys, such maps could allow managers to target areas with high probabilities of mule deer occurrences for accurate counts. Maps may also be useful in development planning processes to help mitigate the impact and displacement of mule deer. For example, the maps can serve as inputs for spatially explicit individual based models to contrast the relative disturbance effects of road development on mule deer (Chapter 2). Furthermore, the extent of the area used by mule deer captured on the Pueblo of Santa Ana reinforces the value of such maps for developing coordinated landscape level management plans that transcend the boundaries of multiple landowners and management agencies.

Mule deer populations have been declining across much of their range for the past 50 years (Unsworth et al. 1999). Mule deer are important resources economically, socially, and culturally, and provide opportunities for recreation, including wildlife viewing and hunting (Preisler et al. 2006). Native American communities in the southwest respect and utilize mule deer as a cultural resource, for food and material, thus conclusions from our work can help improve mule deer management in and around the Pueblo of Santa Ana. For example, biologists might consider providing water during times of high use where forage and cover exist. Such supplemental water could reduce the need for long distance movements by mule deer, which would minimize their expenditures of energy and risk of exposure to mortality from predators or vehicles, thereby increasing fitness (Harris et al. 2015). Our observations of the importance of juniper woodland-shrub cover type, for the mule deer we studied, support existing practices of thinning juniper to increase forage species like shrubs and forbs (Boeker et al. 1972). In conclusion, our results that seasonal variation influenced resource selection far more than daily variation were consistent with other studies on mule deer across the intermountain west. Therefore, the insights from these studies have been established as locally relevant in this unique system.

Table 1.1 Sample size distribution for GPS radio collar locations recorded for all female mule deer, during each period of day for summer and winter seasons in and around the Pueblo of Santa Ana, NM

Data Subset	n	mean	minimum	maximum
All Does	20,214	2887.71	1309	4321
Summer Morning	1,161	165.86	30	243
Summer Day	2,223	317.57	47	474
Summer Evening	1,123	160.43	31	243
Summer Night	2,109	301.29	31	482
Summer Crepuscular	2,284	163.14	30	243
Summer Non-active	4,332	309.43	31	482
Winter Morning	2,157	308.14	70	479
Winter Day	4,322	617.43	282	956
Winter Evening	2,194	313.43	112	481
Winter Night	4,925	703.57	190	963
Winter Crepuscular	4,351	310.79	70	481
Winter Non-active	9,247	660.5	190	963

Table 1.2 Sample size distribution for GPS radio collar locations recorded for all male mule deer, during each period of day for summer and winter seasons in and around the Pueblo of Santa Ana, NM.

Data Subset	n	mean	minimum	maximum
All Bucks	21,304	2663.00	498	4880
Summer Morning	1,205	150.63	0	273
Summer Day	2,951	368.88	0	729
Summer Evening	1,202	150.25	0	276
Summer Night	1,556	194.50	0	343
Summer Crepuscular	2,407	150.44	0	276
Summer Non-active	4,507	281.69	0	729
Winter Morning	2,327	290.88	49	536
Winter Day	4,361	545.13	66	1044
Winter Evening	2,379	297.38	66	537
Winter Night	5,323	665.38	71	1142
Winter Crepuscular	4,706	294.13	49	537
Winter Non-active	9,684	605.25	66	1142

Table 1.3 Adaptive local convex hull (LoCoH.a) utilization distributions (ha) estimated for all female mule deer, for each period of day during summer and winter seasons in and around the Pueblo of Santa Ana, NM.

Data Subset	mean	minimum	maximum
All Does	2,079.68	1,168.75	2,928.85
Summer Morning	1,452.29	617.21	2,199.28
Summer Day	1,426.57	537.14	1,927.36
Summer Evening	1,537.35	984.27	1,937.61
Summer Night	1,538.46	498.94	2,066.22
Summer Crepuscular	1,946.17	992.56	2,902.65
Summer Non-active	1,748.50	706.82	2,390.96
Winter Morning	2,494.28	1,232.46	3,439.34
Winter Day	2,806.09	1,473.50	5,037.34
Winter Evening	2,630.90	1,631.61	3,393.57
Winter Night	2,751.51	1,516.59	3,940.42
Winter Crepuscular	3,076.20	2,024.25	4,288.73
Winter Non-active	3,164.12	2,356.35	4,921.51

Table 1.4 Adaptive local convex hull (LoCoH.a) utilization distributions (ha) estimated for all male mule deer, for each period of day during summer and winter seasons in and around the Pueblo of Santa Ana, NM.

Data Subset	mean	minimum	maximum
All Bucks	4,277.89	2,481.05	7,303.60
Summer Morning	3,137.65	1,080.47	7,890.75
Summer Day	3,556.76	1,466.82	8,234.07
Summer Evening	3,130.24	1,742.44	5,896.25
Summer Night	3,414.88	1,773.06	6,270.80
Summer Crepuscular	5,054.86	1,770.29	8,594.40
Summer Non-active	4,245.51	2,047.26	8,921.20
Winter Morning	4,817.87	1,463.93	8,060.29
Winter Day	5,218.85	2,742.22	8,676.94
Winter Evening	5,143.58	1,539.55	8,690.56
Winter Night	5,818.07	3,323.35	7,818.78
Winter Crepuscular	5,701.00	1,735.88	8,921.20
Winter Non-active	5,988.37	3,246.95	8,173.11

Table 1.5 Top models for female mule deer resource selection during the summer morning in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road	0	0.07	10	-4508.17
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian	0.37	0.06	9	-4509.35
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0.75	0.05	11	-4507.54
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road	0.78	0.05	9	-4509.56
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian	1.15	0.04	10	-4508.74
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Paved Road, Riparian	1.29	0.04	8	-4510.81
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road	1.33	0.04	8	-4510.83

Table 1.5 Continued.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	1.54	0.03	10	-4508.94
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road	1.55	0.03	9	-4509.94
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Water	1.6	0.03	11	-4507.97
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	1.71	0.03	10	-4509.02
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Water	1.76	0.03	10	-4509.05

Table 1.6 Top models for female mule deer resource selection during the summer day in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.45	11	-8506.94
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.48	0.21	12	-8506.68

Table 1.7 Top models for female mule deer resource selection during the summer evening in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0	0.22	11	-4353.92
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road	0.43	0.18	10	-4355.13
All Roads, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road	1.57	0.1	9	-4356.7
All Roads, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	1.75	0.09	10	-4355.79
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.98	0.08	12	-4353.9

Table 1.8 Top models for female mule deer resource selection during the summer night in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0	0.52	10	-8096.46
All Roads, Arroyo, Galleta Grassland, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.9	0.2	11	-8096.41
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	1.99	0.19	11	-8096.45

Table 1.9 Top models for female mule deer resource selection during the summer crepuscular period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0	0.41	11	-8862.89
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road	1.37	0.21	10	-8864.57
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.6	0.18	12	-8862.69

Table 1.10 Top models for female mule deer resource selection during the summer non-active period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.49	12	-16659.7
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0.37	0.4	11	-16660.9

Table 1.11 Top models for female mule deer resource selection during the winter morning in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Riparian	0	0.15	8	-8540.35
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub	1.45	0.07	7	-8542.07
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Riparian	1.54	0.07	9	-8540.12
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian	1.61	0.07	9	-8540.15
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Riparian, Water	1.81	0.06	9	-8540.25
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Riparian	1.89	0.06	9	-8540.29

Table 1.12 Top models for female mule deer resource selection during the winter day in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Water	0	0.26	11	-16851.9
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Water	0.28	0.22	10	-16853.1
All Roads, Arroyo, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Water	1.74	0.11	9	-16854.8
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Riparian, Water	1.86	0.1	11	-16852.9
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.86	0.1	12	-16851.9
All Roads, Arroyo, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Water	1.96	0.1	10	-16853.9

Table 1.13 Top models for female mule deer resource selection during the winter evening in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Water	0	0.31	9	-8615.89
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Water	1.08	0.18	10	-8615.86
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Low Use Dirt Road, Low Use Dirt Road, Paved Road, Water	1.32	0.16	10	-8615.11
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian, Water	1.96	0.12	10	-8615.74

Table 1.14 Top models for female mule deer resource selection during the winter night in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian	0	0.36	10	-19444.2
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian, Water	1.96	0.14	11	-19444.2

Table 1.15 Top models for female mule deer resource selection during the winter crepuscular period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Low Use Dirt Road, Paved Road, Riparian,	0	0.55	7	-17275.9
All Roads, Arroyo, Low Use Dirt Road, Paved Road, Riparian, Water	1.61	0.25	8	-17275.7

Table 1.16 Top models for female mule deer resource selection during the winter non-active period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.61	12	-36386.53
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.55	0.28	11	-36388.31

Table 1.17 Top models for male mule deer resource selection during the summer morning in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All RoadsArroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0	0.33	10	-4754.8
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0.9	0.21	11	-4754.25
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	1.05	0.2	11	-4754.33
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.72	0.14	12	-4753.66

Table 1.18 Top models for male mule deer resource selection during the summer day in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Riparian	0	0.26	4	-11730.6
All Roads, Riparian, Water	0.95	0.16	5	-11730.1
All Roads, Low Use Dirt Road, Water	1.1	0.15	5	-11730.2
All Roads, Low Use Dirt Road, Riparian, Water	1.36	0.13	6	-11729.3
All Roads, Paved Road, Riparian	1.66	0.11	5	-11730.4

Table 1.19 Top models for male mule deer resource selection during the summer evening in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Low Use Dirt Road, Paved Road, Riparian	0	0.51	10	-4693.59
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Low Use Dirt Road, Paved Road, Riparian, Water	1.82	0.21	11	-4693.5
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	1.96	0.19	11	-4693.57

Table 1.20 Top models for male mule deer resource selection during the summer night in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian, Water	0	0.21	10	-6164.08
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.01	0.12	11	-6163.59
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian	1.34	0.11	9	-6165.76
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian, Water	1.55	0.1	11	-6163.86
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.76	0.09	12	-6162.96
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Paved Road, Riparian	1.95	0.08	10	-6165.06

Table 1.21 Top models for male mule deer resource selection during the summer crepuscular period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian	0	0.44	11	-9473.44
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.26	0.23	12	-9473.07

Table 1.22 Top models for male mule deer resource selection during the summer non-active period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.29	10	-17847.2
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0.18	0.27	11	-17846.3
Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0.59	0.22	11	-17846.5
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0.83	0.19	12	-17845.6

Table 1.23 Top models for male mule deer resource selection during the winter morning in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.87	12	-8902.11

Table 1.24 Top models for male mule deer resource selection during the winter day in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.57	11	-16523.3
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0.57	0.43	12	-16522.6

Table 1.25 Top models for male mule deer resource selection during the winter evening in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAICc, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.37	11	-9140.21
All Roads, Arroyo, High Use Dirt Road, Juniper-Grama Grassland, Low Use Dirt Road, Paved Road, Riparian, Water	0.07	0.36	10	-9141.25
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.93	0.14	12	-9140.17

Table 1.26 Top models for male mule deer resource selection during the winter night in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.55	11	-20272.3
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0.47	0.44	12	-20271.5

Table 1.27 Top models for male mule deer resource selection during the winter crepuscular period in and around the Pueblo of Santa Ana, NM. Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	0.66	12	-18052.2
All Roads, Arroyo, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	1.35	0.34	11	-18053.9

Table 1.28 Top models for male mule deer resource selection during the winter non-active period in and around the Pueblo of Santa Ana, NM Models were included here if they performed within 2 ΔAIC_c of the top model. Included for each model is the name, ΔAIC_c, the model weight (w), the number of parameters (K), and log-likelihood (LL). Covariates for all models are measured as distance to nearest occurrence of that feature from point locations.

Best Fit Models	ΔAIC_c	w	K	LL
All Roads, Arroyo, Galleta Grassland, High Use Dirt Road, Juniper-Grama Grassland, Juniper Woodland-Shrub, Low Use Dirt Road, Paved Road, Riparian, Water	0	1	12	-36856

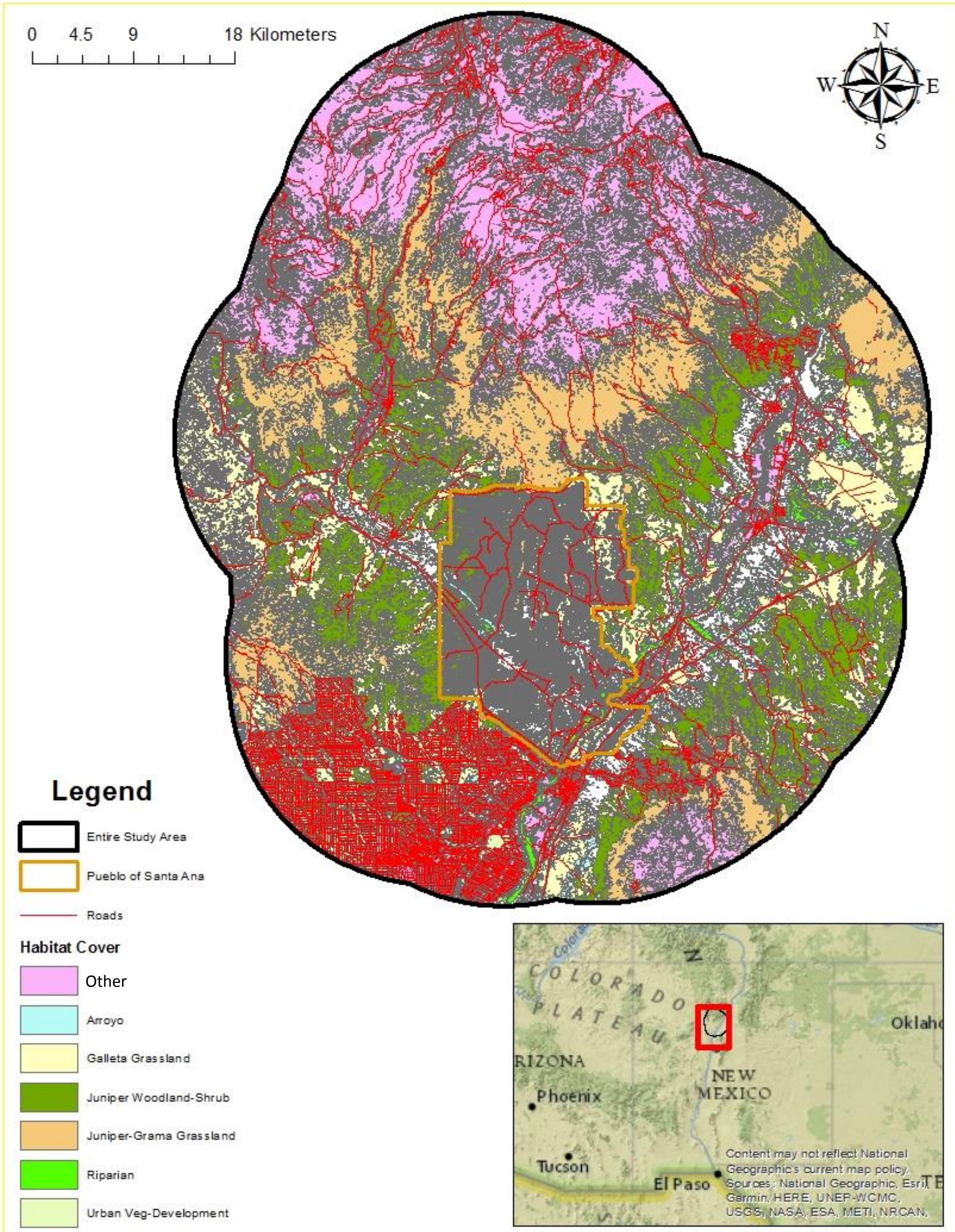

Figure 1.1 The entire study area (~400,708 ha) is displayed by the large polygon that was delineated by creating a 1850 m buffer around each observed mule deer location then merging those into one polygon. The Pueblo of Santa Ana, NM USA (32,045 ha) is located in the middle of the entire study area and is the location where deer were captured and collared.

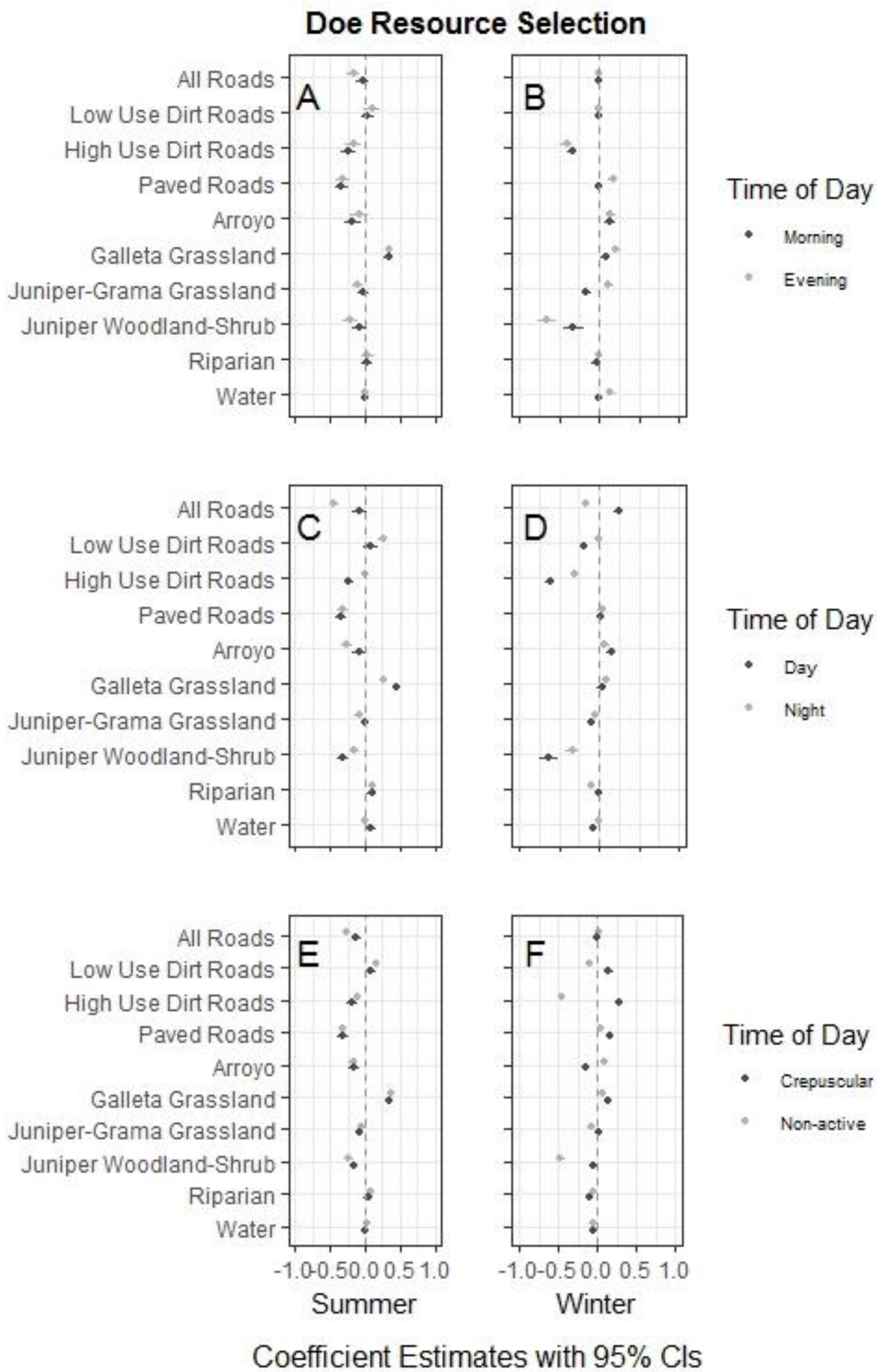

Figure 1.2 Standardized beta coefficients for female mule deer resource selection in and around the Pueblo of Santa Ana, NM during the summer morning and evening (A), winter morning and evening (B), summer day and night (C), winter day and night (D), summer crepuscular and non-active (E), and winter crepuscular and non-active (F), periods of the day. Points represent the model averaged coefficient of the selection probability for each covariate and error bars present the full 95% confidence interval.

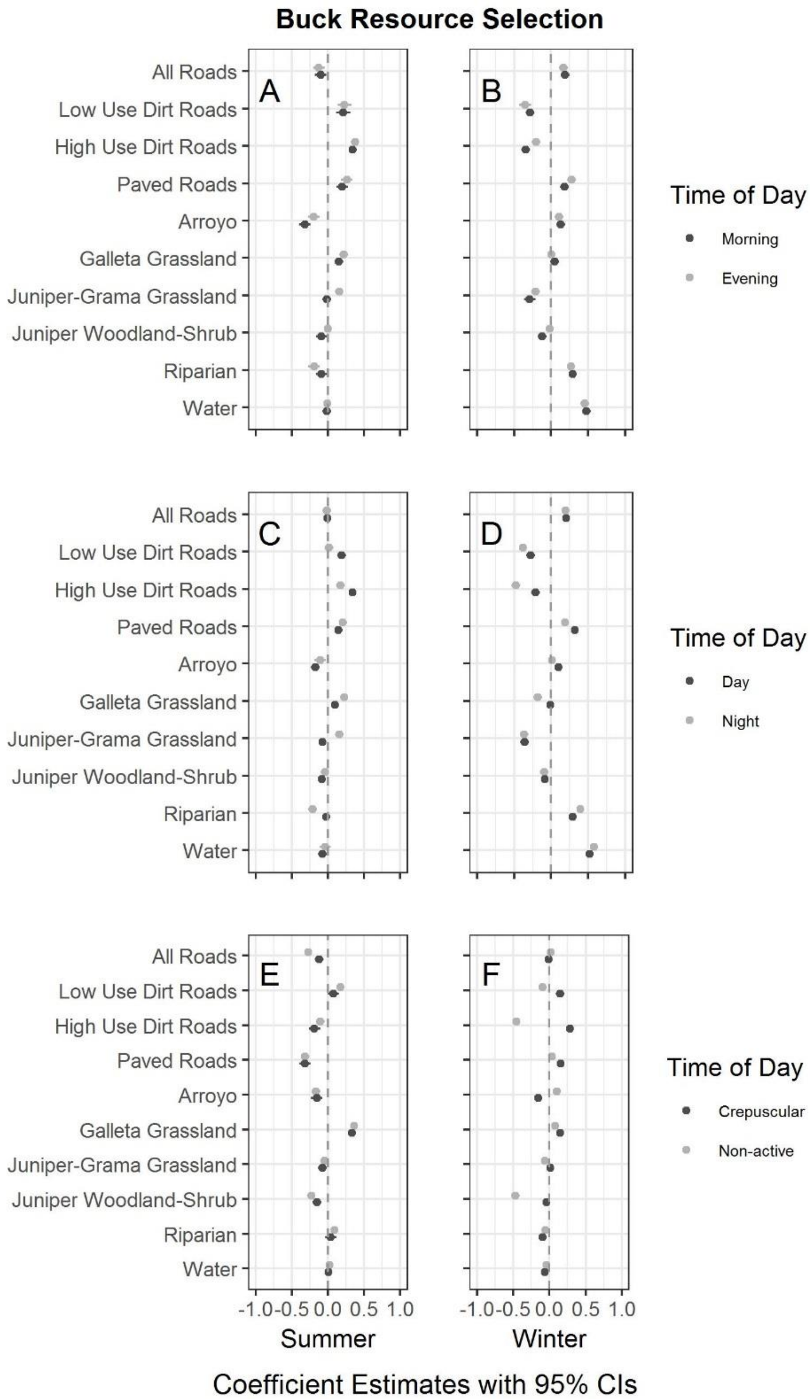

Figure 1.3 Standardized beta coefficients for male mule deer resource selection in and around the Pueblo of Santa Ana, NM during the summer morning and evening (A), winter morning and evening (B), summer day and night (C), winter day and night (D), summer crepuscular and non-active (E), and winter crepuscular and non-active (F), periods of the day. Points represent the model averaged coefficient of the selection probability for each covariate and error bars present the full 95% confidence interval.

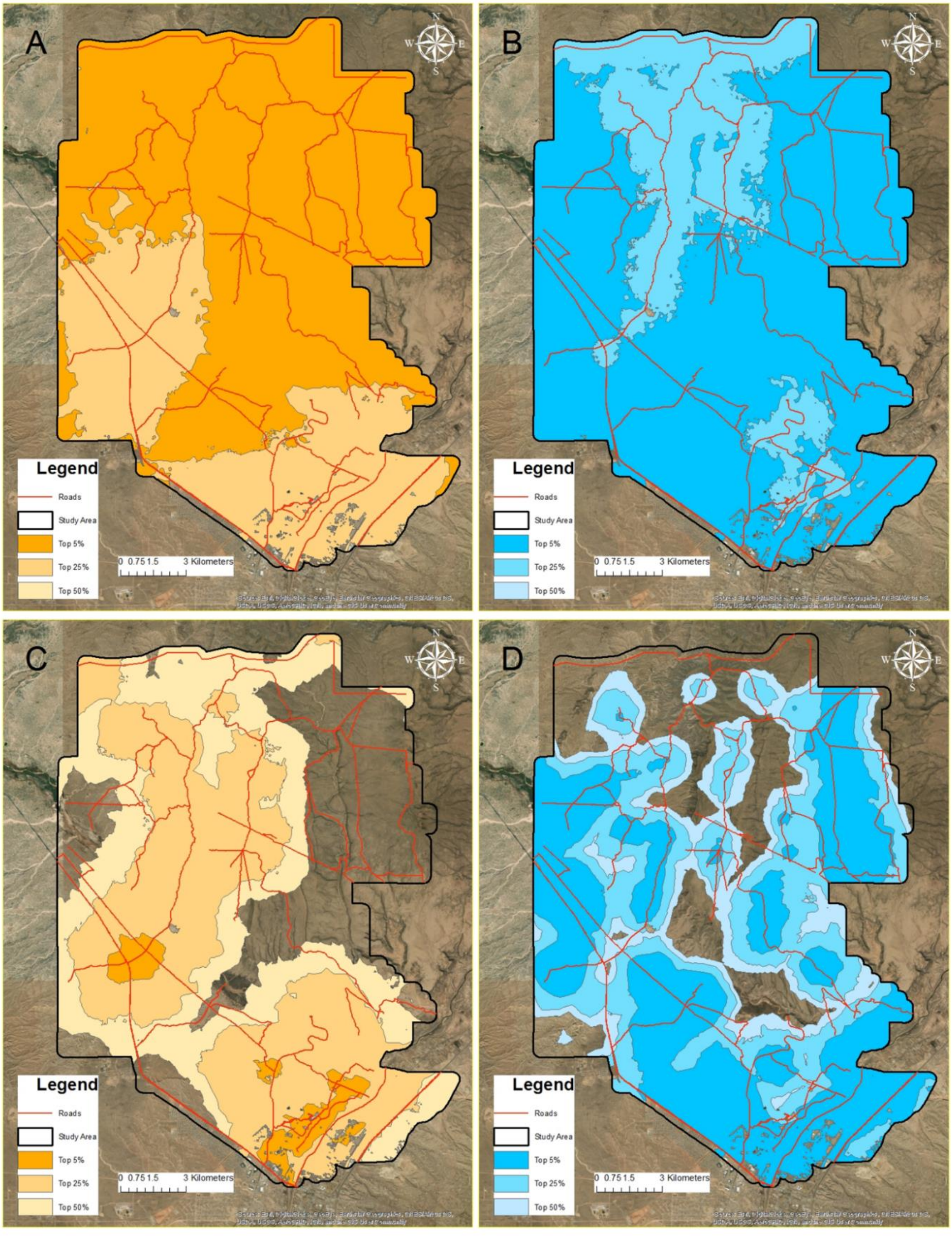

Figure 1.4 Predictive surface maps for the top 5%, 25% and 50% preferred area for mule deer on the Pueblo of Santa Ana, New Mexico. We collected mule deer location data for maps in 2010-2015. Maps display preferred areas for female summer morning (A), female winter morning (B), male summer morning (C), and male winter morning (D).

1.6 References

Ager, A. A., B. K. Johnson, J. W. Kern, and J. G. Kie. 2003. Daily and Seasonal Movements and Habitat Use By Female Rocky Mountain Elk and Mule Deer. Journal of Mammalogy 84:1076–1088.

Alcala-Galvan, C. H., and P. R. Krausman. 2013. Home range and habitat use by desert mule deer in altered habitats. California Fish and Game 99:65–79.

Anderson, E. D., R. a. Long, M. P. Atwood, J. G. Kie, T. R. Thomas, P. Zager, and R. T. Bowyer. 2012. Winter resource selection by female mule deer Odocoileus hemionus : functional response to spatio-temporal changes in habitat. Wildlife Biology 18:153–163.

Bleich, V. C., J. G. Kie, E. R. Loft, T. R. Stephenson, M. W. Oehler, and A. L. Medina. 2012. Managing Rangelands for Wildlife. 7th edition. The John Hopkins University Press, Baltimore, Maryland.

Boeker, E. L., V. E. Scott, H. G. Reynolds, and B. A. Donaldson. 1972. Seasonal Food Habits of Mule Deer in Southwestern New Mexico. Journal of Wildlife Management 36:56–63.

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. H. H. Stevens, and J. S. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24:127–135.

Bowyer, R. . T., J. G. . Kie, and V. Van Ballenberghe. 1996. Sexual Segregation in Black-Tailed Deer : Effects of Scale. Journal of Wildlife Management 60:10–17.

Bowyer, R. T., and J. G. Kie. 2004. Effects of Foraging Activity on Sexual Segregation in Mule Deer. Journal of Mammalogy 85:498–504.

Boyce, M. S. 2006. Scale for resource selection functions. Diversity and Distributions 12:269–276.

Boyce, M. S., J. S. Mao, E. H. Merrill, D. Fortin, M. G. Turner, J. Fryxell, and P. Turchin. 2003. Scale and heterogeneity in habitat selection by elk in Yellowstone National Park. Ecoscience 10:421–431.

Bozdogan, H. 2000. Akaike's information criterion and recent developments in information complexity. Journal of Mathematical Psychology 44:62–91.

Collins, W. B. ., and P. J. Urness. 1983. Feeding Behavior and Habitat Selection of Mule Deer and Elk on Northern Utah Summer Range. Journal of Wildlife Management 47:646–663.

Conner, M. L., M. D. Smith, and W. L. Burger. 2003. A comparison of distance-based and classification-based analyses of habitat use. Ecology 84:526–531.

Harper, G. 2016. Mule Deer and Elk Management on the Pueblo of Santa Ana, Sandoval County, New Mexico. Final Project Report for Grant Agreement: United States Fish and Wildlife Service's Tribal Grants Program.

Harper, G. H., and A. Trafton. 2004. Upland Vegetation as an Indicator of Nonpoint Source Pollution within Watersheds on the Pueblo of Santa Ana, Sandoval County, New Mexico. Final report submitted to United States Environmental Protection Agency, Region 6, Dallas, Texas.

Harris, G., J. G. Sanderson, J. Erz, S. E. Lehnen, and M. J. Butler. 2015. Weather and Prey Predict Mammals ' Visitation to Water. PLoS ONE 1–20.

Hebblewhite, M., and E. Merrill. 2008. Modelling wildlife–human relationships for social species with mixed-effects resource selection models. Journal of Applied Ecology 45:834–844.

Johnson, B. K., J. W. Kern, M. J. Wisdom, S. L. Findholt, and J. G. Kie. 2000. Resource Selection and Spatial Separation of Mule Deer and Elk during Spring. Journal of Mammalogy 64:685–697.

Johnson, D. H. 1980. The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. Ecology 61:65–71.

Keating, K. A., and S. Cherry. 2004. Use and Intepretation of Logistic Regression in Habitat-Selection Studies. Journal of Wildlife Management 68:774–789.

Kelley, V. C., and A. M. Kudo. 1978. Volcanoes and related basalts of Albuquerque Basin , New Mexico Volcanoes and related basalts of Albuquerque Basin , New Mexico. New Mexico Bureau of Mines and Mineral Resources. Volume Circular 1.

Krausman, P. R. 1998. The use of xeroriparian systems by desert mule deer. Arizona Riparian Council 11:11–12.

Leblond, M., C. Dussault, and J. P. Ouellet. 2013. Avoidance of roads by large herbivores and its relation to disturbance intensity. Journal of Zoology 289:32–40.

Lele, S. R. 2009. A New Method for Estimation of Resource Selection Probability Function. Journal of Wildlife Management 73:122–127.

Lendrum, P. E., C. R. Anderson, R. a. Long, J. G. Kie, and R. T. Bowyer. 2012. Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. Ecosphere 3:(9):82.

Lichti, N. I., and R. K. Swihart. 2011. Estimating utilization distributions with kernel versus local convex hull methods. Journal of Wildlife Management 75:413–422.

Long, R. A., J. G. Kie, T. R. Bowyer, and M. A. Hurley. 2009. Resource Selection and Movements by Female Mule Deer Odocoileus hemionus : Effects of Reproductive Stage. Wildlife Biology 15:288–298.

Main, M. B., and B. E. Coblentz. 1996. Sexual Segregation in Rocky Mountain Mule Deer. Journal of Wildlife Management 60:497–507.

Manly, B. F. L., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Springer Science & Business Media.

Marshal, J. . P., P. R. Krausman, and V. C. Bleich. 2005. Dynamics of mule deer forage in the Sonoran Desert. Journal of Arid Environments 60:593–609.

Marshal, J. ason P., V. C. Bleich, P. R. Krausman, M. L. Reed, and N. G. Andrew. 2006. Factors AffectingHabitat Use and Mule Deer in an Arid Environment. Wildlife Society Bulletin 34:609–619.

McKee, C. J., K. M. Stewart, J. S. Sedinger, A. P. Bush, N. W. Darby, D. L. Hughson, and V. C. Bleich. 2015. Spatial distributions and resource selection by mule deer in an arid environment: Responses to provision of water. Journal of Arid Environments 122:76–84. Elsevier Ltd.

Morrison, M. L. 2001. A Proposed Research Emphasis to Overcome the Limits of Wildlife-Habitat Relationship Studies. Journal of Wildlife Management 65:613–623.

Nielsen, S. E., M. S. Boyce, and G. B. Stenhouse. 2004. Grizzly bears and forestry: I. Selection of clearcuts by grizzly bears in west-central Alberta, Canada. Forest Ecology and Management 199:51–65.

Nielsen, S. E., M. S. Boyce, G. B. Stenhouse, and R. H. M. Munro. 2003. Development and testing of phenologically driven grizzly bear habitat models. Ecoscience 10:1–10.

Northrup, J. M., C. R. Anderson, and G. Wittemyer. 2015. Quantifying spatial habitat loss from hydrocarbon development through assessing habitat selection patterns of mule deer. Global Change Biology 21:3961–3970.

Northrup, J. M., C. R. Anderson, and G. Wittemyer. 2016*a*. Environmental dynamics and anthropogenic development alter philopatry and space-use in a North American cervid. Diversity and Distributions 22:547–557.

Northrup, J. M., C. R. Anderson Jr., M. B. Hooten, and G. Wittemyer. 2016*b*. Movement reveals scale dependence in habitat selection of a large ungulate. Ecological Applications 26:2746–2757.

Northrup, J. M., M. B. Hooten, C. R. J. Anderson, and G. Wittemyer. 2013. Practical guidance on characterizing availabilty in resource selection functions under a use – availability design. Ecology 94:1456–1463.

Preisler, H. K., A. A. Ager, and M. J. Wisdom. 2006. Statistical methods for analysing responses of wildlife to human disturbance. Journal of Applied Ecology 43:164–172.

Prokopenko, C. M., M. S. Boyce, and T. Avgar. 2017. Extent-dependent habitat selection in a migratory large herbivore: road avoidance across scales. Landscape Ecology 32:1–13. Springer Netherlands.

Sawyer, H., R. M. Nielson, F. Lindzey, and L. L. Mcdonald. 2006. Winter Habitat Selection of Mule Deer Before and During Development of a Natural Gas Field Winter Habitat Selection of Mule Deer Before and During Development of a Natural Gas Field. 70:396–403.

Shoemaker, K. T., L. J. Heffelfinger, N. J. Jackson, M. E. Blum, T. Wasley, and K. M. Stewart. 2018. A machine-learning approach for extending classical wildlife resource selection analyses. Ecology and Evolution 8:3556–3569.

Short, H. L., W. Evans, and E. L. Boeker. 1977. The Use of Natural and Modified Pinyon Pine-Juniper Woodlands by Deer and Elk. Journal of Wildlife Management 41:543–559.

Unsworth, J. W., D. F. Pac, G. C. White, and R. M. Bartmann. 1999. Mule Deer Survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315–326.

Webb, S. L., M. R. Dzialak, D. Houchen, K. L. Koschiuch, and J. B. Winstead. 2013*a*. Spatial ecology of female mule deer in an area proposed for wind energy development. Western North American Naturalist 73:347–356.

Webb, S. L., M. R. Dzialak, K. L. Kosciuch, and J. B. Winstead. 2013*b*. Winter Resource Selection by Mule Deer on the Wyoming-Colorado Border Prior to Wind Energy Development. Rangeland Ecology and Management 66:419–427.

CHAPTER 2. USING AN INDIVIDUAL BASED MODEL TO COMPARE IMPACTS OF ROAD DEVELOPMENT SCENARIOS UPON MULE DEER AT PUEBLO OF SANTA ANA, NEW MEXICO

2.1 Introduction

As human activity expands across the globe, disturbance of wildlife by anthropogenic activities such as fragmentation of habitat, and wildlife-human conflicts escalates (Blas et al. 2016). With increasing human population, there is also an increase in the use of roads and transportation systems (Prokopenko et al. 2017). As new roads are constructed and existing roads expand, the overall impact of vehicles becomes more intense and traffic density increases (Blas et al. 2016). With the expansion of roads and traffic, wildlife conflict with human transportation increases (Ascensão et al. 2013). The increase in human-wildlife conflict due to roads and traffic activity have direct and indirect effects on wildlife by disrupting natural behaviors (Ascensão et al. 2013), creating barriers for movement (Hennessy et al. 2018), restricting access to valuable resources, and even mortalities to wildlife when vehicle accidents occur (Bauduin et al. 2016, D'Amico et al. 2016). Mule deer (*Odocoileus hemionus*) on the Pueblo of Santa Ana, New Mexico may experience such effects as road development continues in this area. Barriers created by roads and vehicle traffic may have profound impacts on habitat use, dispersal, distribution, and fitness (D'Amico et al. 2016).

Anticipating the impact of a growing transportation system upon wildlife is a fundamental challenge because it is difficult if not impossible to conduct controlled experiments (Bennett et al. 2013). Some empirical studies have collected data before and after changes occurred to road systems however most approaches provide insight for only one scenario (Bauduin et al. 2016). In contrast individual based modeling (IBM), if appropriately parameterized is an approach that can provide insights to the relative effects across a range of scenarios (Ascensão et al. 2013). IBMs work by parameterizing the responses of wildlife to disturbance from empirical data and using a virtual environment to assess the implications of common sets of assumptions to different configurations of roads and volumes of traffic (Bauduin et al. 2016). Thus a model built on local empirical studies can be modified to investigate a suite of potential layouts (scenarios), allowing relativistic comparisons of the potential impacts of a number of plans (Bennett et al. 2009). For example, an IBM may require the use of explicit spatial and temporal parameterization to fit the system (Bennet et al. 2009).

Expansion of roads and increased development and their relative impact on wildlife are challenges natural resource managers face. Understanding current and potential impacts of roads and vehicle traffic upon mule deer behavior on the Pueblo of Santa Ana using an IBM will help their Department of Natural Resources (DNR) anticipate potential consequences of road development scenarios upon local mule deer populations. This understanding is important because mule deer have been declining across much of their range for the past 50 years (Unsworth et al. 1999). Mule deer are a culturally significant species that play a huge role in preserving traditional practices and serve as subsistence when hunted for by Pueblo of Santa Ana community members and for many other Native American Communities in the Southwest USA (Heffelfinger 2006). In an effort to better understand habitat and space use patterns DNR manager's monitored mule deer movements using GPS telemetry collars and VHF radio telemetry from 2010 to 2017 (Chapter 1). Data collected from mule deer monitoring can provide an invaluable foundation for investigating the behavioral response of mule deer to vehicles and roads using spatially explicit maps of habitat use, road networks, and mule deer distribution (Webb et al. 2013*a*, *b*). For this study, we focused on mule deer disturbance behaviors, alert and fleeing, in response to vehicle traffic during the summer season (Chapter 1). The objectives for our study were to use a simulation modeling approach to determine (1) the effects of current configurations of roads and vehicle traffic on the mule deer disturbance behaviors, alert and fleeing, (2) the relative frequency of disturbance behaviors, alert and fleeing, resulting from road expansion scenarios, (3) the effectiveness of a proposed wildlife mitigation feature over highway U.S. 550, and (4) the overall disturbance to mule deer from a new highway bypass across the Pueblo of Santa Ana.

2.2 Methods

Study Area

The Pueblo of Santa Ana is located within the Lower Basin and Range Physiographic Province, which contains broad desert basins with discontinuous mountain ranges (Harper 2016). Undulating mesas and lower rolling plains are interrupted by hill slopes and dissected by rivers and ephemeral washes which characterize the area. A total estimate of 336 km of ephemeral washes drain into the Rio Jemez River and Rio Grande River within the Pueblo of Santa Ana’s boundaries. The Santa Ana Mesa, above the river bottoms, reaches its highest elevation at 1,950 m. Lower elevations range between 1,580 m and 1,700 m, which consist of rolling and sand dominated desert surfaces that overlay sandstone and gravel surfaces originating from the Santa Fe Formation (Kelley and Kudo 1978). Sand deposits stabilized by vegetation are common in the plains, washes, and leeward hillslopes. Vegetation in the study area is diverse. The arid high desert watersheds in the study area receive on average 8.86 inches of rainfall per year, mostly in months of July and August during short intense monsoon rainstorm events (Bernalillo weather station data collected 1924-1982). Winter precipitation averages 2.56 inches per year mostly during the months of December, January and February (Harper 2016). We simulated the landscapes around the Pueblo of Santa Ana located in central New Mexico, USA under the management of their DNR.

We delineated simulated landscapes on the Pueblo of Santa Ana which includes an extended buffer area of 333 m around the boundary (Figure 1). The buffer area was chosen based on the maximum fleeing distance recorded for mule deer on the Pueblo of Santa Anna (see section "Wildlife inputs" below).

Simulation of Disturbance Activity Description

The IBM framework we utilized in this study to investigate the effect of different road configurations on simulated mule deer in central New Mexico was the Simulation of Disturbance Activities (SODA) (Bennett et al. 2009). SODA is an IBM framework that is flexible, spatially explicit, and can be used as a transferable tool. This tool was designed to investigate species-specific responses to site-specific anthropogenic disturbance (Bennet et al. 2009). Modifications of SODA have been used to investigate anthropogenic disturbance upon a diverse range of wildlife in various habitat types and landscapes (Bennet et al. 2009, 2011, 2013a, 2013b; D'Acunto et al. 2018, Rodriguez-Prieto et al. 2014).

SODA allows the user to create a virtual environment that is specific to the particular study site of interest (Bennett et al. 2013). The SODA model framework requires three types of GIS file inputs: (1) a polygon file to delineate the distribution of habitat/cover types that virtual animals and humans respond to in their movements, 2) a line file to delineate relevant linear features such as roads or trails that human objects move along, and 3) a point file to delineate locations of interest such as resting places for animals or where virtual human objects enter the simulation. Additionally, the user must specify relevant scenario parameters such as time step, the length of simulation (year, season, activity period etc.), anthropogenic disturbance modes, animal behavior modes, and animal behavioral responses to disturbance. Parameters for anthropogenic and wildlife inputs are based on previously collected data. Note, not all parameters must be specified for each model construction within SODA (Bennett et al. 2009). For example, in our study mule deer simulation models focused on behavioral responses to disturbance, thus we did not implement SODA's energetic features.

Model Parameterization

Main Simulation Parameters

To parameterize the SODA modeling framework we used several data sources including the mule deer resource selection functions (Chapter 1), and observations from the 2017 summer field season as well as established values from published literature. We chose a 5-min interval for each timestep. We judged temporal timesteps longer than 5 min as too coarse for our research objectives because mule deer disturbance response behavior occurs at fine temporal scales. All scenarios simulated a period ranging from mid-May through mid-August to reflect a summer season. During this timeframe, disturbance of foraging female mule deer via vehicle traffic can alter natural behavior causing additional stress and energy expenditure (Ciuti et al. 2012, Webb et al. 2013), which can have profound implications when female deer are investing energy in activities related to parturition (Long et al. 2009, Webb et al. 2013).

Environmental Inputs

Using SODA, we created a virtually realistic study area that uses ArcGIS shapefiles for mule deer point locations, habitat type polygon features and polyline features representing the road systems. These point locations indicate where the deer begin to forage at the start of each time period and were generated as inputs for each replicate developed for each scenario. Based upon census data provided by the DNR the mule deer population on the Pueblo of Santa Ana, over the time period studied, was estimated to be 11 male and 52 female deer (Harper 2016). To simulate mule deer activity (foraging, resting, alert, fleeing, and homing) in our SODA models in areas associated with best habitat, we created 11 points for males and 52 points for females for each period of the day to most accurately reflect deer activity patterns. We simulated morning (0600-0955 hr), day (1000-1755 hr), evening (1800-2155 hr), and night (1200-0555 hr) periods for each SODA model simulation. A SODA model simulation will be referred to as a replicate from now on. In each replicate for male mule deer, 44 point locations (4 time periods x 11 male mule deer) were created using ArcMap. For each female mule deer replicate, 208 point locations (4 time periods x 52 female mule deer) were created using ArcMap. Where each scenario had a total of 10 replicates (5 replicates for male mule deer and 5 for female mule deer). Point locations were randomly generated within the top 5% predictive probability of occurrence maps (Chapter 1) configured for morning, day, evening, and night in each scenario.

In order to parameterize mule deer movement through habitat types in the virtual landscape, we reclassified the resource selection function outputs from chapter one into suitable and avoided habitat types. We created rasters of suitable (cell values ≥ 0.33) and avoided (cell values < 0.33) habitat types based upon the resource selection functions from chapter one using the "Raster Calculator (Spatial Analyst)" tool in ArcMap. Separate raster surfaces were created for mule deer during crepuscular periods as well as for female and male mule deer within each scenario. These raster surfaces were converted into polygons using the "Raster to Polygon (Conversion)" tool in ArcMap. The suitable and avoided categories correspond to predictive probabilities of mule deer occurrence based on resource coefficient estimates from Chapter 1. Avoided habitat type, included all urban development such as: buildings, roads, parking lots, etc., within the study area.

The polyline shapefiles represented the road systems present during each scenario. Human mobile objects, which are virtual vehicles in our simulations, were spatially constrained and moved along linear road features. The Pueblo of Santa Ana DNR provided the baseline scenario road polyline shapefile. Each segment of road was then categorized as either low use dirt road, high use dirt road, highway (U.S. 550), or major interstate (I-25).The roads were then modified by editing the baseline polyline shapefile into the desired road expansion scenarios (DamRoad, ByPass, DeerCrossing), which will be explained in more detail in the Model Scenario section.

Anthropogenic Inputs

The same delineated categories of roads (low use dirt road, high use dirt road, highway, and interstate) created for resource selection functions in chapter one were also used to categorize the roads for all scenarios. Speed and traffic density for the two dirt road categories were recorded using camera traps (HyperFire Reconyx model PC900) during the 2017 summer field season (mid-June to mid-August). Two camera traps with synchronized clocks were placed on a road segment at an angle to capture photos that include the vehicle(s) and a time stamp of when the vehicle(s) passed each camera as it traveled along the road segment. Distance vehicles traveled over time was used to estimate the speed of vehicles traveling along the road segment, this method has been used by Ciuti et al. (2012). Three sets of cameras, each set containing two camera traps, were placed along different roads and then were relocated to different road segments in 2-week intervals. Using the camera trap data we documented the number of cars passing daily road segments. We used that information to parameterize the number of simulated vehicles for low use dirt roads and high use dirt roads at different times of the day. The camera trap data recorded for vehicles provided sufficient information to calculate the number of vehicles per meter every 5 minutes on the total length of low use and high use dirt roads in our system which is an important input for SODA. Low use dirt roads were simulated using a density of 0.00002512 vehicles/m/5 min with vehicles moving 7 m/sec. High use dirt roads were simulated with a density of 0.00015459 vehicles/m/5 min with vehicles moving 8 m/sec. Highway U.S. 550 and Interstate-25 were both parameterized in SODA using New Mexico Department of Transportation online data to estimate 24-hr daily traffic, which we translated to the probability of vehicles/m/5 min along the length of roads within our virtual landscape. Highway U.S. 550 was simulated using a density of 0.00272 vehicles/m/5 min, vehicles moving at the speed 31 m/sec. Interstate-25 was simulated using a density of 0.013 vehicles/m/5 min, vehicles moving at speed 34 m/sec. Using estimates for the number of vehicles/m/5 min and average speed (m/sec) for vehicles, we parameterized roads in all scenarios for the Pueblo of Santa Ana during the summer season.

Wildlife Inputs

Wildlife mobile objects (WMO) in this study were mule deer. We chose to simulate female and male mule deer as distinct WMO's in SODA because male and female deer are known to have different patterns of movement during the summer season (Bowyer et al. 1996, Bowyer and Kie 2004). Simulating disturbance behavior for mule deer require empirical data to set rules for such behavior. In SODA, the minimum homing distance represents the distance away from the point location where that WMO began its activity at which that WMO will probabilistically deviate from a correlated random walk to move back toward its origin. The corresponding maximum homing distance is the greatest distance a WMO will move from its origin without moving back toward its origin. Homing distances were calculated by estimating the average 50th (minimum homing distance) and 95th (maximum homing distance) percentile Kernel Density Estimations (KDE) for mule deer home ranges within our study area (Chapter 1) using R studio. Homing distances for female mule deer used in simulations were a minimum of 1,380 m and a maximum of 3,092 m. Homing distances for male mule deer used in simulations were a minimum of 2,355 m and a maximum of 5,256 m. Mule deer behavioral response parameters in the Pueblo of Santa Ana SODA framework were alert distance (104 m), flight initiation distance (43 m), fleeing timestep distance (93 m), and timesteps latent (0 timesteps). Distance of disturbance response behaviors by simulated mule deer result from observations during the 2017 summer field season. Alert distance (m), was the distance from an approaching vehicle to the individual or group of deer when it or they first became alert. Flight initiation distance was the distance from an approaching vehicle (disturbance) to the individual or group when the deer began to flee (run).

During road based surveys, observed disturbance behaviors were recorded from a vehicle while driving on all road types except for one instance when a spotting scope was used to determine the disturbance moved for fleeing behavior in response to a different vehicle. Based on this observation made on a female mule deer, fleeing timestep distance for our study was parameterized as 93 m. This observation was made when the female mule deer was in a preferred habitat and was disturbed by a vehicle. The fleeing timestep was determined by the total distance the deer fled from disturbance until it began to show normal behavior divided by the time latent, which is the duration of time between flight initiation and when normal behavior resumes (Bennett et al. 2009).

Mule deer movements were parameterized according to user-defined rules, which were characterized from empirical data. We estimated the average four hours displacement distance of mule deer in our study area during periods of high activity, two hours before, after, sunrise and sunset (Webb et al. 2013) using GPS telemetry collar data (Chapter 1). We conducted a sensitivity analysis to choose a correlated random walk value that allowed deer in our simulations to match the displacement (700 m) of GPS telemetry collared deer over four hours using a timestep distance (the length of meters traveled in 5 minutes) of 70 m for simulated deer. We used the correlated random walk value of 0.90 with a timestep distance of 70 m for all foraging deer during the morning and evening periods. During the day and night, we simplified mule deer movement with a correlated random walk value of 0.90 and timestep distance of 0.5 m when deer are likely bedded during day and less active during the night (Webb et al. 2013).

Observations from the summer 2017 fieldwork of mule deer response behaviors to approaching vehicles were recorded using two techniques. Empirical data were collected by direct observation using a spotting scope and from a vehicle during road surveys. Data were collected from mid-May to mid-August 2017. Observations were conducted at dawn, and dusk, with binoculars (8x45), and a spotting scope (Vortex, 25-45x60) to observe mule deer disturbance response behavior within areas used by mule deer on the Pueblo of Santa Ana. Spotting scope observations were conducted 250 m or further from roads. Locations for observations were selected using GPS collar data (Ciuti et al. 2012) and recommendations from DNR staff. During each mule deer observation date, time, location, indication of individual or group size, sex and age class of the individual or group were recorded. Age class and sex were categorized as adult male (more than two antler tines per side), adult female, and yearlings (smaller than females). Distance to approaching vehicles by deer as they displayed alert behavior or flight initiation were assessed using a GPS and a laser rangefinder (Nikon Aculon AL11 6X20 Laser Rangefinder- 8397). Observations were made on adult female mule deer. Mule deer alert behaviors were recorded when an individual or individuals displayed an alert posture (e.g. erect neck, ears angled upward facing disturbance) (Lingle and Wilson 2001). For mule deer, flight initiation distance was displayed when deer became alarmed and moved away using an escape gait (Lingle and Wilson 2001).

During the 2017 field season, we also collected empirical data on mule deer by observing response behavior to approaching vehicles on the Pueblo of Santa Ana. Road surveys were conducted on routes predetermined by consultation with DNR personnel and by scouting for areas of high use by mule deer near roads. Road surveys were conducted between dawn and dusk at least two days each week. Road surveys consisted of driving a route, and recording observed mule deer response behavior when individuals were encountered. We recorded alert distance, flight initiation distance, and distance at which normal behavior resumed using a rangefinder from a vehicle base on methods from a previous study on elk (*Cervus elaphus*) (Ciuti et al. 2012). We recorded the date, time, location, group size, sex and age class composition of all deer we encountered. If observations of flight behavior were made easier to observe by driving further along the road then we did so. However, if deer fled from our disturbance to locations where we could no longer observe them we continued on route to collect observations on other mule deer. Additionally, we recorded data opportunistically as we drove to rotate cameras to new road segments and while going and returning from binocular/spotting scope survey locations.

Model Scenarios

Once the best-case baseline SODA model scenario was constructed, we modified it to simulate alternative scenarios of road development on the Pueblo of Santa Ana. We consulted with DNR managers and authorities to develop realistic scenarios for expansion of road systems and vehicular traffic rates on the Pueblo of Santa Ana. We then used SODA to estimate the relative impacts of each of these scenarios on rates of disturbance behaviors alert and fleeing on mule deer. Scenarios for road configurations were, (A) expanding an existing high use road (DamRoad scenario) to a relatively low impacted area, (B) creating an additional route to an existing highway U.S. 550 (ByPass scenario), and (C) creating a wildlife passage (DeerCrossing scenario) mitigation feature on the U.S. 550 highway in areas of high predictive probabilities of occurrence male mule deer during the summer season.

Model Application

We ran five replicate SODA simulation models for each scenario including the baseline model for both female and male mule deer. Five replicate SODA models were simulated for comparisons. Each model simulation recorded mule deer behavior (foraging, sleeping, homing, alert, and fleeing) and recorded response behaviors in 5-min timesteps for 30 days in the virtual environment. Output textfiles for each model simulation was produced for both human mobile objects and wildlife mobile objects. Output textfiles contain X and Y coordinates, behavioral mode, ID, TYPE, timestep, and day, for all timesteps simulated in SODA.

Data Analysis

For data analysis, we used an Analysis of Variance (ANOVA) for response variables. Alert and fleeing behavioral responses were separated for both female and male mule deer for all scenario results including for each time of day. ANOVA's were used to analyze data with TukeyHSD multiple comparisons to examine each response variables sensitivity to alternative road scenarios. The use of frequentist-based hypothesis testing approaches to analyze results from individual based models have been challenged for several reasons including the risk of obtaining statistical rather than ecological significance from the large number of replicates such models may generate (White et al. 2014). However, this risk was not a primary consideration for our work given that we limited our replications to five replicates per scenario. Furthermore, our interpretations focused upon effect size rather than alpha values. We present summary statistics and model predictions from our SODA analysis in tables and figures in the form of box plots.

2.3 Results

During the 2017 summer field season, we monitored vehicle traffic on 15 different segments of dirt roads. Within sets of camera traps, cameras were on average were spaced 285.94

m apart with a minimum of 68.54 m and maximum of 418.31 m. Cameras on high use dirt roads recorded 1,087 vehicles passing any given set of cameras during the summer of 2017. Cameras on low use dirt roads recorded 72 vehicles passing any given set of cameras during the summer of 2017. Across all dirt roads, cameras recorded 1,159 vehicles passing any given set of cameras during the summer of 2017. Cameras on low use dirt roads recorded vehicles passing any given set during the hours of 0500 to 1600 hr during the summer of 2017. Cameras on high use dirt roads recorded vehicles passing any given set during the hours of 0500 to 1900 hr.

Disturbance behavior were recorded for female mule deer only, because male mule deer were never observed during the 2017 summer field season. Ten observations of mule deer were recorded during vehicle surveying, and three observations of deer were recorded using a spotting scope. Mean alert distance recorded for mule deer was 104.15 m (SD = 54.74), with a minimum of 36 m and maximum of 198 m. Mean fleeing distance recorded for mule deer was 42.57 m (SD = 32.88), with a minimum of 13 m and a maximum of 104 me. Mule deer were observed becoming alert but not fleeing in six instances in response to vehicles on the Pueblo of Santa Ana. Once, a deer was recorded fleeing and returning to normal behavior over a distance of 264 m from the time that deer fled to resuming normal behavior. Once, a deer was recorded crossing a set of cameras located on a segment of road in preferred habitat with a distance traveled of 56.5 m undisturbed in 5 min via timestamps on camera traps. Once a deer was observed using a spotting scope traveling 70 m in 5 min in preferred habitat.

Fifty-two female mule deer were simulated for 30 days in each of five replicate SODA simulation runs for each of the four scenarios (Baseline, DamRoad, ByPass, and DeerCrossing). Overall, the ANOVA found no difference in the frequency of total alert behavior by female mule deer between the scenarios ($F_{3, 16}$ = 1.117, P = 0.372; Figure 2). We found there was no difference in the frequency of alert behavior between scenarios during the morning for female mule deer ($F_{3, 16}$ = 1.618, *P* = 0.225; Figure 3), during the day ($F_{3, 16}$ = 0.813, *P* = 0.505; Figure 4), during the evening ($F_{3, 16}$ = 1.65, *P* = 0.218; Figure 5), or during the night for female mule deer ($F_{3, 16}$ = 0.035, *P* = 0.991; Figure 6).

Female mule deer fleeing behavior frequency results were similar to alert results in the lack of significant differences. Overall, the ANOVA found no difference in the frequency of total fleeing behavior by female mule deer between the scenarios ($F_{3, 16}$ = 1.248, *P* = 0.325; Figure 7). We found there was no difference in the frequency of fleeing behavior between scenarios during the morning for female mule deer ($F_{3, 16}$ = 0.467, *P* = 0.710; Figure 8), during the day ($F_{3, 16}$ = 0.272, *P* = 0.844; Figure 9), during the evening ($F_{3, 16}$ = 2.235, *P* = 0.124; Figure 10), or during the night for female mule deer ($F_{3, 16}$ = 0.838, *P* = 0.493; Figure 11).

Eleven male mule deer were simulated for 30 days in each of five replicate SODA simulation runs for each scenario. Overall, means differed in frequency of total alert behavior by male mule deer between scenarios ($F_{3, 16}$ = 10.29, $P \leq 0.001$; Figure 12). Frequency of total alert behavior for male mule deer in the baseline model were significantly greater, relative to ByPass (*P* = 0.025), DamRoad (*P* = 0.038), DeerCrossing ($P \leq 0.001$) (Table 1). We found means differed in the frequency of alert behavior between scenarios during the morning for male mule deer ($F_{3, 16}$ = 4.526, *P* = 0.018) (Figure 13). Frequency of morning alert behavior for male mule deer in the baseline scenario was significantly greater relative to DamRoad (*P* = 0.046), DeerCrossing (*P* = 0.020) but not ByPass (*P* = 0.074) (Table 1). We found there was no difference in the frequency of alert behavior between scenarios during the day for male mule deer ($F_{3, 16}$ = 1.065, *P* = 0.392) (Figure 14) however, means differed in the frequency of alert behavior between scenarios during the evening for male mule deer ($F_{3, 16}$ = 3.692, *P* = 0.034; Figure 15). Frequency of evening alert behavior for male mule deer in the Baseline scenario was significantly greater relative to DeerCrossing (P = 0.002) but not ByPass (P = 0.230) or DamRoad (P = 0.191; Table 1). We found there was no difference in the frequency of alert behavior between scenarios during the night for male mule deer ($F_{3, 16}$ = 1.464, P = 0.262; Figure 16).

We found means differed in the frequency of total fleeing behavior by male mule deer between scenarios ($F_{3, 16}$ = 8.573, P = 0.001; Figure 17). Frequency of total fleeing behavior for male mule deer in the Baseline scenario was significantly greater relative to DamRoad (P = 0.002), DeerCrossing (P = 0.0005), but not ByPass (P = 0.381; Table 1). We found there was no difference in the frequency of fleeing behavior between scenarios during the morning ($F_{3, 16}$ = 3.032, P = 0.060; Figure 18) or during the day for male mule deer ($F_{3, 16}$ = 2.613, P = 0.087; Figure 19). We found means differed in the frequency of fleeing behavior between scenarios during the evening for male mule deer ($F_{3, 16}$ = 5.493, P = 0.009) (Figure 20). Frequency of evening fleeing behavior for male mule deer in the Baseline scenario was significantly greater relative to DamRoad (P = 0.011), DeerCrossing (P = 0.020), but not ByPass (P = 0.073; Table 1). We found there was no difference in the frequency of fleeing behavior between scenarios during the night for male mule deer ($F_{3, 16}$ = 1.027, P = 0.407; Figure 21)

2.4 Discussion

Contrary to our expectations, our SODA simulations found few significant differences in the alert and fleeing disturbance of mule deer between road expansion scenarios. Results for female mule deer disturbance behavior show no significant differences in the frequency of alert or fleeing behavior between the baseline model and different road expansion scenarios. Results for male mule deer frequency of disturbance behaviors differed from other road expansion scenarios with the baseline scenario having relatively higher frequencies of alert and fleeing instances than DamRoad, ByPass, and DeerCrossing scenarios during the morning and evening (Table 1).

There are several potential explanations to account for the relatively low significant differences between our road expansion scenarios and their impacts upon mule deer disturbance. For example, Rost and Bailey (1979), found that mule deer moved away from areas where road expansion or increased traffic volumes occurred. Similarly, we simulated mule deer at locations across the Pueblo of Santa Ana based upon our model of where the best habitat occurs (Chapter 1). This model was applied to each road development scenario simulating mule deer activity in different portions of the Pueblo of Santa Ana as a function of altered habitat quality from new road configurations. An unintended consequence of the above assumption was that simulated mule deer in alternative road scenarios ended up further from roads in the modeling environment than similar animals in the baseline scenario. Specifically, our best habitat models (Chapter 1) placed female mule deer in areas far from manipulated roads, while concentrating male deer closer to highway U.S. 550 in the southern portion of the Pueblo of Santa Ana. This disparity may explain why we saw some differences in disturbance behavior between scenarios for males and not for female mule deer. Our decision to simulate deer within preferred habitat is consistent with comparisons of space use by mule deer from north-central Colorado between low traffic density in the 1980's and high traffic density in 2007-2009 (Anderson et al. 2012). This comparison supports the hypothesis that habitat availability would influence resource selection patterns, including selecting areas far from roads (Anderson et al. 2012). It is worth noting that if female mule deer do in fact move into other portions on the Pueblo of Santa Ana in response to road development they will be moving into lower quality habitat where reduced nutrition may influence productivity (Northrup et al. 2016).

Such phenomenon are beyond the scope of SODA, which treats areas of activity as an input and focuses on estimating the frequency of disturbance.

An alternative explanation for the disparity in our results may be that assumptions made in our SODA modeling were responsible for our observations. Specifically, deer may not move away from traditional areas with road development as we had assumed (Northrup et al. 2015, 2016). If mule deer on the Pueblo of Santa Ana are similar to mule deer from the Piceance Basin in north-west Colorado (Northrup et al. 2016) they may remain philopatric to high quality locations despite the expansion of transportation infrastructure. Mule deer could remain in these locations by habituating to the presence of vehicles, thereby reducing the frequency of disturbance (Northrup et al. 2015). Our SODA modeling did not address scenarios of either mule deer remaining philopatric despite road expansion or of deer habituating to increasing encounters of vehicles. Both of these sets of questions are ideas that could be explored in SODA as interesting future directions.

Our application of SODA to simulate the disturbance of mule deer on the Pueblo of Santa Ana may have also been limited by our implementation of this tool. We only simulated five replicates for each road expansion scenario including the baseline scenario. Often, simulation models are criticized for psuedoreplication, although such criticisms are not a concern in our application. In fact, our statistical power was actually quite low because each of the five replicates provided us with only one value for statistical analysis. This suggests that conducting a power analysis could be a fruitful future direction prior to additional modeling. Other limitations with our model include constraints associated with how SODA tracks individual wildlife mobile objects and human mobile objects. We did our best to parameterize vehicle traffic rates from camera trap data and utilizing New Mexico Department of Transportation data for roads U.S. 550 and Interstate-25. Despite our best efforts, we parameterized vehicles on low use and high use dirt roads to move orders of magnitude slower in the models than they do in reality. This may have profoundly impacted encounter results of virtual mule deer and vehicles on dirt roads. Additionally, the traffic rate data we used may not reflect the range of relevant variation from the real world. Furthermore, challenges with how SODA tracks activity patterns forced us to simulate female and male mule deer at different times of the day using separate models. This approach treated mule deer at different times of the day as independent, when in fact they are not. Despite our unexpected results, simulation models still hold potential to inform questions like these. Doing so requires careful matching of assumptions, extensive replications, and a full range of scenarios rather than the limited subset presented in this work.

Road networks are expanding, and there is a clear need to understand potential effects of expansion on wildlife (Ascensão et al. 2013). Our results, while tentative, emphasize the importance of considering behavior associated with habitat quality when investigating development expansions. Our approach shows promise, but more replicates will be required to reach any definite conclusions.

2.5 References

Anderson, E. D., R. a. Long, M. P. Atwood, J. G. Kie, T. R. Thomas, P. Zager, and R. T. Bowyer. 2012. Winter resource selection by female mule deer Odocoileus hemionus : functional response to spatio-temporal changes in habitat. Wildlife Biology 18:153–163.

Ascensão, F., A. Clevenger, M. Santos-Reis, P. Urbano, and N. Jackson. 2013. Wildlife-vehicle collision mitigation: Is partial fencing the answer? An agent-based model approach. Ecological Modelling 257:36–43.

Bauduin, S., E. McIntire, M. H. St-Laurent, and S. Cumming. 2016. Overcoming challenges of sparse telemetry data to estimate caribou movement. Ecological Modelling 335:24–34.

Bennett, V. J., M. Beard, P. A. Zollner, E. Fernández-Juricic, L. Westphal, and C. L. LeBlanc. 2009. Understanding wildlife responses to human disturbance through simulation modelling: A management tool. Ecological Complexity 6:113–134.

Bennett, V. J., D. W. Sparks, and P. A. Zollner. 2013. Modeling the indirect effects of road networks on the foraging activities of bats. Landscape Ecology 28:979–991.

Blas, J., T. Abaurrea, M. D'Amico, F. Barcellona, E. Revilla, J. Rom??n, and M. Carrete. 2016. Management-related traffic as a stressor eliciting parental care in a roadside-nesting bird: The European bee-eater Merops apiaster. PLoS ONE 11:1–14.

Ciuti, S., J. M. Northrup, T. B. Muhly, S. Simi, M. Musiani, J. A. Pitt, and M. S. Boyce. 2012. Effects of Humans on Behaviour of Wildlife Exceed Those of Natural Predators in a Landscape of Fear. PLoS ONE 7.

D'Amico, M., S. Périquet, J. Román, and E. Revilla. 2016. Road avoidance responses determine the impact of heterogeneous road networks at a regional scale. Journal of Applied Ecology 53:181–190.

Frid, A., and L. Dill. 2002. Human-caused disturbance as a form of predation risk. Journal of Wildlife Management 78:58–67.

Harper, G. 2016. Mule Deer and Elk Management on the Pueblo of Santa Ana, Sandoval County, New Mexico, USA. Santa Ana Pueblo.

Heffelfinger, J. 2006. Deer of the Southwest: A Complete Guide to the Natural History, Biology, and Management of Southwestern Mule Deer and White-Tailed deer. 1st edition. Texas A&M University Press, College Station.

Hennessy, C., C. C. Tsai, S. J. Anderson, P. A. Zollner, and O. E. Rhodes. 2018. What's stopping you? Variability of interstate highways as barriers for four species of terrestrial rodents. Ecosphere 9.

Kelley, V. C., and A. M. Kudo. 1978. Volcanoes and related basalts of Albuquerque Basin , New Mexico Volcanoes and related basalts of Albuquerque Basin , New Mexico. New Mexico Bureau of Mines and Mineral Resources. Volume Circular 1.

Lingle, S., and W. F. Wilson. 2001. Detection and avoidance of predators in white-tailed deer (Odocoileus virginianus) and mule deer (O-hemionus). Ethology 107:125–147.

Northrup, J. M., C. R. Anderson, and G. Wittemyer. 2015. Quantifying spatial habitat loss from hydrocarbon development through assessing habitat selection patterns of mule deer. Global Change Biology 21:3961–3970.

Northrup, J. M., C. R. Anderson, and G. Wittemyer. 2016. Environmental dynamics and anthropogenic development alter philopatry and space-use in a North American cervid. Diversity and Distributions 22:547–557.

Prokopenko, C. M., M. S. Boyce, and T. Avgar. 2017. Extent-dependent habitat selection in a migratory large herbivore: road avoidance across scales. Landscape Ecology 32:1–13. Springer Netherlands.

Rost, G. R., and J. A. Bailey. 1979. Distribution of Mule Deer and Elk in Relation to Roads. The Journal of Wildlife Management 43:634–641.

Unsworth, J. W., D. F. Pac, G. C. White, and R. M. Bartmann. 1999. Mule Deer Survival in Colorado, Idaho, and Montana. Journal of Wildlife Management 63:315–326.

Webb, S. L., M. R. Dzialak, D. Houchen, K. L. Koschiuch, and J. B. Winstead. 2013*a*. Spatial ecology of female mule deer in an area proposed for wind energy development. Western North American Naturalist 73:347–356.

Webb, S. L., M. R. Dzialak, K. L. Kosciuch, and J. B. Winstead. 2013*b*. Winter Resource Selection by Mule Deer on the Wyoming-Colorado Border Prior to Wind Energy Development. Rangeland Ecology and Management 66:419–427.

White, J. W., A. Rassweiler, J. F. Samhouri, A. C. Stier, and C. White. 2014. Ecologists should not use statistical significance tests to interpret simulation model results. Oikos 123:385–388.

Zollner, P. A., L. J. Roberts, E. J. Gustafson, H. S. He, and V. Radeloff. 2008. Influence of forest planning alternatives on landscape pattern and ecosystem processes in northern Wisconsin, USA. Forest Ecology and Management 254:429–444.

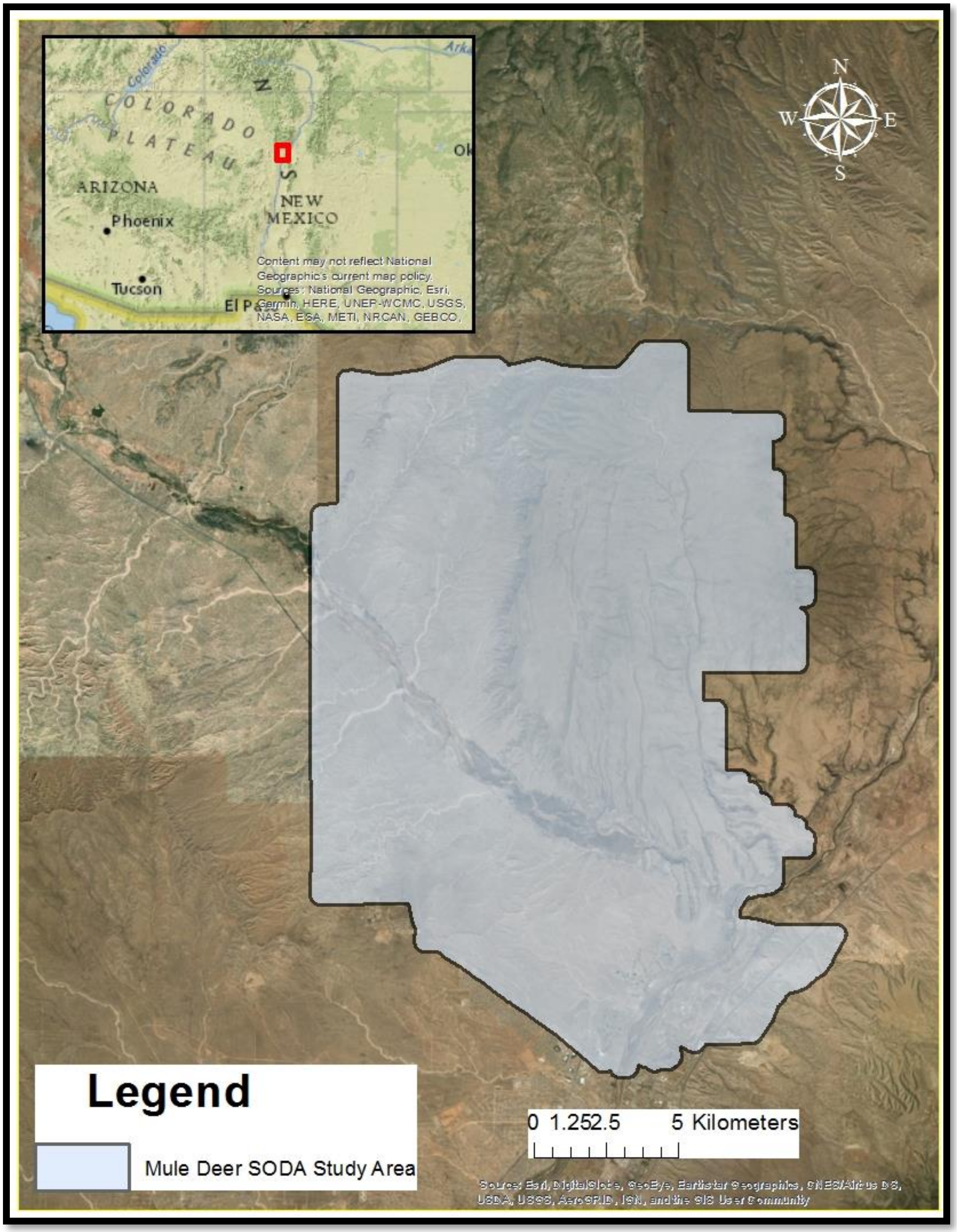

Figure 2.1 The entire mule deer SODA study area (~35,380 ha) is displayed by the large polygon that was delineated for simulated landscapes which includes an extended buffer area of 333 m around the Pueblo of Santa Ana's boundary. Pueblo of Santa Ana, NM USA.

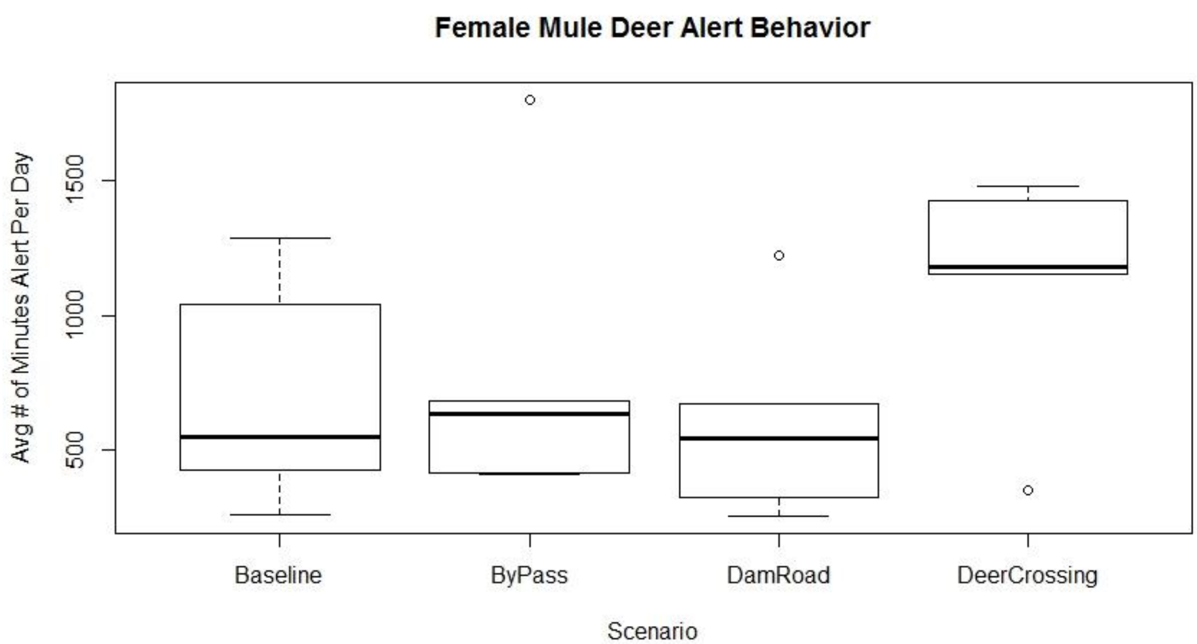

Figure 2.2 Box plot displaying the average number of minute's female mule deer spent alert per full day in response to virtual vehicles for each of the road scenarios.

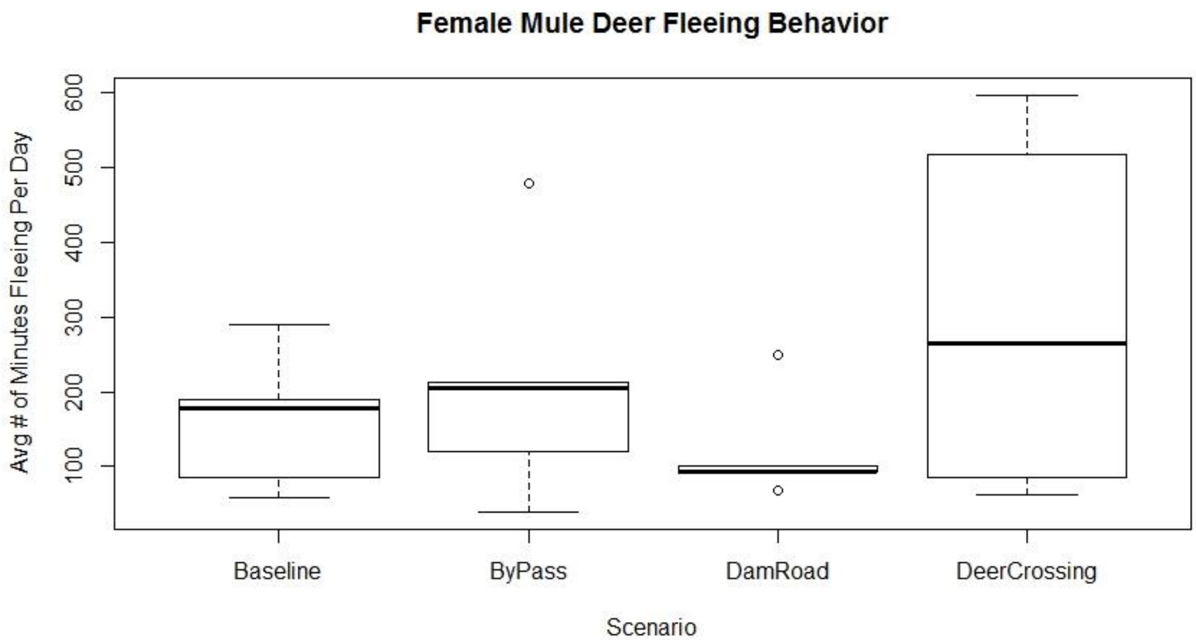

Figure 2.3 Box plot displaying the average number of minute's female mule deer spent fleeing per full day in response to virtual vehicles for each of the road scenarios.

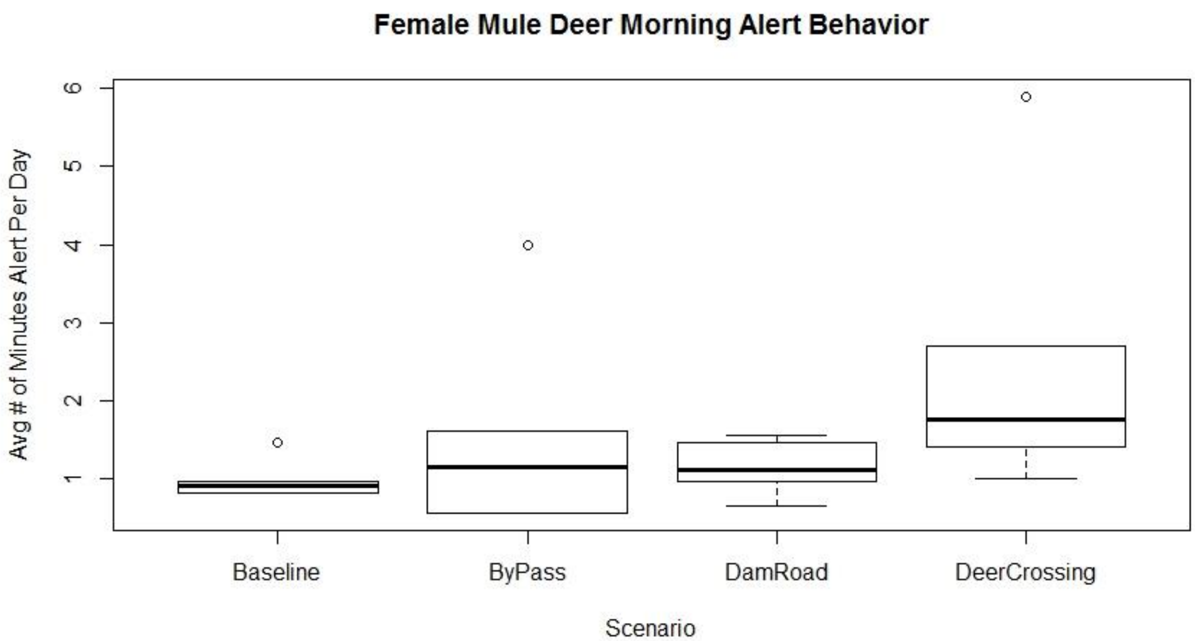

Figure 2.4 Box plot displaying the average number of minute's female mule deer spent alert per morning in response to virtual vehicles for each of the road scenarios.

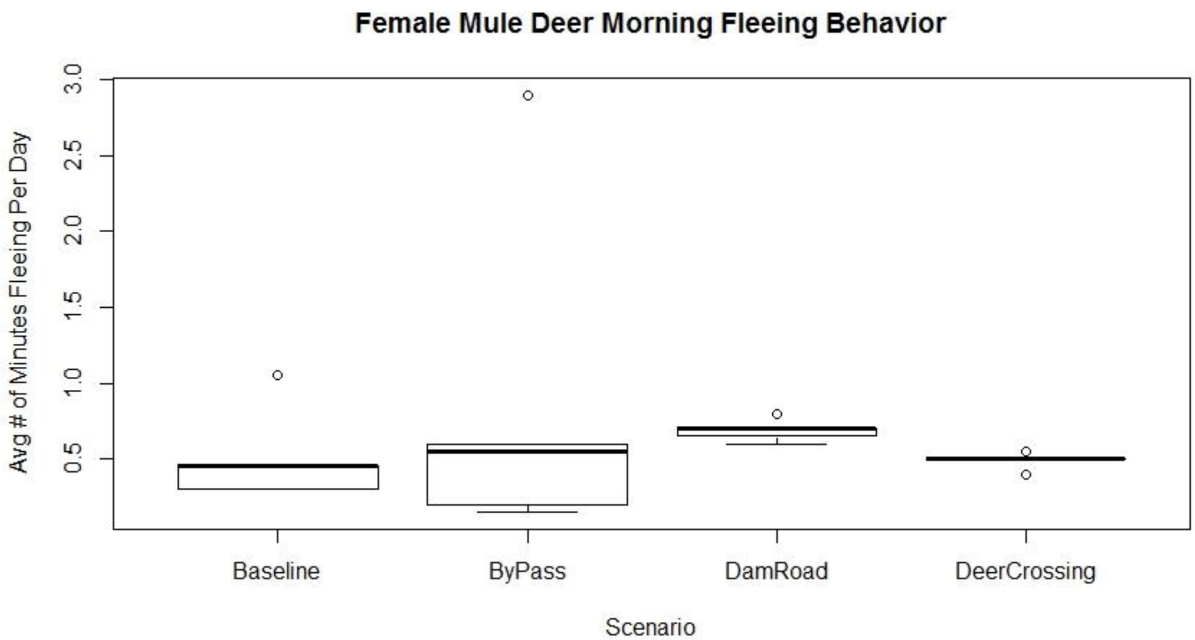

Figure 2.5 Box plot displaying the average number of minute's female mule deer spent fleeing per morning in response to virtual vehicles for each of the road scenarios.

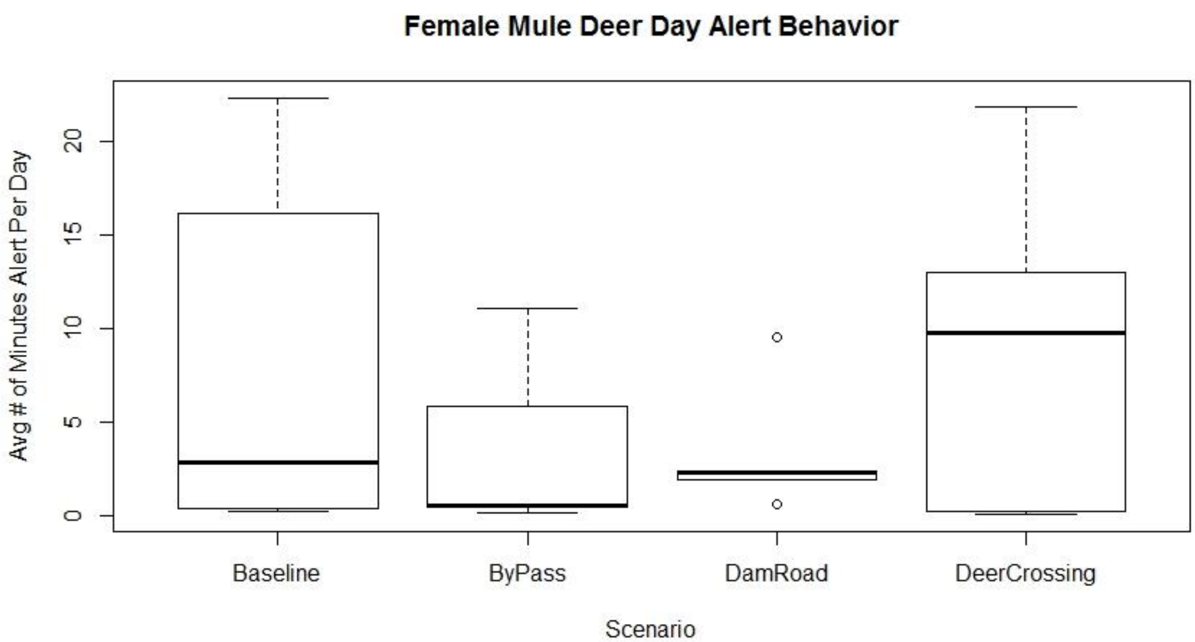

Figure 2.6 Box plot displaying the average number of minute's female mule deer spent alert per day period in response to virtual vehicles for each of the road scenarios.

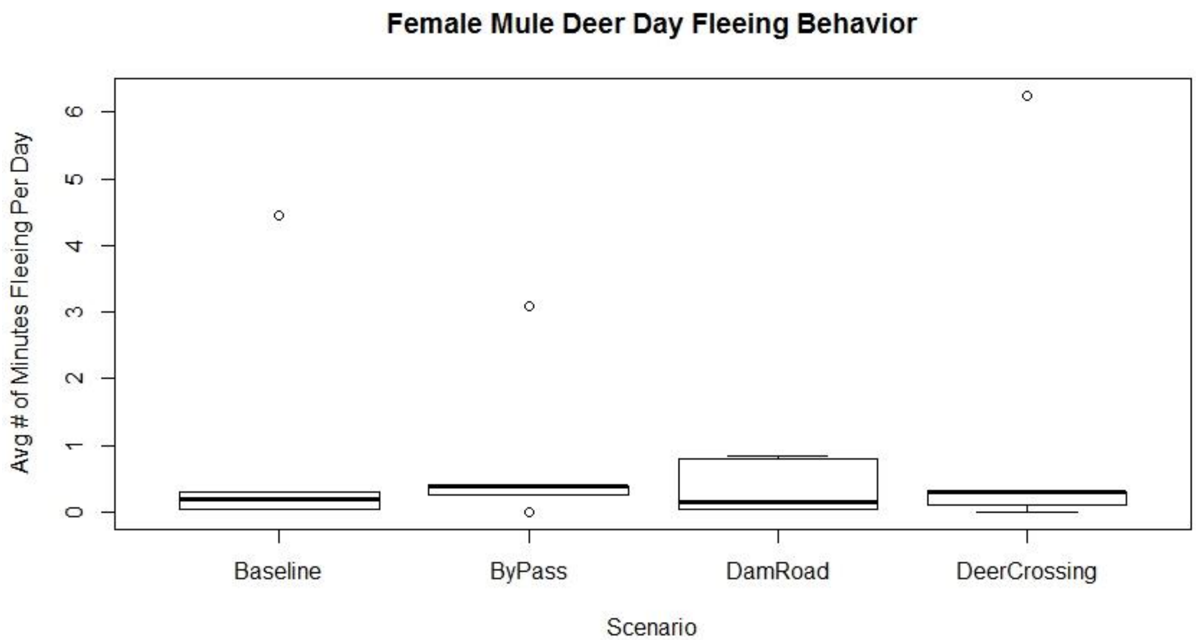

Figure 2.7 Box plot displaying the average number of minute's female mule deer spent fleeing per day period in response to virtual vehicles for each of the road scenarios

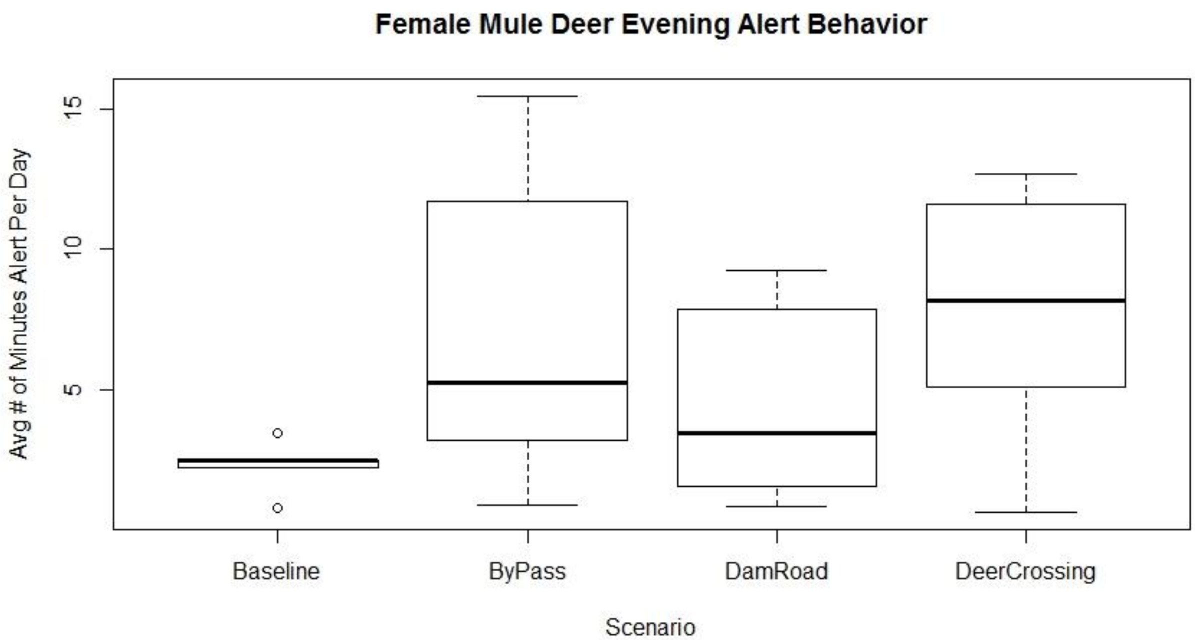

Figure 2.8 Box plot displaying the average number of minute's female mule deer spent alert per evening in response to virtual vehicles for each of the road scenarios.

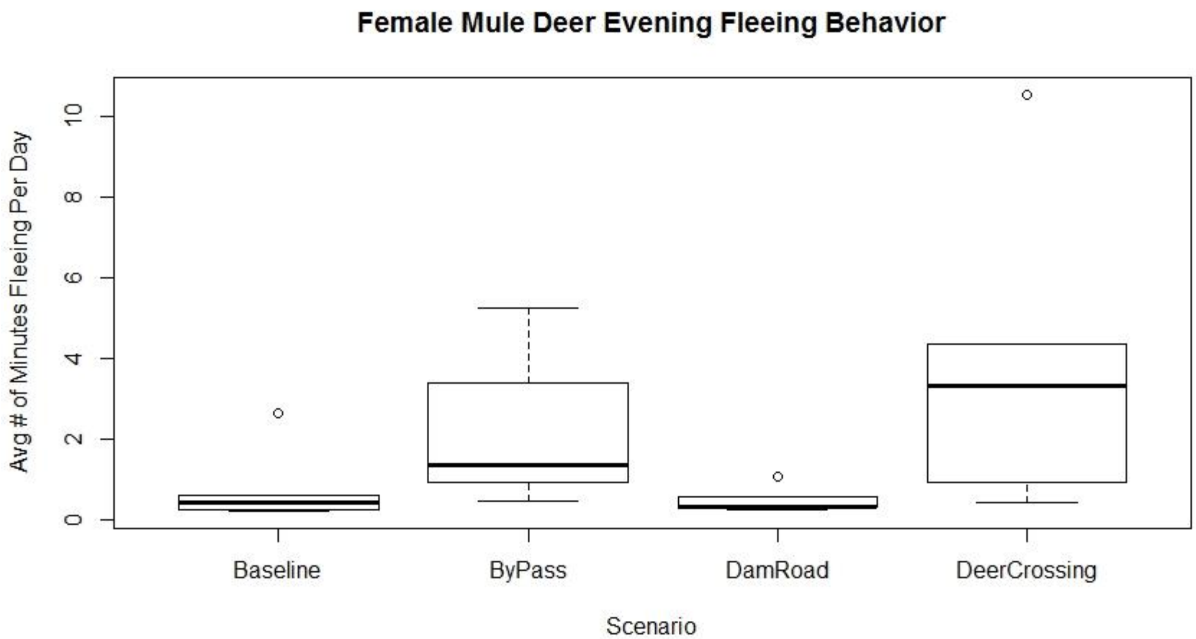

Figure 2.9 Box plot displaying the average number of minute's female mule deer spent fleeing per evening in response to virtual vehicles for each of the road scenarios.

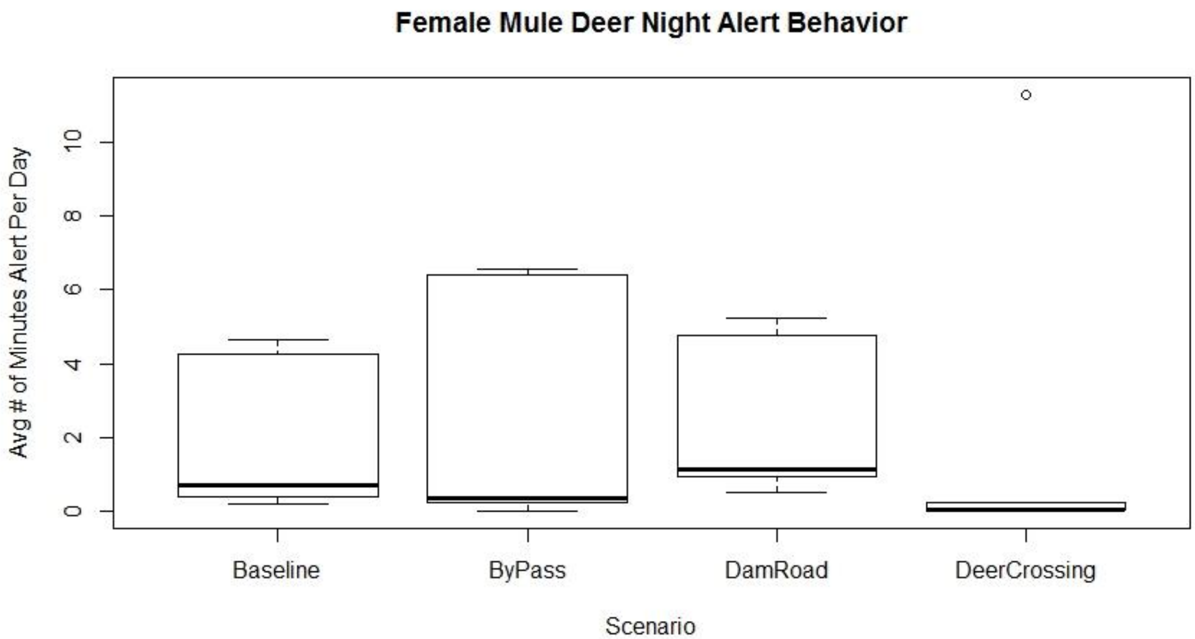

Figure 2.10 Box plot displaying the average number of minute's female mule deer spent alert per night in response to virtual vehicles for each of the road scenarios.

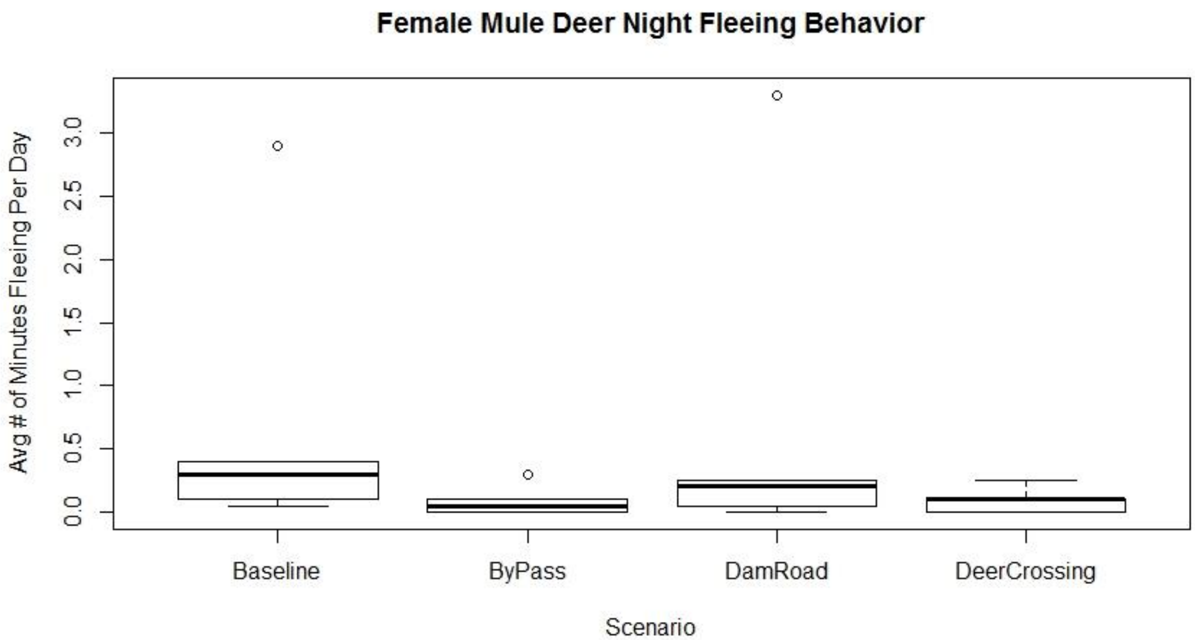

Figure 2.11 Box plot displaying the average number of minute's female mule deer spent fleeing per night in response to virtual vehicles for each of the road scenarios.

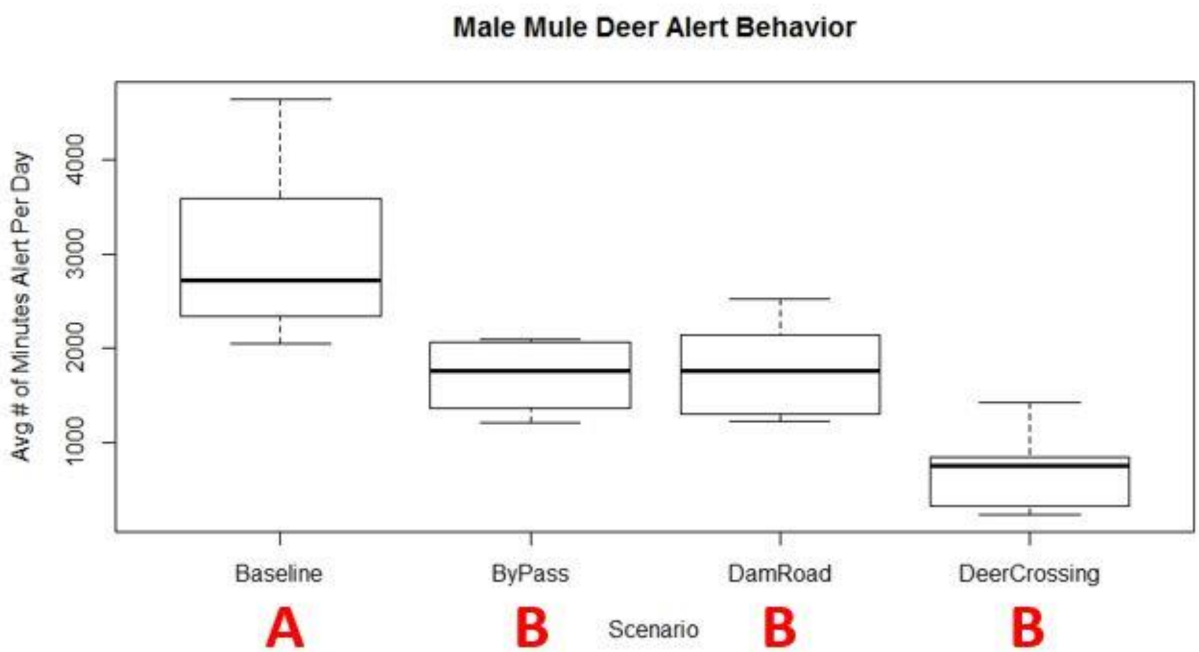

Figure 2.12 Box plot displaying the average number of minute's male mule deer spent alert per full day in response to virtual vehicles for each of the road scenarios. Uppercase letters indicate statistically significant differences between scenarios.

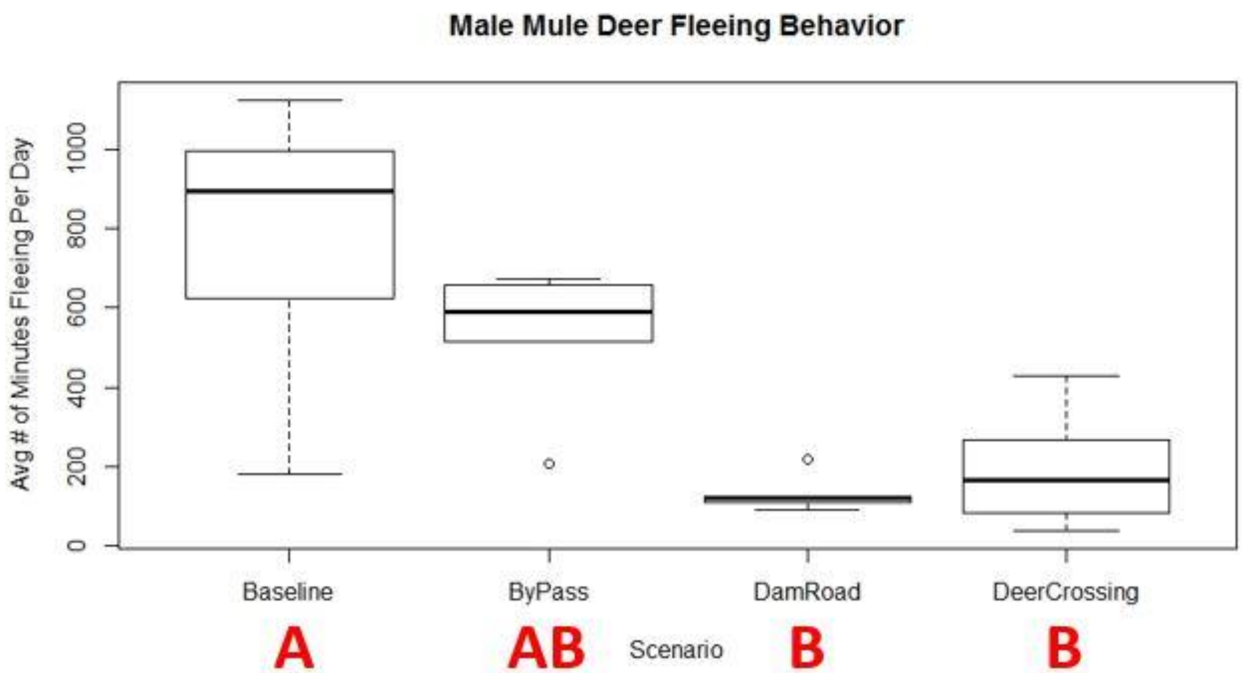

Figure 2.13 Box plot displaying the average number of minute's male mule deer spent fleeing per full day in response to virtual vehicles for each of the road scenarios. Uppercase letters indicate statistically significant differences between scenarios.

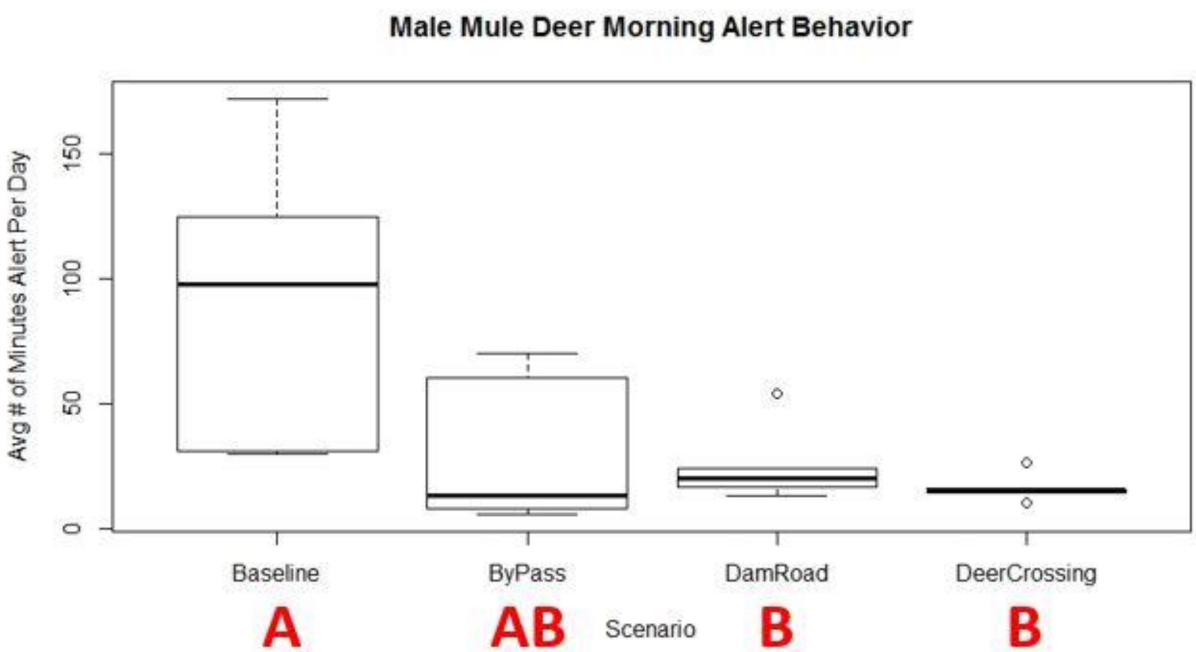

Figure 2.14 Box plot displaying the average number of minute's male mule deer spent alert per morning in response to virtual vehicles for each of the road scenarios. Uppercase letters indicate statistically significant differences between scenarios.

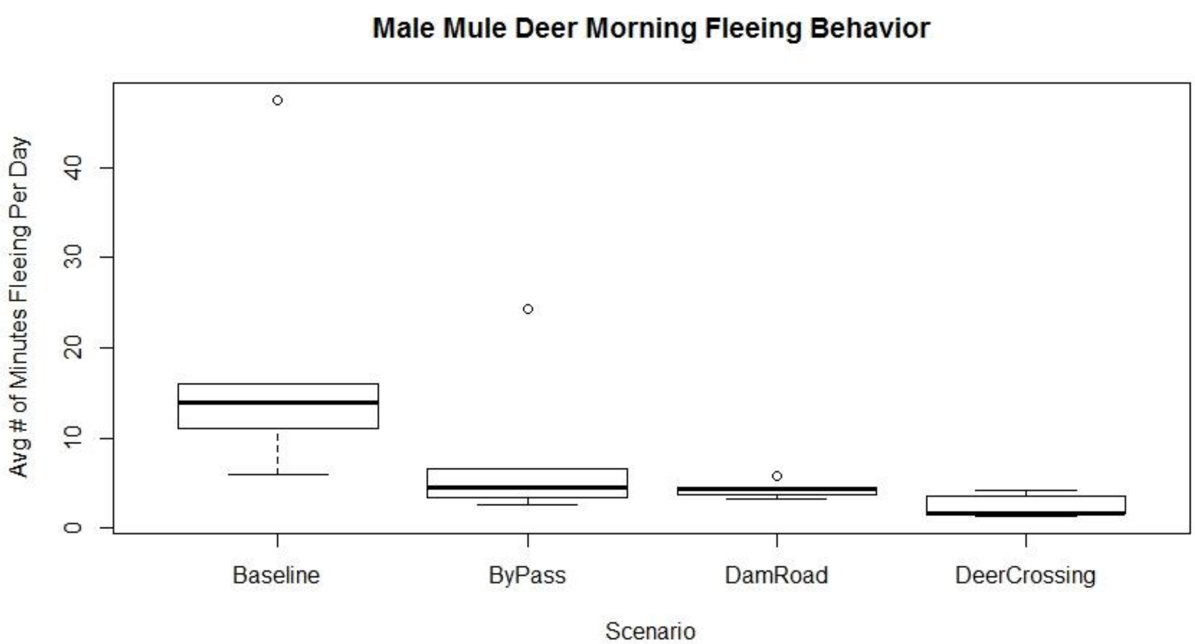

Figure 2.15 Box plot displaying the average number of minute's male mule deer spent fleeing per morning in response to virtual vehicles for each of the road scenarios.

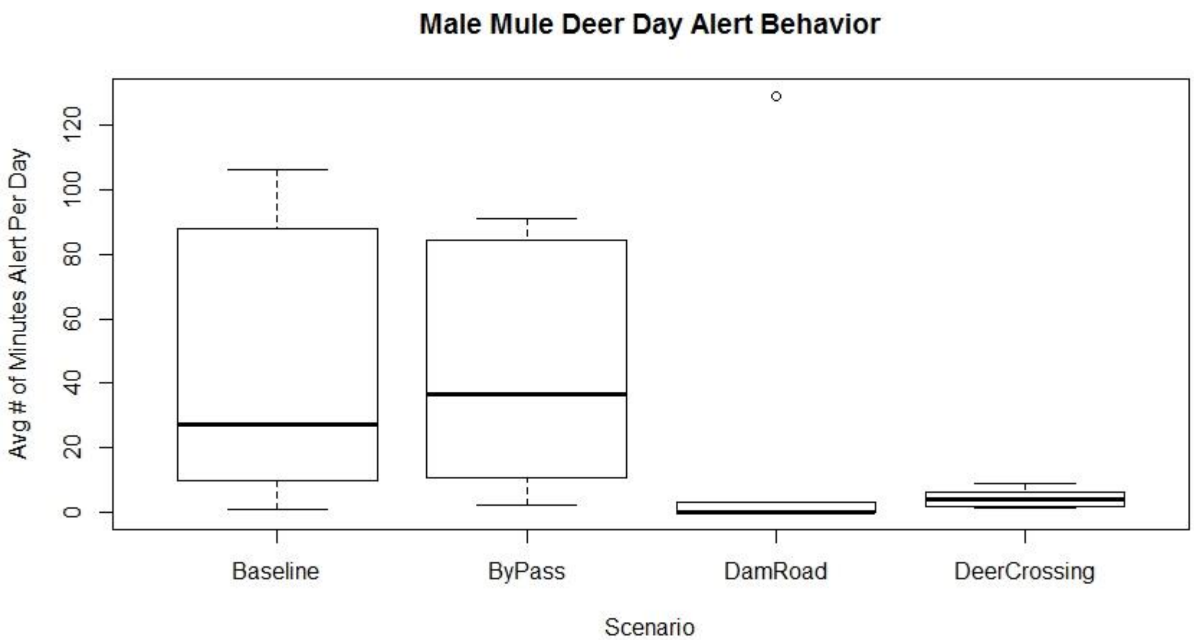

Figure 2.16 Box plot displaying the average number of minute's male mule deer spent alert per day period in response to virtual vehicles for each of the road scenarios

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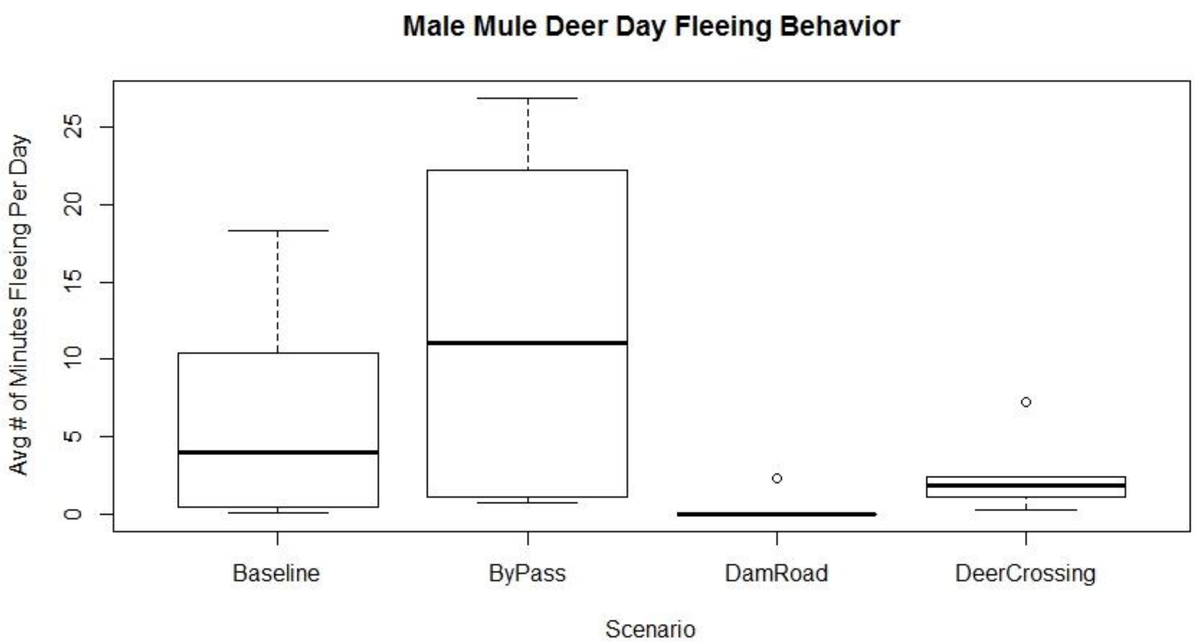

Figure 2.17 Box plot displaying the average number of minute's male mule deer spent fleeing per day period in response to virtual vehicles for each of the road scenarios.

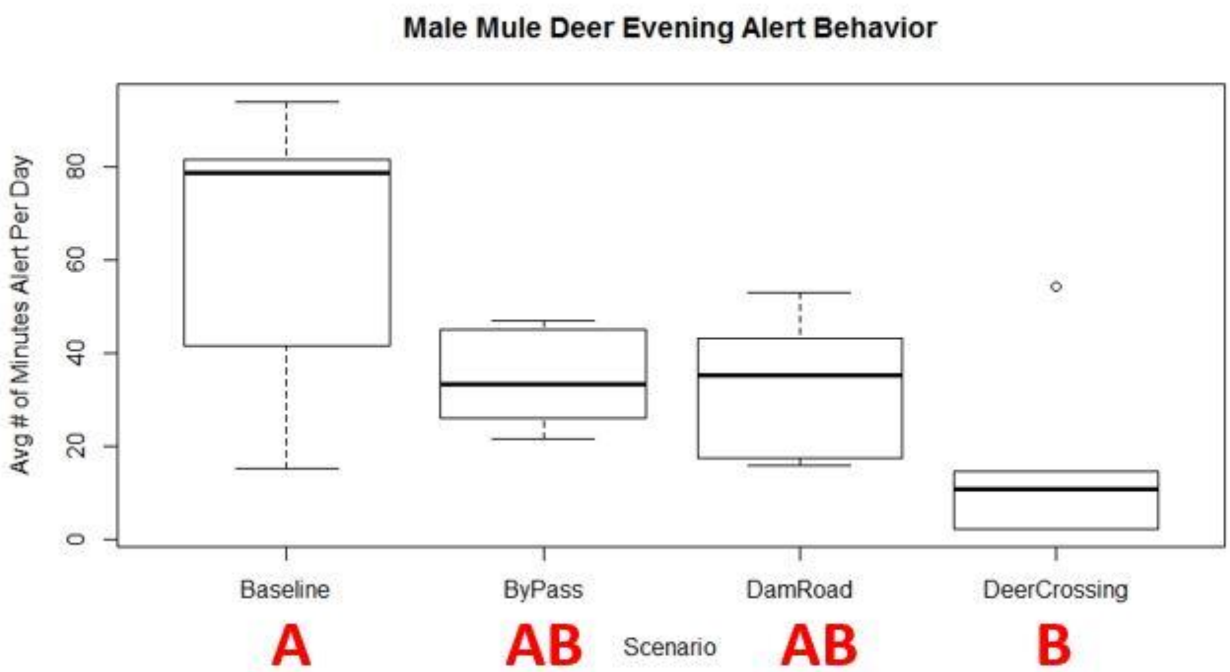

Figure 2.18 Box plot displaying the average number of minute's male mule deer spent alert per evening in response to virtual vehicles for each of the road scenarios. Uppercase letters indicate statistically significant differences between scenarios.

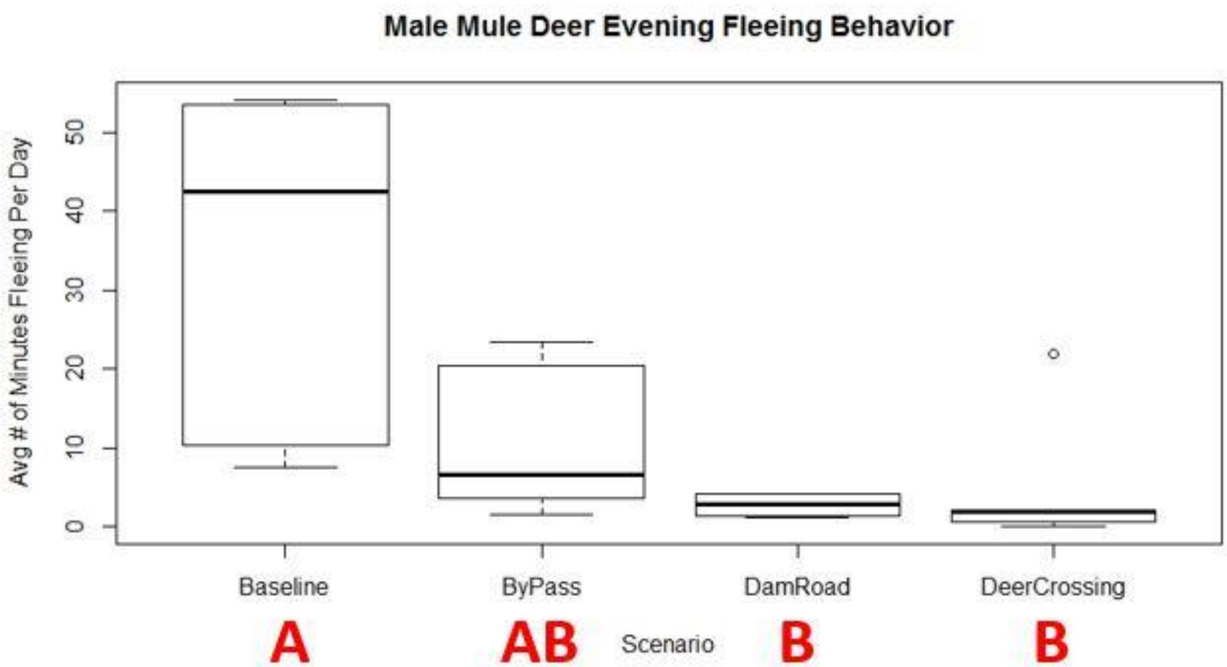

Figure 2.19 Box plot displaying the average number of minute's male mule deer spent fleeing per evening in response to virtual vehicles for each of the road scenarios. Uppercase letters indicate statistically significant differences between scenarios.

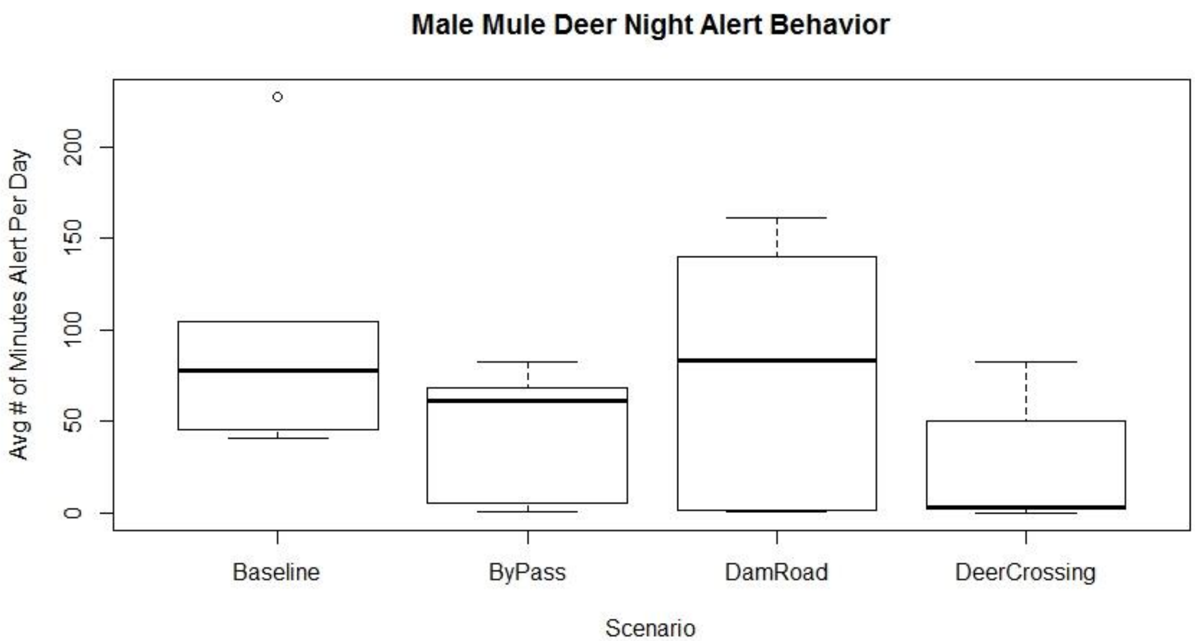

Figure 2.20 Box plot displaying the average number of minute's male mule deer spent alert per night in response to virtual vehicles for each of the road scenarios.

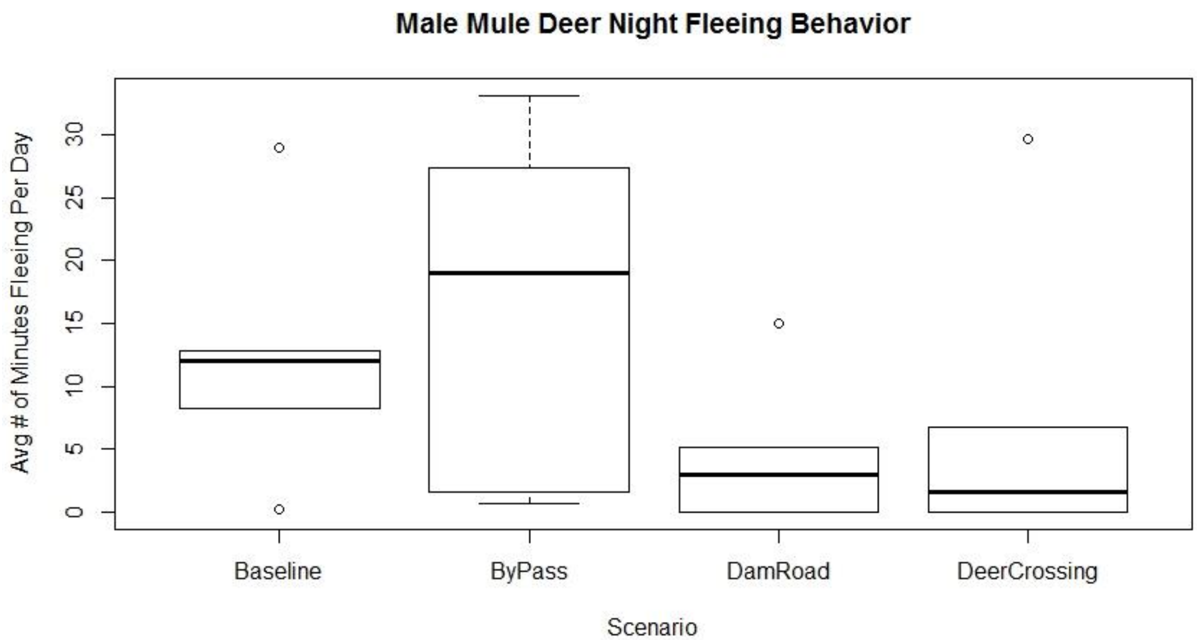

Figure 2.21 Box plot displaying the average number of minute's male mule deer spent fleeing per night in response to virtual vehicles for each of the road scenarios.