EXAMINING THE IMPACTS OF STATE ROUTE 101 ON WILDLIFE USING ROAD KILL SURVEYS AND REMOTE CAMERAS

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ABSTRACT

Examining the impacts of State Route 101 on wildlife using road kill surveys and remote cameras

Sara Ann Snyder

Roads can negatively impact the survival of wildlife populations through additional mortality from road kill and population fragmentation caused by road avoidance behaviors. The 11.9 mile section of State Route 101 between the towns of San Luis Obispo and Atascadero, CA, USA, crosses a mountain lion movement corridor and an area important to maintaining ecological connectivity between protected lands in the Los Padres National Forest to the north and south.

I examined the spatial patterns and landscape and roadway factors associated with road kill occurrence for six taxa; large mammals, mesocarnivores, squirrels, rabbits, birds and raptors. Between 1 May 2009 and 30 June 2010 road kills were documented using vehicle-based surveys. Small mammals were the most common road kill (58.3%), followed by mesocarnivores (10.9%), birds (10.6%), rabbits (5.1%), large mammals (3.3%) and raptors (3.2%). Twenty-nine large mammal road kills were observed; eighteen mule deer, six black bears and five feral pigs. Road kill was highest in the middle of the survey area between the top of Cuesta Grade and the southern edge of Atascadero and lowest along the Cuesta Grade. I modeled road kill occurrence using logistic regression to identify landscape and roadway characteristics that were associated with road kill locations. Large mammal and mesocarnivore road kills were more likely to occur near riparian corridors. Mesocarnivore and squirrel road kills were associated with locations with greater roadside tree cover. Squirrel and rabbit road kills were more likely to occur along sections of the road with large grassy center medians.

I documented animal activity patterns around the roadway during three survey periods (summer 2009, fall 2009 and spring 2010) using remote cameras placed on game trails and underpasses along the roadway. Mule deer displayed crepuscular activity patterns with peaks in activity in the morning between 05:00h and 07:00h and in the evening between 16:00h and 18:00h. Mesocarnivores generally displayed a nocturnal activity pattern with most activity occurring between 18:00h and 06:00h. I used logistic regression to determine if there was a relationship between animal activity patterns and traffic patterns while controlling for time of day, day of the week, and season. Mule deer and mesocarnivore activity patterns varied significantly by time of day and mule deer activity also varied significantly by season; however only mesocarnivore activity varied significantly in relation to traffic volume suggesting that mesocarnivores were less active when traffic volume was high. Using traffic volume and animal activity patterns I calculated a collision potential value for both mule deer and mesocarnivores. Collision potential for mule deer was high in the morning, between 06:00h and 08:00h, and in the evening, between 16:00h and 18:00h in all three seasons. Collision potential for mesocarnivores was high in the evening in fall 2009 (18:00h and 21:00) and spring 2010 (17:00h), and high in the morning in summer 2009 (09:00h).

Road kill mitigation measures should be focused primarily on the section of roadway between Cuesta Pass and the southern edge of Atascadero where road kill was the highest. A combination of wildlife fencing and wildlife crossing structures could be installed to prevent

wildlife from accessing the roadway and allow for safe passage under the roadway. The addition of wildlife crossing structures have also been shown to reduce road avoidance behavior related to traffic. Crossing structures should be placed where riparian corridors pass under or close to the roadway to optimize their use by wildlife.

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GENERAL INTRODUCTION: THE IMPACTS OF ROADS ON WILDLIFE

Roads have become a very prominent feature upon the world wide landscape, dividing up habitats and in the process wildlife populations. Within the United States there is over 4 million miles of roads and while the addition of miles to this systems has slowed, the width and complexity of existing roads has increased to accommodate increasing vehicle traffic (Forman et al. 2003). The two major impacts that roads have on wildlife populations are vehicle-related mortality, or road kill, and fragmentation due to roads acting as barriers to animal movement (Forman and Alexander 1998). Road kill is probably the most apparent impact of roads on wildlife, resulting in an estimated 365 million dead animals a year (Huijser et al. 2008). Fragmentation is less obvious but likely has a greater negative impact on the health of wildlife populations (Forman et al. 2003). Together road kill and fragmentation can result in subdivided populations that experience negative genetic effects which impact the long term survival of local populations and in extreme cases, such as with the Florida Panther, jeopardize the survival of an entire species (Forman et al. 2003). Overall, the impact of roads on wildlife has been recognized as a significant contributor to the global biodiversity crisis for many taxa (Forman and Alexander 1998, Trombulak and Frissell 2000).

This thesis attempts to gain a better understanding of the possible impacts on wildlife of an 11.9 mile section of State Route 101 between the towns of San Luis Obispo and Atascadero in San Luis Obispo County, California, USA. Hopefully the insight gained in this thesis can be used as a starting point to begin to address the impacts of this roadway on the wildlife community.

I. SPATIAL PATTERNS AND ASSOCIATED LANDSCAPE AND ROADWAY CHARACTERISTICS OF ROAD KILL ON STATE ROUTE 101 BETWEEN SAN LUIS OBISPO AND ATASCADERO, CA

INTRODUCTION

Road killed wildlife is one of the most obvious impacts of roadways and vehicle traffic on wildlife. A collision with a vehicle typically results in the death of the animal, but may also cause extensive damage to the vehicle and seriously injure, or even kill, the vehicles occupants (Allen & McCullough 1976, Conover et al. 1995). The survival of at least 21 federally listed threatened and endanger species is at risk due to additional mortality caused by collisions with vehicles, including the California tiger salamander (*Ambystoma californiense*), the San Joaquin kit fox (*Vulpes macrotis mutica*) and the desert tortoise (*Gopherus agassizii*) (Huijser et al. 2008). Wildlife-vehicle collisions account for approximately 5 percent of all reported motor vehicle accidents, and between the years 1990 and 2004 increased by approximately 50 percent in the United States (Huijser et al. 2008). An estimated one to two million collisions between large mammals and vehicles occur annually in the United States at an economic cost of > $8.3 billion in vehicle damage, resulting in approximately 211 human fatalities and 29,000 injuries annually (Conover et al. 1995, Huijser et al. 2008). Collisions that result in human fatalities typically involve deer, however, collisions with other large mammals and medium-sized mammals have also resulted in human fatalities (Huijser et al. 2008).

Collisions between motor vehicles and wildlife tend to occur at specific locations year after year, and are associated with landscape and roadway characteristics (Puglisi et al. 1974, Bashore et al. 1985, Hubbard et al. 2000, Malo et al. 2004, Forman & Alexander 1998, Gunson et al. 2011). Collisions typically occur at locations with preferred habitat for specific species or groups of species: amphibians are killed near wetlands, turtles near open-water areas, deer

along edge habitats between wooded areas and fields or near conservation areas in urban areas (Bashore et al. 1985, Forman & Alexander 1998, Clevenger et al. 2003, Nielsen et al. 2003, Gunson et al. 2006, Gunson et al. 2011). Roadway characteristics also play a role in road kill occurrence. Road kill is less likely to occur where a center median barrier is present, suggesting that animals are less likely to cross where there are barriers to movement (Gunson et al. 2011, Malo et al. 2004, Barnum 2003). Road kill is also less likely to occur near culverts and underpasses which can be used by animals to move safely from one side of the roadway to the other without crossing the roadway (Clevenger et al. 2003). Factors that impact the ability of the motorist to see an animal before it enters the roadway are important as well. Road kill is more likely to occur where vegetation around the roadway can obscure an animal from view (Bashore et al. 1985).

The goal for managing road kill should be to reduce wildlife-vehicle collisions in order to protect individual animals and, in turn, wildlife populations, as well as improve motorist's safety (Forman et al. 2003, Huijser et al. 2008, Gunson et al. 2011). Targeted mitigation can have the greatest impact with the least financial cost (Clevenger et al. 2003, Huijser et al. 2008). To effectively target mitigation it is necessary to determine what species are susceptible, where road kill is occurring and what factors are associated with those locations (Clevenger et al. 2003, Gunson et al. 2011). To achieve this goal along this section of SR 101 I attempted to: (a) quantify road kill occurrence among all species, with a primary focus on large mammals such as black bear (*Ursus americanus*), feral pig (*Sus scrofal*), mule deer (*Odocoileus hemionus*), and mountain lion (*Puma concolor*); (b) identify sections of the roadway where road kill is highest and determine if it is taxa-specific; (c) determine if scavengers are drawn to the roadway by road kill and then killed themselves; and (d) develop predictive models of road kill to identify landscape and roadway characteristics influencing the likelihood of collisions.

METHODS

Study Area

I focused on an 11.9 mile section of State Route 101, from the northeastern edge of San Luis Obispo to the Santa Barbara Road exit in southern Atascadero, California, USA (Fig. 1.1). The speed limit for this entire section of road is 65 mph. This section of highway climbs from 106m elevation outside San Luis Obispo up the Santa Lucia Mountain range to the Cuesta Pass at 464m. This portion of the roadway is referred to as the Cuesta Grade. From Cuesta Pass the road descends into the Santa Margarita Valley following the western edge of the valley to the town of Atascadero. The roadway has two lanes of traffic in both directions, except along Cuesta Grade where there are three lanes in both directions. There is a center median barrier separating the northbound and southbound lanes along this entire section of roadway. From San Luis Obispo to just north of the Cuesta Pass the median barrier is a solid concrete barrier approximately 32 inches tall. From Cuesta Pass north the northbound and southbound lanes are divided by a vegetated median with guard rail median barriers – metal beam attached to wooden posts leaving a 12 to 18 inch gap between the beam and ground – running down either side or up the middle of the median. There are a few breaks in the center median at intersections with side roads and private driveways (Fig. 1.1). The vegetation types along the roadway vary greatly and include grazed grassland, cultivated crops, coastal scrub, chaparral, mixed evergreen forest, riparian woodland, oak woodland and oak savannah. There are two major waterways along this stretch: San Luis Obispo Creek and Santa Margarita Creek. The roadway runs parallel to these creeks in places and crosses over the San Luis Obispo Creek once and the Santa Margarita Creek twice (Fig. 1.1).

Road Kill Survey Data Collection

Between 1 May 2009 and 30 June 2010 road kills were documented using vehicle based surveys conducted weekday mornings between 07:00h and 09:00h. The survey route had two parts: the northbound lanes and southbound lanes. The northbound survey route began just north of San Luis Obispo (postmile (PM) 30.4) and ended at the southern exit for Atascadero: Santa Barbara Road (PM 42.1). The southbound survey route was the reverse of the northbound. The northbound survey was always conducted first, followed by the southbound survey. For analysis I divided the roadway into 0.1 mi segments using the PM locations provided by the California Department of Transportation (Caltrans). Each road kill observed was assigned to one of these sections.

Two observers conducted each survey: one drove and the other recorded data while both looked for road kill. The location of each road kill was recorded using the vehicle's trip odometer which was zeroed at the beginning of both the northbound (PM 30.4) and southbound routes (PM 42.3). The trip odometer reading was used to assign each road kill to the nearest PM location for analysis. For each road kill the route, species, and its location on the roadway (lane, shoulder or median) was also recorded. The location of large mammal road kills (mountain lion, black bear, mule deer or feral pig) was recorded using a Garmin eTrex GPS unit for a more accurate location.

Spatial Analysis

To identify spatial trends in road kill occurrence I divided the study area into five sections and used a Chi-squared Goodness of Fit test on total road kills and five of the seven taxonomic groups (the raptor and rabbit group was not analyzed because the sample size was

too small). The expected number of road kills per section was calculated using the proportion of the 11.9 mi contained within that section. I choose the sections based on differences in landscape and/or roadway features and to be as similar in length as possible. This analysis was performed using Microsoft Excel. The study area was divided as follows (Fig 1.2):

A) San Luis Obispo city limits to the base of Cuesta Grade (PM 30.4 – 32.7)

This section is mostly flat and runs parallel to San Luis Obispo Creek. There are two lanes of travel in both directions divided by a concrete median barrier. There is a gap in the barrier at the intersection with Reservoir Canyon Road.

B) The base of Cuesta Grade to the summit of Cuesta Pass (PM 32.8 – 35.2)

The roadway climbs the western side of the Santa Lucia Mountain range. The roadsides are steep and in places the southbound side is built on fill making the side of the road impassible to animals due to the vertical engineered walls holding up the roadway. There are three lanes of travel in both directions separated by a concrete median barrier with a gap in the barrier at the base of Cuesta Grade, one third of the way up the Grade and just south of the summit to allow for left hand turns onto side-roads and private driveways.

C) The summit of Cuesta Pass to the Highway 58 junction (PM 35.3 – 37.8)

From Cuesta Pass the roadway descends down the eastern side of the Santa Lucia Mountain range. The vegetation transitions sharply to a mixture of chaparral and dense oak woodland. Santa Margarita Creek runs parallel to the roadway and crosses underneath the roadway twice. This section has two lanes of travel in both directions separated by a large grassy median with some shrubs and mature oak trees and guard rail median barrier lining both edges.

D) The Highway 58 junction to the southern edge of Atascadero (PM 37.9 – 40.3)

This section hugs the eastern edge of the Santa Lucia foothills. The southbound side is dominated by oak savannah (*Quercus lobata*), while the northbound side is mostly grassland with an increasing number of houses and other buildings in close proximity to the highway. This section has two lanes of travel in both directions separated by a grassy center median with paired guard rail median barriers down the center.

E) The southern edge of Atascadero to the Santa Barbara exit (PM 40.4 – 42.3)

The southern edge of Atascadero runs along the northbound side of this section with houses within 50m of the roadway. There are two lanes of travel in both directions with the same type of center median as in zone D. This section ends at the Santa Barbara Road exit ramp in Atascadero.

Scavengers and Road Kill

To determine if the scavenging of road kill by other animals could be responsible for additional road kill I used linear regression to compare the number of small mammal road kills to the number of mesocarnivore road kills at each PM location. Prior to analysis both variables were transformed using square root to normalize the distribution because it is count data. Small mammals made up almost two-thirds of the road kill documented, therefore I considered this group as the most likely to be scavenged. The group mesocarnivores was made up of medium-sized carnivores and omnivores that are known scavengers. This analysis was performed in MINITAB 10.0.

Landscape and Roadway Characteristic Data Collection

For each PM section I measured nine landscape and roadway characteristics as possible predictors of road kill occurrence (Table 1.1). Variables were obtained either through measurements taken in the field or using Geographic Information System (ArcMap 10, Environmental Systems Research Institutes, 2010). Field measurements were collected by visiting each PM section for both the northbound and southbound routes (PM 30.4 – 42.1). Caltrans provided the geographic coordinates for each PM location and we used a Garmin eTrex hand-held GPS unit to locate each PM location in the field. The following landscape and roadway factors were considered in the analysis:

A) TREE: Roadside Vegetation Type

I measured vegetation cover along a 50m transect perpendicular to each PM on both the northbound and southbound sides of the roadway. Each transect began at the edge of the right-hand lane (white line) and extended perpendicular away from the roadway. I classified vegetation along each transect as either bare, grass, shrub or tree and measured the distance covered by each type. I summed the results from both the northbound and southbound sides to create one measurement for each vegetation type at each PM. Tree and grass were the most common vegetation types, while shrub and bare rarely accounted for more than 5m of each transect. I therefore decided to use the distance within each 100m transect covered by trees to describe the vegetation around the roadway and scaled it by 10m.

B) COVER: Motorist's Visibility

I measured the perpendicular distance from the road edge to vegetation that was greater than one meter tall, and therefore could obscure even the largest animals from view, at each PM for both the northbound and southbound routes. To be conservative I used the shorter of

the two measurements (northbound vs. southbound) as the value for the PM. If neither side of the roadway had one meter vegetation within 50m of the roadway then 50m was used as the measurement.

C) MTYPE: Type of center median

At each PM I noted the type of center median barrier as either metal guard rail or concrete median barrier.

D) SLOPE: Landscape Topography

To determine the effect of topography on road kill occurrence I assigned an average slope value to each PM. This value is the average slope, in degrees, of two 100m diameter circles centered 100m from the roadway, one on the northbound side and one on the southbound side of the highway (northbound and southbound values were averaged at each PM), and derived from the 1/3 Arc second (~10m) digital elevation model for San Luis Obispo County (http://lib.calpoly.edu/collection/gis/slodatafinder/) (See appendix for specifics on how the 100m diameter circles and slope value were created) (Fig 1.3).

E) HABITAT: Landscape Habitat Type

This variable captures the habitat type of the landscape surrounding the road corridor (50 – 100m from the road). I used the California Wildlife Habitat Relationships (CWHR) habitat classification scheme to identify the habitat type located within the 100m diameter circles used for SLOPE. CWHR consists of 59 habitat categories, eight of which occurred along this section of roadway: evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, emergent herbaceous wetlands, cultivated crops, developed open space, and developed low intensity. To simplify analysis I condensed these eight categories into two vegetation classes: CLOSED,

categories with canopy cover (evergreen forest, mixed forest, shrub/scrub) and OPEN, categories with no canopy cover (grassland/herbaceous, emergent herbaceous wetlands, cultivated crops, developed open space, and developed low intensity). PMs were classified to the class, CLOSED or OPEN, that covered > 50% of the area of the northbound and southbound 100m circle areas combined (Fig. 1.4).

F) STREAM: Distance to nearest riparian corridor

To determine if there was an association of road kill with riparian corridors I calculated the Euclidean distance from each PM to the nearest creek or tributary. I obtained the locations of creeks from the National Hydrography Dataset (downloaded from the National Map Viewer available on the US Geological Survey website) (Fig. 1.1).

G) MBREAK: Distance to nearest gap in center median

The presence of gaps in the center median was not effectively captured by MTYPE because these gaps are smaller than one tenth of a mile. To determine the relationship of road kill to gaps in the median I measured the Euclidean distance from each PM to the nearest gap (Fig. 1.1).

H) UPASS: Distance to nearest large underpass

There are two large underpasses within the study area: the railroad flyover where the highway bridges over the railroad tracks just north of Cuesta Pass and the Santa Margarita Bridge where the roadway bridges over the Santa Margarita Creek just north of the Highway 58 junction. Large mammals and mesocarnivores were observed using both underpasses during the study. UPASS is the Euclidean distance from each PM to the nearest large underpass (Fig. 1.1).

I) URBAN: Distance to nearest developed area

This section of roadway is between two areas of human development, San Luis Obispo to the south and Atascadero to the north, and there is a smaller developed area, Santa Margarita, to the east. URBAN is the Euclidean distance from each PM to the nearest developed area, an area with and overall density of at least 500 people per square mile, as defined by the 2000 Census (Fig. 1.1).

Multivariate Analysis of Factors Associated with Road Kill Occurrence

I used multiple logistic regression to determine which landscape and roadway characteristics were important in the occurrence of road kill (Hosmer and Lemeshow 1989). Separate models were created for six taxa: squirrels (California ground squirrel (*Otospermophilus beecheyi*) and western gray squirrel (*Sciurus griseus*)), rabbits (California black-tail jackrabbit (*Lepus californicus*) and Audubon's cotton tail (*Sylvilagus audubonii*), mesocarnivores (gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*), and striped skunk (*Mephitis mephitis*)), large mammals (black bear, mule deer, feral pig and mountain lion), birds and raptors (hawks, owls and unidentified raptors). The PM section of the roadway was the unit of analysis and the response variable was binary; each PM was classified as either a "kill" or "no kill" section. PMs where ≥ 1 road kill occurred were classified as "kill" and PMs where no kills occurred as "no kill". Some PMs were excluded because the side of the road along that section was impassible to wildlife; e.g. the vertical drop-offs along the southbound side on the Cuesta Grade, the bridge over the railroad tracks and at the base of Cuesta Grade and just north of San

Luis Obispo where the road was cut in the side of a rock face resulting in a vertical wall of rock along the southbound lanes (17 sections out of 118 total).

The continuous predictor variables (TREES, COVER, SLOPE, STREAM, MBREAK, UPASS, URBAN) were tested for collinearity before the models were run (Menard 1995, Mac Nally 2000). If two predictors were correlated, ($r > |0.7|$), one of the predictors was dropped from the model. The variables URBAN and SLOPE were highly correlated ($r = 0.821$) (Table 1.2). The predictor URBAN was retained while SLOPE was dropped because the presence of urban areas is a factor that is likely to change over time due to urban sprawl and therefore would provide insight into how this sprawl could impact road kill in the future.

I first ran saturated models for each taxon with all the predictors that I thought might be associated with where road kill occurred for that taxon (Mac Nally 2000). All eight remaining predictors (TREE, COVER, MTYPE, HABITAT, MBREAK, STREAM, UPASS, and URBAN) were included in the full models for large mammals and mesocarnivores. I excluded the variable UPASS from the squirrel, rabbit, bird and raptor and MBREAK from the bird and raptor models because they were not biologically appropriate for these taxa. If the saturated model was significant for that taxon (p-value < 0.10) then I created a final model using backward elimination: removing non-significant predictor variables (p-value > 0.10) one at a time (predictor with largest p-value first) until all remaining predictors were significant. This was done to determine if there were any predictors that were not significant in the saturated model but were significant once other variables were removed. I compared the AICc and BIC values to determine if the saturated or the final was the better model. These analyses were performed in JMP Pro 11.

RESULTS

Species Detected by Road Kill Surveys

A total of 278 surveys were completed between 1 May 2009 and 30 June 2010 with an average of 19.9 surveys per month (Table 1.3). In total 687 road kills were detected (23 identified species) and on average 2.5 ± 0.1 (SE) road kills were observed per survey (Table 1.4). Of the 687 road kills, 48 (7.0%) were not identified due to the condition of the carcass. These road kills were not included in the taxon-specific analysis. Of the identifiable road kills, 544 were mammals (9 species), 73 were birds (13 species) and 22 snakes (one species). Mammals accounted for 79% of the road kills, followed by birds (11.4%) and snakes (3.4%). Included within the mammals group were five domestic cats and two domestic dog road kills (which were excluded from subsequent analyses).

Only two large mammal species were documented during the surveys: mule deer and feral pig (Table 1.4). Mule deer made up the majority of large mammal road kills with 18 road kills. Five feral pigs were killed; however four of those five were killed together, a sow with three piglets, and treated as one road kill event. No mountain lion or black bear road kills were observed during the surveys; however, six black bears were killed within the study area during the period of the study. These road kills were not detected by the survey crew because they typically occurred during the weekend when surveys were not conducted (Perrine and Snyder 2011). The California Department of Fish and Wildlife provided information on these road kills (Bob Stafford, CDFW, pers. com.) and they were incorporated into the taxon-specific analysis.

Mesocarnivores were the second most common group of mammals killed, making up almost 11% of all road kills and 14% of mammals (Table 1.4). We documented seven species:

coyote, gray fox, red fox, striped skunk, raccoon, opossum and badger. The two most common mesocarnivore killed were skunks and raccoons.

Small mammals were the majority of all road kills (63.7%) and of mammals (80.7%) (Table 1.4). Five species were observed: California ground squirrel, Western gray squirrel, Audubon's cotton tail, black-tailed jackrabbit, and woodrat (*Neotoma sp.*). Squirrels made up the majority of the small mammals and were the most common road kill, accounting for 58.3% of all road kill and 73.9% of mammals. Most of the squirrels were California ground squirrels; however, western gray squirrels were observed. Rabbits were the next most common, accounting for 5% of all road kill observed. Rabbits included 35 Audubon's cottontails and one black tailed jackrabbit.

Birds accounted for 10.6% of all road kill and included 13 species (Table 1.4). Raptors accounted for 30.1% of all birds. Yellow-billed magpies (*Pica nuttalli*) were the most common single bird species identified with 11 road kills. There were 22 snakes killed during the survey. Only three were identified to the species, gopher snake (*Pituophis catenifer*).

The most road kills per survey occurred during the summer of 2009, 5.58 in June and 4.30 in July, and the fewest in winter 2010, 0.67 in January and 0.89 in February (Table 1.5). January was also the month with the most surveys (11) where no road kills were detected (Table 1.3). Squirrel road kill per survey was highest in summer, 3.17 in July and 2.95 in June, and the least in winter, 0.19 in January and 0.21 in December. The most rabbit road kills per survey occurred in summer and the fewest in winter. The most mesocarnivores killed per survey occurred in December (1.00) and the fewest in August (0.05). Large mammal road kills were highest in May 2010 (0.24) and none were detected in September and December 2009 and February 2010. The most bird road kills occurred in June 2009 (0.95) and the fewest were killed

during the winter months. The most raptors were killed in November 2009 (0.33) and no raptors were killed in June, August and September 2009 and January and February 2010. Snake road kills were only detected during the late spring/early summer months – the most snakes were detected in May (0.45) and June 2009 (0.58).

Spatial Patterns of Road Kill

The Chi-squared test was significant for the vertebrate community, mammals, squirrels, mesocarnivores and birds indicating that road kills did not occur evenly throughout the study area (Table 1.6). The taxa raptors and rabbits were not tested because of the small sample size. Large mammals was not significant. More road kills than expected occurred in zone C for seven of the eight taxa and in zone D for six of the eight taxa. More mesocarnivore and mammal road kills than expected occurred in zone A, but fewer than expected for the six remaining taxa. Fewer than expected road kills occurred for all eight taxa in zone B and E.

The greatest proportion of vertebrate road kills occurred in zone D (43%) followed by zone C (33%). Squirrels accounted for the majority in these zones; 49% in zone D and 34% in C. The greatest proportion of birds, rabbits and raptors were killed in zone D, 42%, 75% and 45% respectively. The greatest proportion of mesocarnivore road kill occurred in zone C (48%) followed by zone A (23%).

The Chi-squared test was not significant for large mammals as a group, likely because the three species that made up the group peaked in different zones. Deer road kills occurred in all zones however the greatest proportion occurred in zone A (Fig 1.5). Bear road kills were only observed in zone A and C, with five of the six road kills occurring in zone C, within one mile of

each other. The two feral pig road kill events both occurred in zone E within 0.1 mile of each other, approximately 1 mile south of the Santa Barbara Road on-ramp.

Scavengers and Small Mammal Road Kill

Mesocarnivores and small mammal road kills were not correlated spatially ($p = 0.11$) (Fig 1.6). The greatest proportion of small mammal road kills occurred in zone D, 49% of the squirrels and 75 % of the rabbits, while the greatest proportion of mesocarnivore road kills occurred in zone C (75%) (Table 1.6). There was also no temporal correlation: mesocarnivore road kills peaked during winter when small mammal road kills were at their lowest (Fig 1.7).

Landscape and Roadway Characteristics Contributing to Road Kill Occurrence

The saturated models were significant ($p < 0.10$) for large mammals, mesocarnivores, squirrels and rabbits, but not for birds or raptors (Table 1.7). The final model for large mammals contained only the predictor STREAM (Table 1.8, Fig. 1.8). The predictor MBREAK was significant in the saturated model but was dropped from the final because it became non-significant as other predictors were removed. Mesocarnivores retained STREAM and TREE (Fig. 1.9), squirrels TREE and MTYPE (Fig. 1.10) and rabbits MTYPE and MBREAKS (Fig. 1.11). For all taxa the AICc and BIC values indicated that the final model described the data better than the saturated model (Table 1.7).

DISCUSSION

During a thirteen-month period 687 road kills were documented, of which the majority were small mammals (63.7%). Using a Chi-square Goodness of fit test I found that most taxa exhibited clustering and the majority of road kill occurred in zone D (43%) and C (33%). I modeled road kill occurrence using logistic regression and found that roadside tree cover, riparian corridors and type of center median barrier were important predictors (Table 1.8). Which predictors were important varied by taxon. Large mammal and mesocarnivore road kill was associated with riparian corridors (Fig. 1.8 and 1.9), mesocarnivores and squirrels were more likely to occur at locations with greater roadside tree cover (Fig. 1.9 and 1.10), and squirrels and rabbits were associated with large grassy center medians with metal guard rail barriers (Fig. 1.10 and 1.11).

Species Detected by Road Kill Surveys

The majority of the road kill belonged to common species of small mammals with large population sizes that are not a concern for population or local-level extinction and are not a concern for motorist's safety. Large mammals made up the smallest proportion of observed road kill. Deer were the most common large mammal killed and most likely large animal in the US to be involved in fatal wildlife-vehicle collisions (Huijser et al. 2008). The black bear and feral pig road kills are also a concern because they are species that are also known to be involved in fatal-crashes (Huijser et al. 2008). Mesocarnivores while typically not involved in fatal wildlife-vehicle collisions, on occasion have been responsible.

There are several potential reasons bobcat or mountain lion road kills were not observed during the surveys. These species might be exhibiting road avoidance behavior. A study in

southern California found that bobcats appeared to avoid crossing roads (Riley 2006). Mountain lions have also been found to avoid paved roads (Dickson et al. 2005, Van Dyke et al. 1986, Sweanor et al. 2000, Dickson and Beier 2002). Another possibility is that individuals are safely crossing under the highway by using underpasses. During the time of the road kill survey bobcats were photographed with remote cameras using the railroad bridge underpass. However, only one mountain lion was detected during the camera surveys and that was at the camera station farthest from the roadway, possibly a sign of road avoidance. As for mountain lions, it is also possible that the local population could be reduced due to high road kill rates in the past or some other factor.

Spatial Patterns of Road Kill

The majority of vertebrate road kills occurred in zone D (43%) and zone C (33%). All of zone C and most of zone D cross an area that was identified to be essential to maintaining ecological connectivity between relatively natural habitat blocks to the north and south of SR 101 (Spencer et al. 2010). Zone C also crosses a corridor that is important for maintaining connectivity for mountain lion populations to the north and south (Thorne et al. 2002). These corridors were identified using least cost path analysis which took into account the quality of habitat, distance between natural habitat blocks and level of human impacts, therefore it is probably not surprising that road kill was highest in these zones. And because these zones cross areas important to maintaining connectivity between habitats on either side of SR 101, measures should be taken to provide safe crossing opportunities for wildlife, such as wildlife crossing structures. As well as maintaining connectivity across the highway, wildlife crossing

structures have been found to reduce road kill which increases motorist safety (Huijser et al. 2008, Clevenger and Huijser 2011, Ford et al. 2011).

The lowest proportion of road kill occurred in zone B, the Cuesta Grade. This is the only section with three lanes of traffic in both directions, instead of two, increasing the distance animals must travel to cross the roadway. In studies that compared roads of different widths, fewer road kills occurred on the wider roads (Forman et al. 2003, Grilo et al. 2009, Taylor and Goldingay 2004). Road kill might also be low because access to the roadway by wildlife is limited along portions of the southbound side due to the vertical engineered walls holding up the roadway. A concrete median barrier divides the northbound and southbound sides of the roadway along this entire section with only two small breaks. This barrier would likely hinder small and probably median-sized mammals from successfully crossing. Fewer road kills occur along highways with median barriers, one explanation being that median barriers impede movement, therefore animals are less likely to cross (Clevenger and Kociolek 2006). All of these factors likely work together to make this section of roadway at least a partial barrier to animal movement and therefore contributed to the lower number of road kills.

Large mammals were the only taxon to not exhibit clustering based on the Chi-squared analysis. Overall, large mammal road kill appeared to be spread fairly evenly throughout the study area. However, the individual species did exhibit small scale clustering in different sections of the roadway: deer near the southern end of the study area (zone A), bear in the center (zone C) and feral pigs near the north end (zone E). Large mammals are a concern for motorists' safety because they are involved in the majority of fatal wildlife-vehicle collisions. To effectively reduce large mammal road kill each species would need to be addressed separately which makes a simple solution to large mammal road kill unlikely.

Scavengers and Small Mammal Road Kill

Mesocarnivore road kills were not significantly correlated spatially to small mammal road kills and also occurred during different parts of the year. This suggests that scavenging was likely not a major factor contributing to mesocarnivore road kill. It is possible that some mesocarnivore road kills could have been the result of the animal scavenging existing road kill. However, it is likely that other factors are more important in the location and timing of mesocarnivore road kill than scavenging.

Landscape and Roadway Characteristics Contributing to Road Kill Occurrence

Large mammal road kills were associated with sections of the roadway close to riparian corridors (Fig. 1.8). Road kill for the three species included in the large mammal group clustered along different sections, therefore, the presence of riparian corridors was likely the only significant predictor because this was the only factor that all three species had in common. Other studies have found that ungulate road kill was more likely to occur closer to riparian corridors (Finder et al. 1999, Gunson et al. 2009, Dussault et al. 2006, Hubbard et al. 2000) the theory being that animals use riparian corridors to move through the landscape (Patton 1997). Five of the six black bear road kills that occurred within one mile of each other, were located where Santa Margarita Creek runs parallel to the road way and were centered around where the roadway crossed over the creek. A combination of wildlife fencing to direct bears and wildlife crossing structures to allow the safe passage of bears under the roadway would reduce road kill and maintain movement of bears. Installing new wildlife crossing structures would likely be the most expensive option but retrofitting the existing culvert where the creek runs

under the roadway to allow the passage of large mammals could be a more cost effective option.

Similar to large mammals, mesocarnivores were more likely to be killed near riparian corridors (Fig. 1.9). A study by Barrientos and Bolonio (2009) observed that European polecats were more likely to be killed near riparian corridors. Mesocarnivores were likely using these riparian corridors to move through the landscape (Patton 1997). Mesocarnivores were also more likely to be killed at locations with greater roadside tree cover (Fig. 1.9). Other studies have observed that road kill is more likely to occur near wooded area or where vegetative cover adjoins both sides of the road (Bellis and Graves 1971). Roadside vegetative cover was an important predictor of small and medium-size mammal (coyote and smaller) road kill along the Trans-Canada Highway near Banff National Park in Canada (Clevenger et al. 2003). The theory is that vegetative cover near the roadway provides greater protection and security for animals approaching the road (Forman et al. 2003).

Both squirrel and rabbit road kills were more likely to occur at locations with metal guard rail center median barriers (Fig. 1.10 and 1.11). Intuitively this makes sense because a 35 inch tall solid concrete median barrier would be completely impassable to a small mammal, while a guard rail median, with the 18 – 21 inch gap between the metal beam and the ground, would pose no impediment to their movements. However, more likely the driving factor for this trend was that the guard rail median barrier was associated with a wide vegetated median. It has been suggested that a large vegetated median barrier can serve as a 'safe zone' by decreasing the distance the animal has to cross at one time in order to reach safety. Clevenger et al. (2003) observed that birds were more likely to be killed on road with center medians and suggested this was because birds were more likely to cross the narrower gap. These center medians might also serve as habitat for squirrels and rabbits. Bellis and Graves (1971) observed

that deer road kills were more likely to occur where there was good grazing on both sides of the highway and in the center median strip.

Squirrel road kill was also more likely to occur at locations with greater roadside tree cover (Fig. 1.10). This species group was a combination of California ground squirrels and western gray squirrels. While it is not surprising that western gray squirrels are more likely to be killed at location with more tree cover it might be surprising for ground squirrels that are normally associated with grasslands. However, on average the vegetation within 50m of the roadway was < 20% covered in trees, therefore even if an area had greater tree cover, comparatively, it was still predominately grassland which is preferred by ground squirrels. Sections of the roadway with no tree cover occurred closer to San Luis Obispo or Atascadero and along the Cuesta Grade where roads kills were lower than expected by chance.

Distance to gaps in the center median was the other factor significant in the rabbit model, suggesting that rabbit road kill was less likely to occur near breaks in the center median (Fig. 1.11). This likely was not an important relationship but simply an artifact caused by the majority of the rabbit road kills occurring along the longest section of the road with no median breaks (only one did not occur along this section). This section of the roadway also had guard rail median barriers which rabbits would be able to pass under without difficulty.

CONCLUSION

Small mammals accounted for the majority of the road kill observed, however 29 large mammals were killed, and collisions with large mammals such as these pose the greatest risk to motorist's safety. The loss of one individual likely has a greater impact on the survival of large mammals than small mammals or mesocarnivores because large mammals have smaller

population densities, are slow to reach sexual maturity and have fewer offspring. Large mammal also tend to be wide ranging; therefore an individual will likely encounter more roads. This section of SR 101 crosses a corridor that is important to maintaining ecological connectivity between the protected lands of the Los Padres National Forest to the north and south (Spencer et al. 2010) and is an important movement corridor for mountain lions (Thorne et al. 2002). The challenge then for this section of SR 101 is to reduce road kill to improve motorist's safety and protect individual animals while still allowing for animal movement across the roadway in order to maintain ecological connectivity and protect the long term survival of wildlife populations.

The combination of wildlife fencing and wildlife crossing structures is the ideal solution to reducing road kill while maintaining animal movement across a roadway (Clevenger and Huijser et al. 2011). Wildlife fencing without crossing structures would be less expensive; however fencing by itself would prevent wildlife movement across the roadway, reducing connectivity. In situations where only fencing was used, wildlife have been documented forcing fences to cross roadways (Forman et al. 2003, Gibeau and Heuer 1998). Black bears near Banff Park in Canada were observed climbing over wildlife fences around the Trans-Canada Highway and vehicle collisions with black bear occurred within the fenced sections of the highway after fencing was installed (Gibeau and Heuer 1998).

Large mammal road kill was greatest in zone C and zone A; therefore measures to reduce large mammal road kill should be implemented in these sections first to achieve the greatest reduction in road kill and improvement to motorist safety. Large mammal road kill was also associated with riparian areas. In zone A San Luis Obispo Creek runs parallel to the road way, as does Santa Margarita Creek in zone C. There were also several locations along these sections were the roadway passes over a riparian areas. In some of the locations where the roadway crosses riparian areas there are existing culverts to allow the passage of water under

the roadway. These culverts could be modified to allow the passage of large mammals as well as water and wildlife fencing along the road way could be used to funnel animals towards these culverts. Mesocarnivores would benefit from these measures as well because their road kill locations were also associated with riparian areas.

TABLES

Table 1.1. Landscape and roadway characteristics used as predictors in the modeling analysis of road kill locations.

Variable	Description	Type	Field/GIS
TREE	Distance of 100 meter transect in (two 50 meter transect, one perpendicular to the northbound side and the other to the southbound) dominated by tree cover (scaled to 10m).	Continuous	Field
COVER	Least perpendicular distance (m) from the roadway to vegetation that is 1 meter tall or greater (used the shorter of the two distances between northbound and southbound). If there was no 1m tall cover within 50m of roadway 50m was used.	Continuous	Field
STREAM	Distance each postmile to the nearest riparian area (scaled by 100m).	Continuous	GIS
SLOPE	Mean landscape slope (in degrees) of a 100m diameter circle centered 100m away from the roadway at each postmile (north and southbound side averaged).	Continuous	GIS
HABITAT	The dominant habitat type of a 100m in diameter circle centered 100m away from the roadway at each postmile location. The habitat type was determined using the California Wildlife Habitat Relationships habitat classification scheme. The habitat types were simplified into two categories: 0 = habitats with no canopy cover (grassland/herbaceous, emergent herbaceous wetlands, cultivated crops, developed - open space, developed – low intensity) and 1 = habitats with canopy cover (shrub/scrub, evergreen forest, mixed forest).	Categorical	GIS
MTYPE	The type of the center median located between the north and southbound lanes: 0 = concrete barrier, 1 = no barrier or guard rail.	Categorical	Field
MBREAK	Distance to the nearest break in the median barrier (left hand turn lanes with no concrete or guardrail median (scaled by 100m).	Continuous	GIS
UPASS	Distance to either Santa Maria Creek Bridge or Railroad overpass, whichever is closest (scaled by 100m).	Continuous	GIS
URBAN	Distance to the nearest Urban Area (scaled by 100m).	Continuous	GIS

Table 1.2. Correlation matrix of continuous predictor variables used in the road kill modeling analysis.

	TREE	COVER	SLOPE	MBREAKS	STREAM	UPASS
COVER	-0.415 0.000					
SLOPE	0.109 0.278	-0.183 0.067				
MBREAK	-0.216 0.030	0.228 0.022	-0.375 0.000			
STREAM	-0.468 0.000	0.267 0.007	-0.208 0.037	0.300 0.002		
UPASS	-0.116 0.247	0.045 0.656	-0.183 0.067	-0.182 0.069	-0.097 0.334	
URBAN	-0.060 0.550	-0.238 0.017	**0.821** 0.000	-0.488 0.000	-0.117 0.244	-0.207 0.038
	Pearsons Correlation p-value					

Table 1.3. Number of road kill surveys by month; number of surveys completed, number of road kills detected and number of surveys that detected no road kills by month.

Date		Surveys Completed	Unique Road Kills	Surveys with No Road Kills Detected
2009				
	May	20	61	2
	June	19	106	0
	July	23	99	0
	August	19	43	2
	September	13	43	0
	October	20	66	2
	November	18	37	3
	December	19	33	5
2010				
	January	21	14	11
	February	19	17	8
	March	22	34	7
	April	22	23	9
	May	21	45	6
	June	22	66	1
Total		278	687	56

Table 1.4. List of observed road kills, number detected, percent of total road kill and percent of group (mammal, bird, and snake).

Common Name	Observed road kills	% of total road kill	% of identified road kill	% of group
Mammals	**544**	**79.0**	**84.9**	
Large Mammals	**23**	**3.3**	**3.6**	**4.2**
Deer	18	2.6	2.8	3.3
Pig, feral	5	0.7	0.8	0.9
Mesocarnivore	**75**	**10.9**	**11.7**	**13.8**
Badger	1	0.1	0.2	0.2
Coyote	8	1.2	1.2	1.5
Fox, gray and red	6	0.9	0.9	1.1
Opossum	11	1.6	1.7	2.0
Raccoon	24	3.5	3.7	4.4
Skunk, striped and spotted	25	3.6	3.9	4.6
Small Mammals	**439**	**63.7**	**68.5**	**80.7**
Jackrabbit, black-tailed	1	0.1	0.2	0.2
Rabbit	35	5.1	5.5	6.4
Squirrel, gray and ground	402	58.3	62.7	73.9
Woodrat	1	0.1	0.2	0.2
Other Mammals	**7**	**1.0**	**1.1**	**1.3**
Cat, domestic	5	0.7	0.8	0.9
Dog, domestic	2	0.3	0.3	0.4
Birds	**73**	**10.6**	**11.4**	
Raptors	**22**	**3.2**	**3.4**	**30.1**
Hawk, red-tailed	4	0.6	0.6	5.5
Owl, barn	6	0.9	0.9	8.2
Owl, great-horned	2	0.3	0.3	2.7
Turkey Vulture	1	0.1	0.2	1.4
Unknown owl species	1	0.1	0.2	1.4
Unknown raptor	8	1.2	1.2	11
Birds, non-raptor	**51**	**7.4**	**8.0**	**69.9**
Blackbird	2	0.3	0.3	2.7
Dove	1	0.1	0.2	1.4
Jay	1	0.1	0.2	1.4
Magpie, yellow-billed	11	1.6	1.7	15.1
Pheasant, ring-necked	1	0.1	0.2	1.4
Quail, California	2	0.3	0.3	2.7
Starling, European	1	0.1	0.2	1.4
Turkey	5	0.7	0.8	6.8
Woodpecker, acorn	1	0.1	0.2	1.4
Unknown bird (Non-raptor)	26	3.8	4.1	35.6
Snakes	**22**	**3.2**	**3.4**	
Snake, gopher	3	0.4	0.5	13.6
Unknown snake species	19	2.8	3.0	86.4
Unidentified animal	**48**	**7.0**		
Total Road Kills	**687**			

Table 1.5. The average number of road kill detected per survey day during each month for various taxa during the road kill survey. Large mammals only included mule deer and feral pigs because black bear road kills were not detected during the road kill surveys. Values of 0.00 have been replaced with "—" for clarity.

	2009								2010					
	May	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
Total	3.05	5.58	4.30	2.26	3.31	3.30	2.06	1.74	0.67	0.89	1.55	1.05	2.14	3.00
Mammal	1.85	3.58	3.65	1.95	2.77	3.00	1.50	1.42	0.52	0.74	1.23	0.86	1.71	2.77
Large Mammal	0.05	0.05	0.13	0.05	—	0.10	0.06	—	0.05	—	0.05	0.09	0.24	0.14
Mesocarnivore	0.10	0.37	0.13	0.05	0.15	0.15	0.28	1.00	0.19	0.21	0.18	0.27	0.38	0.32
Squirrel	1.45	2.95	3.17	1.74	2.38	2.65	1.17	0.21	0.19	0.47	0.91	0.41	0.81	1.95
Rabbit	0.25	0.21	0.22	0.05	0.23	0.05	—	—	0.10	0.05	0.09	0.05	0.29	0.23
Bird	0.25	0.95	0.26	0.11	0.38	—	0.11	0.05	0.10	0.50	—	0.09	0.29	0.05
Raptor	0.05	—	0.17	—	0.15	0.05	0.33	—	—	—	0.05	0.09	0.14	0.09
Snake	0.45	0.58	0.04	—	—	—	—	—	—	—	—	—	—	0.05

Table 1.6. The proportion of road kills that occurred in the different sections of the roadway for the eight taxa. The highest proportion value for each taxa is in bold as well as the significant X^2 values.

	Total Amount	Proportion per Zone A	B	C	D	E	X^2 p-value
Distance	11.9 miles	0.20	0.21	0.22	0.21	0.16	-
Total	687	0.10	0.06	0.33	**0.43**	0.09	**0.000**
Mammal	544	0.10	0.05	0.33	**0.44**	0.08	**0.000**
Squirrel	402	0.06	0.04	0.34	**0.49**	0.07	**0.000**
Rabbit	36	0.03	0.00	0.08	**0.75**	0.14	n/a
Mesocarnivore	75	0.23	0.11	**0.48**	0.13	0.05	**0.000**
Large Mammal	26	**0.31**	0.12	**0.31**	0.15	0.12	0.378
Bird	73	0.11	0.11	0.29	**0.42**	0.07	**0.000**
Raptor	22	0.14	0.05	0.32	**0.45**	0.05	n/a

* A: Before Cuesta Grade (PM 30.4 - 32.7)
B: Cuesta Grade (PM 32.8 – 35.2)
C: Between Cuesta Pass and Hwy 58 (PM 35.3 – 37.8)
D: Between Hwy 58 and Atascadero (PM 37.9 -40.3)
E: Southern Atascadero (PM 40.4 – 42.3)

Table 1.7. Results of the saturated and final landscape and roadway characteristic modeling of all taxa. Final models were not run for the bird and raptor models because the saturated models were not significant. Comparison of the AICc and BIC values between saturated and final models indicated that in all cases the final model was the better model.

	Model	Log-likelihood	DF	Chi-Square	p-value	R^2	AICc	BIC
Mammal	Saturated	45.473	8	28.30	0.0004	0.237	110.9	132.5
Bird	Saturated	64.664	6	9.49	0.1480	0.068	144.5	161.6
Raptor	Saturated	38.337	6	8.19	0.2244	0.097	91.9	109.0
Squirrel	Saturated	49.829	7	17.62	0.0138	0.150	117.2	136.6
	Final	51.152	2	14.97	0.0006	0.128	108.6	116.1
Rabbit	Saturated	42.272	7	23.83	0.0012	0.220	102.1	121.5
	Final	43.873	2	20.63	< 0.0001	0.190	94.0	101.6
Mesocarnivore	Saturated	59.506	8	17.41	0.0261	0.128	139.0	160.5
	Final	60.474	2	15.47	0.0004	0.113	127.2	134.8
Large Mammal	Saturated	43.387	8	16.49	0.0359	0.160	106.8	128.3
	Final	47.214	1	8.83	0.0030	0.085	98.6	103.7

Table 1.8. Final landscape and roadway characteristic model results: final models were created using backward elimination (predictor with largest p-value was removed and the model was rerun until all the predictors left in the model had a p-value less than 0.10).

	β	SE	Chi Square	p-value	Odds Ratio	Odds Ratio Lower CI	Odds Ratio Upper CI
Squirrels							
Intercept	0.5345	0.3010	3.15	0.0758			
TREES	0.2201	0.1144	3.70	0.0544	1.25	1.00	1.59
MTYPE	-0.8098	0.2466	10.78	0.0010	5.05	1.97	13.79
Rabbits							
Intercept	-2.6174	0.5938	19.43	< 0.0001			
MTYPE	-1.2300	0.5410	5.17	0.0230	11.70	2.04	221.87
MBREAK	0.0587	0.0308	3.64	0.0565	1.06	1.00	1.13
Mesocarnivores							
Intercept	-0.1006	0.5165	0.04	0.8456			
TREES	0.1932	0.1024	3.56	0.0591	1.21	1.00	1.50
STREAM	-0.6838	0.3596	3.62	0.0572	0.50	0.23	0.97
Large Mammals							
Intercept	-0.2710	0.4422	0.38	0.5399			
STREAM	-1.2296	0.5077	5.87	0.0154	0.29	0.09	0.69

FIGURES

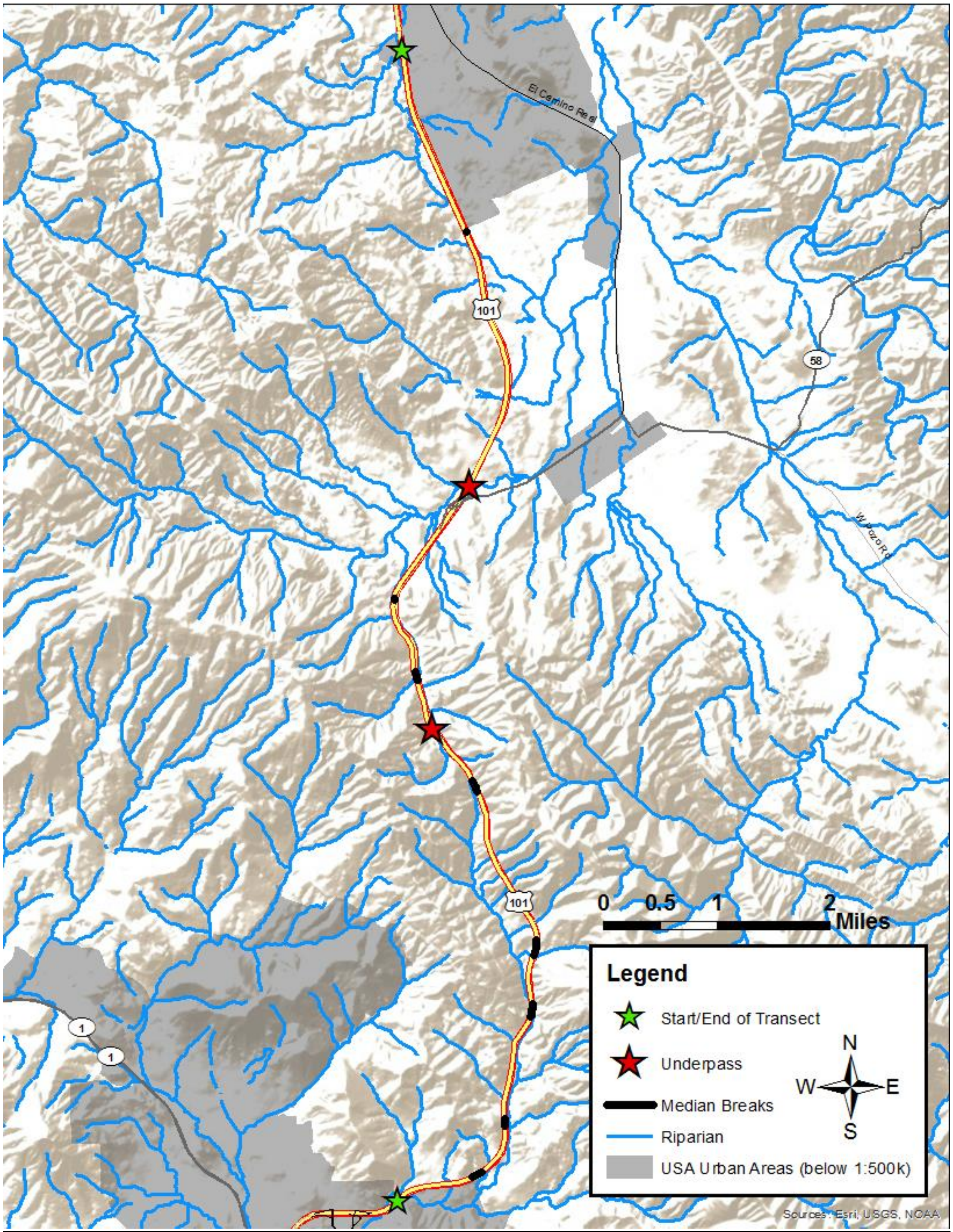

Figure 1.1. Map of study site. State Route 101 is in yellow and red. Other major roadways are in dark gray and labeled. The areas in light gray are the urban areas with a minimum density of 500 people per square mile.

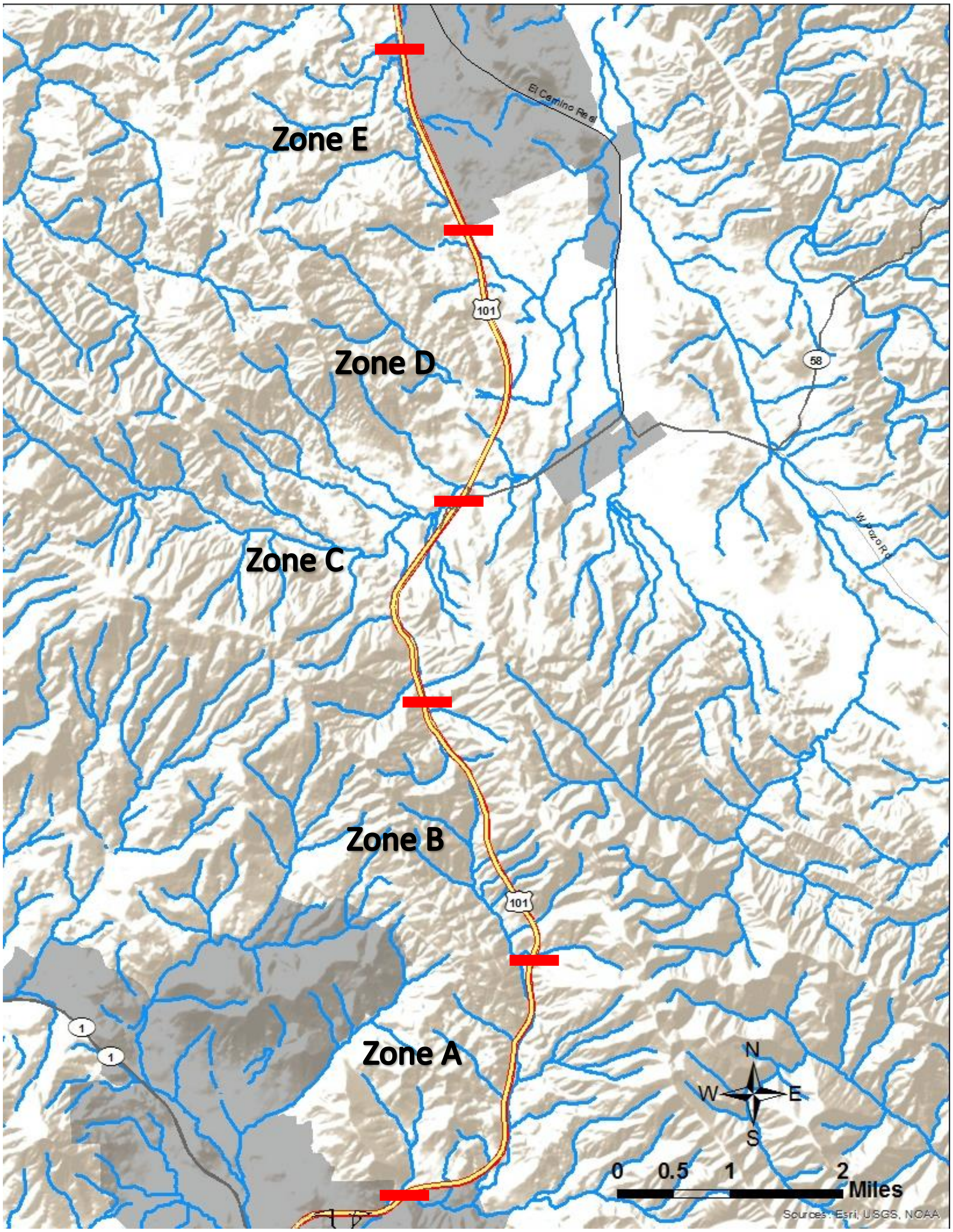

Figure 1.2. Zones the study area was divided into for the spatial analysis.

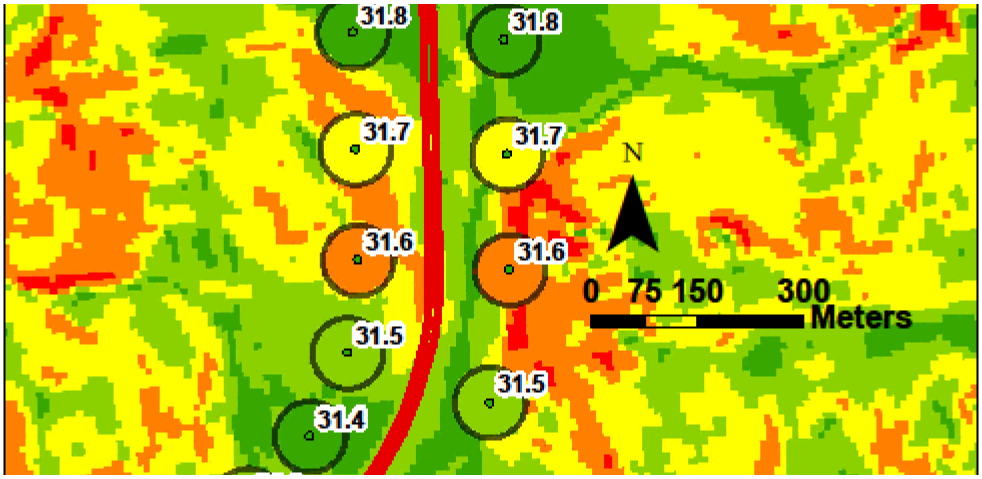

Figure 1.3. Example of how the slope value was determined for each PM. The average slope within the 100m diameter circles was calculated using 'Zonal Statistics' tool in ArcMap 10. The background layer is the slope layer created from the 1/3 Arc second DEM of San Luis Obispo County. The number labels are the corresponding PM. The red lines in between the circles are the northbound and southbound lanes of the highway. The slope increases from flat to steep from darker green to red.

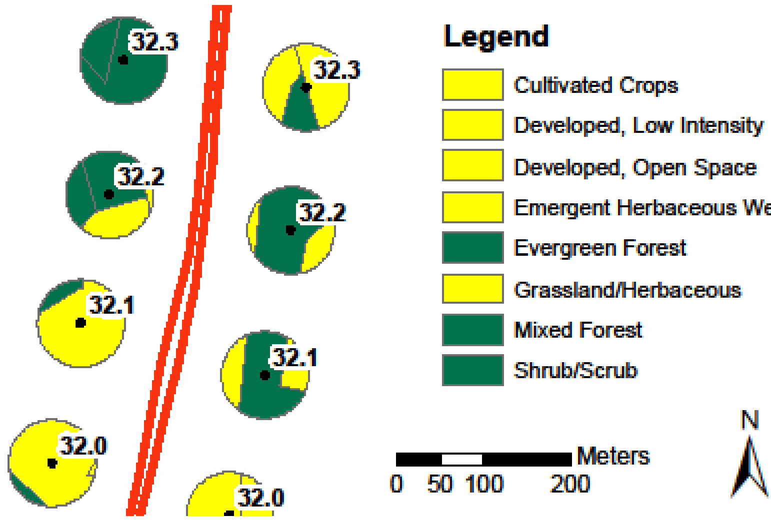

Figure 1.4. Example of how the habitat type was determined for each PM. This is a section of the study site with the results of the simplified habitat classification applied to the CWHR vegetation classification system. Habitat types in dark green are ones that were classified as CLOSED (vegetation structure has a canopy). Habitat types in yellow are ones that were classified as OPEN (vegetation structure does not have a canopy). The label on the 100m polygons is the PM they are associated with.

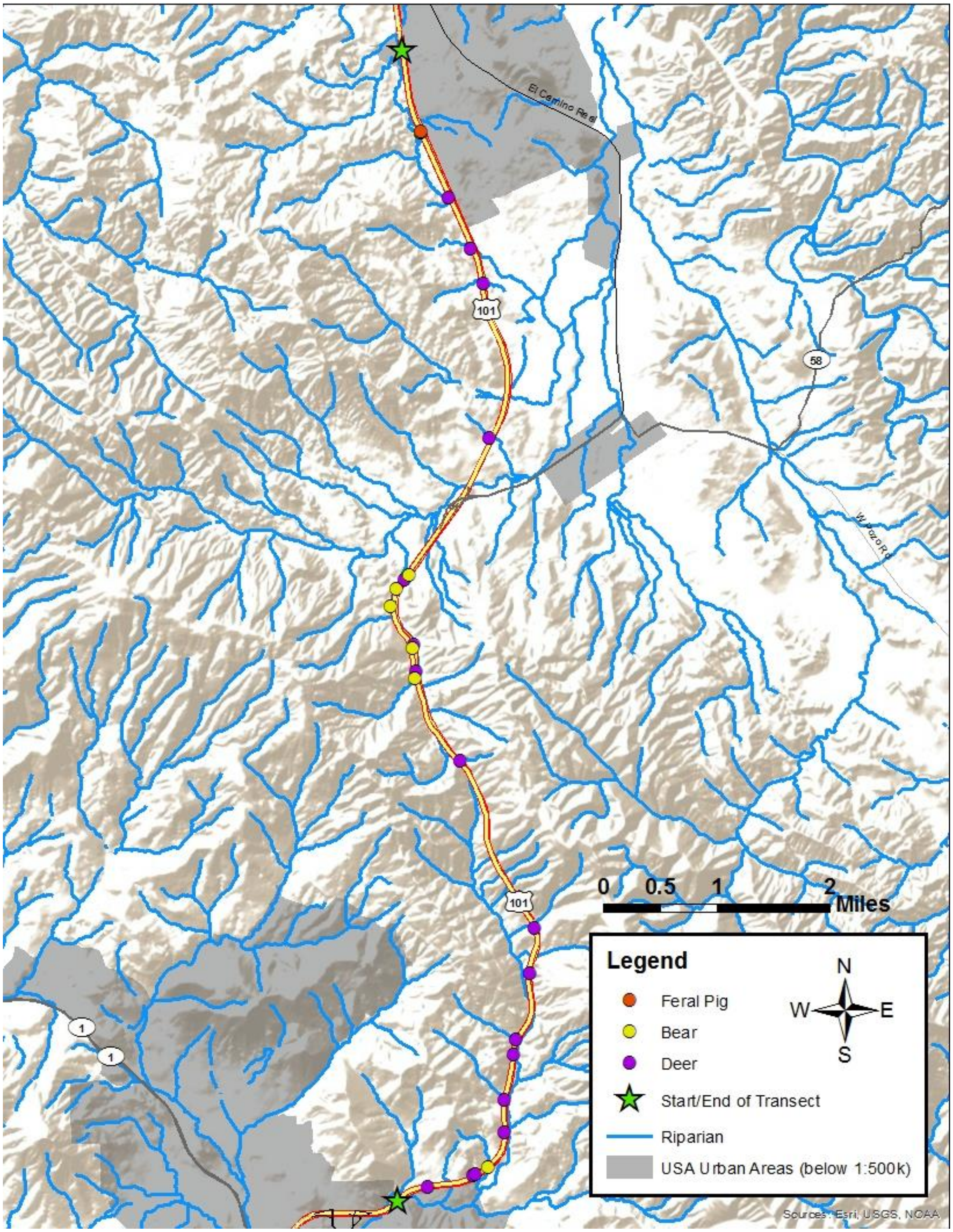

Figure 1.5. Location of large mammal road kills. The deer and feral pig locations were documented during the road kill survey. The black bear road kill occurred while the survey was being conducted but were not documented. The locations were provided by the California Department of Fish and Wildlife.

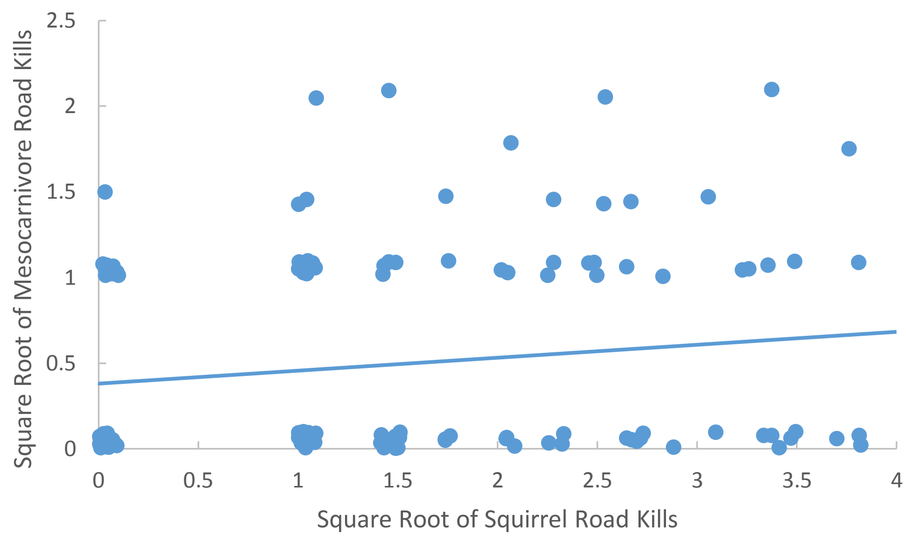

Figure 1.6. Spatial relationship between small mammal and mesocarnivore road kills (points were jittered to reveal obscured points; linear trend line is based on non-jittered points). There was no significant correlation between squirrel road kills and mesocarnivores ($p= 0.11$).

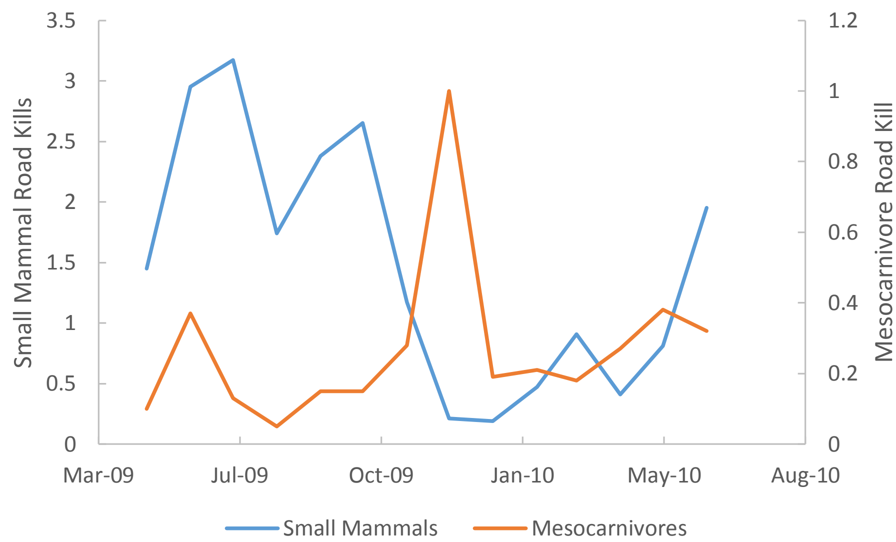

Figure 1.7. Temporal relationship between small mammal and mesocarnivore road kills. The average number of small mammal and mesocarnivore road kills detected per month during the road kill survey. The small mammal road kills were highest in the summer when mesocarnivore road kills were low and mesocarnivore road kills peaked in the winter when small mammal road kills were lowest.

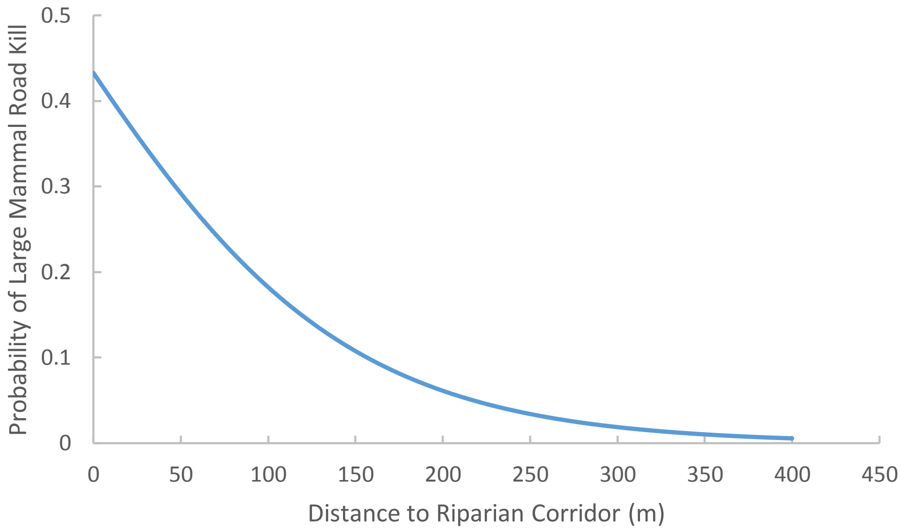

Figure 1.8. The probability during the 13 month survey of large mammal road kill occurrence depending on distance to the nearest riparian corridor (m). These probabilities were determined using the final model for large mammals.

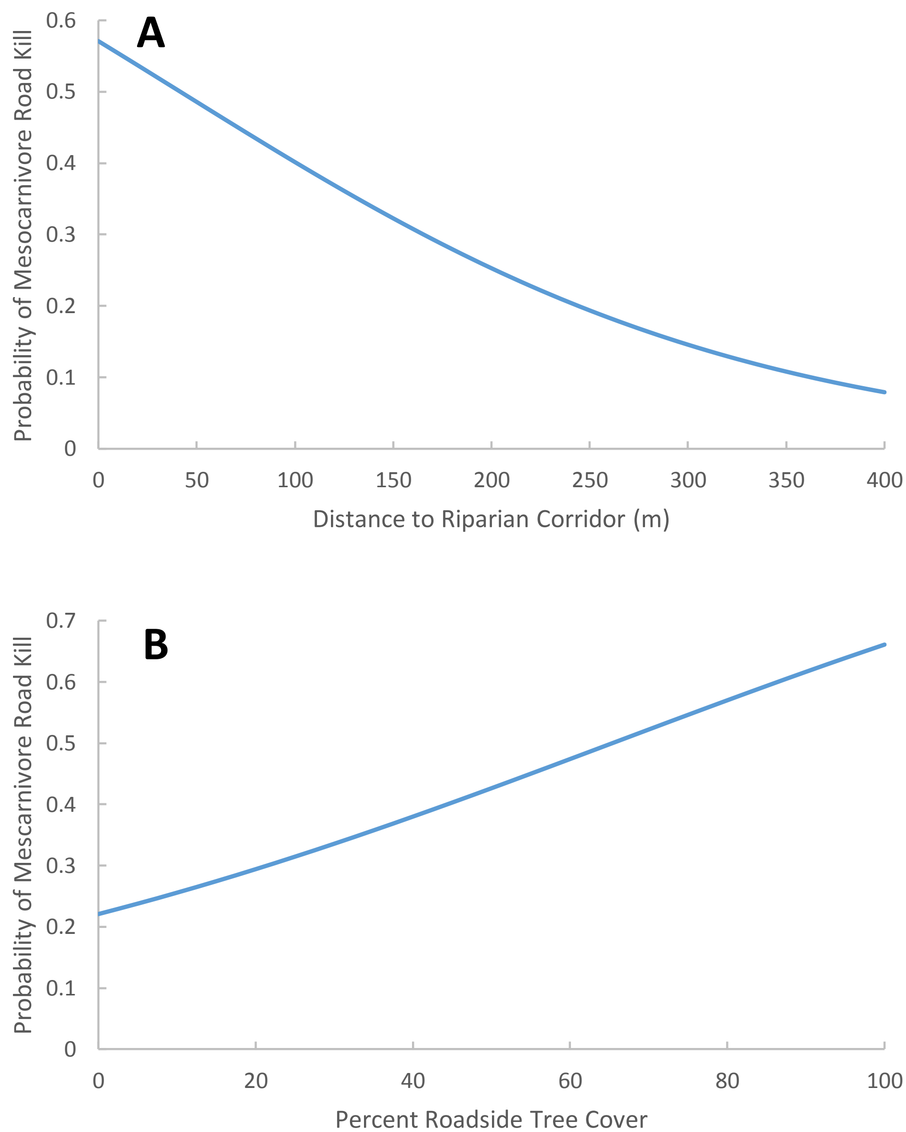

Figure 1.9. The probability during the 13 month survey of mesocarnivore road kill occurrence depending on distance to the nearest riparian corridor (A) or percent of roadside tree cover (B). These probabilities were determined using the final model for mesocarnivores. For graph A percent roadside tree cover was held constant at its average and for graph B distance to riparian corridor was held constant at its average.

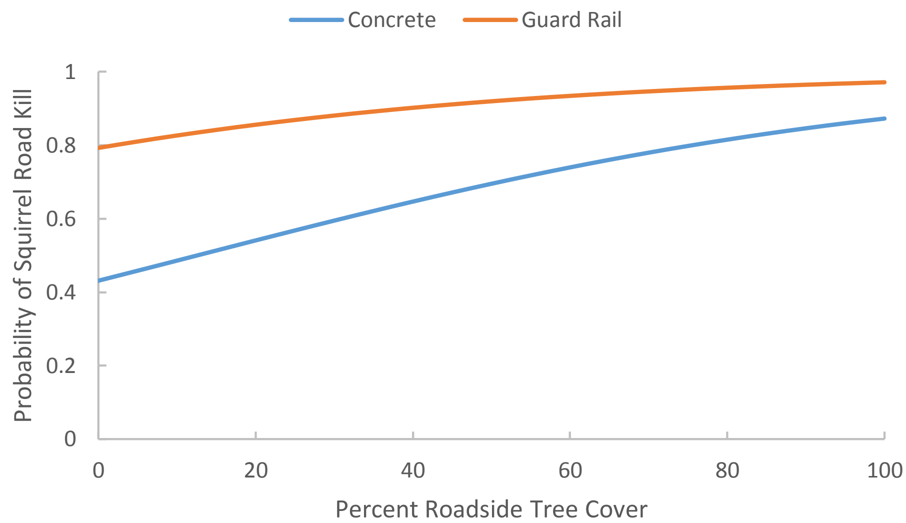

Figure 1.10. The probability during the 13 month survey of squirrel road kill occurrence depending on the percent roadside tree cover and the type of center median barrier (concrete vs. guard rail). These probabilities were determined using the final model for squirrels.

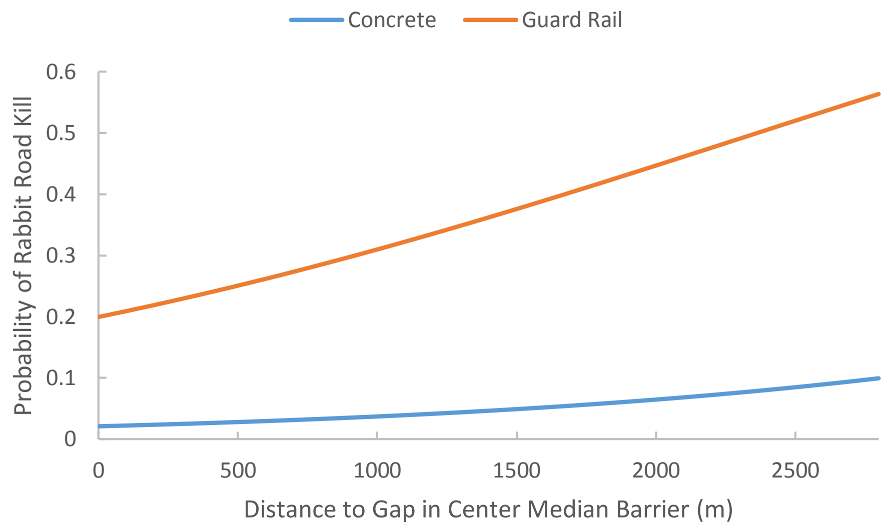

Figure 1.11. The probability during the 13 month survey of rabbit road kill occurrence depending on the distance to nearest gap in the center median and the type of center median barrier present (concrete vs. guard rail). These probabilities were determined using the final model for rabbit road kill.

II. USING REMOTE CAMERAS TO EXAMINE THE RELATIONSHIP BETWEEN WILDLIFE ACTIVITY PATTERNS AND TRAFFIC AND TO CALCULATE WILDLIFE-VEHICLE COLLISION POTENTIAL IN MULE DEER AND MESOCARNIVORES

INTRODUCTION

While increasing mortality due to road kill is an obvious impact of roads on wildlife, there are other impacts that are less apparent, such as road avoidance. Road avoidance is when animals avoid the habitat adjacent to a roadway because of the associated noise and/or human activity. This behavior has been seen in birds in the Netherlands (Reijnen et al. 1995), mountain lions in Arizona (Van Dyke et al. 1986), elk in Oregon (Rowland et al. 2000), grizzly bears (Montana - Waller and Servheen 2005, British Columbia - Archibald et al. 1987, British Colombia - McLellan and Shackleton 1988, Montana - Kasworm and Manley 1990, Montana - Mace et al. 1996, Wyoming - Mattson et al. 1987), black bears in Montana (Kasworm and Manley 1990) and caribou in Northern Alberta (Dyer et al. 2001) to name a few. Road avoidance can limit access to preferred habitat, thus negatively affecting the health and possibly the survival of individuals by forcing them into substandard habitat that does not provided adequate life requirements. Road avoidance behavior can also contribute to population fragmentation by limiting animal movement across roadways. This results in smaller populations that have less genetic diversity and are less resilient to demographic and environmental stochasticity and in some cases reduced biodiversity in environments around roads due to the absence of some species (Forman et al. 2003).

While many studies have found correlations between increasing road densities and decreased wildlife abundances (Vos and Chardon 1998, Fahrig et al. 1995, Carr and Fahrig 2001, Mace et al. 1996), traffic volume might be a more important factor contributing to road avoidance. Eigenbrod et al. (2008) found that traffic density was a significant predictor of the

relative abundance of frog species near roads in Ottawa, Canada.   Reijnen et al. (1995) suggested that traffic, specifically the associated noise, was also driving the trends they saw in reduced breeding bird density. Mace et al. (1996) found grizzly bears avoided roads with > 10 vehicles per day but not roads with < 10 vehicles per day and Chruszcz et al. (2003) observed that grizzly bears tended to be located closer to roads with low traffic volume and farther from roads with high traffic volume than expected by chance. Traffic volume has also been suggested to be the road characteristic likely to have the largest impact on how permeable a roadway is to animal movement (Forman and Alexander et al. 1998, Forman et al. 2003, Jaeger et al. 2005). Roads with higher daily traffic volumes are crossed less frequently by wildlife than roads with lower daily traffic volumes (Alexander et al. 2005, Brody and Pelton 1989). Also, the traffic volume at which crossing rates decrease varies depending on the taxa. Alexander et al. (2005) found that the crossing rate of carnivores (wolverine (*Gulo gulo*), marten (*Martes americana*) lynx (*Felis lynx*), cougar (*Puma concolor*), wolf (*Canis lupus*) and coyote (*Canis latrans*)) decreased at lower traffic levels than ungulates (elk (*Cervus elaphus*), deer (*Odocoileus virginianus* and *Odocoileus hemionus*), moose (*Alces alces*), and sheep (*Ovis canadensis*)).

While traffic volume can vary between road types, it also varies along individual roads seasonally, weekly and hourly. These temporal fluctuations in traffic volume can lead to seasonal and even daily variations in road avoidance behaviors. In Arizona and Oregon elk responded to changes in traffic volume during the day by moving away from the roadway during periods of high traffic but then returning when traffic volume was low (Gagnon et al. 2007a, Ager et al. 2003). Grizzly bears in Montana preferred to cross roads when traffic volumes were lowest (Waller and Servheen 2005).

High traffic volume can deter animals from crossing roads, but if an animal does cross the likelihood of the animal being struck by a vehicle is likely to increase with increasing traffic

volume. Periods with higher animal activity are a concern because more animals could be attempting to cross the roadway, increasing the likelihood of an animal being struck. Several studies have found that increasing rates of ungulate-vehicle collisions were correlated to increasing traffic volume (Allen and McCullough 1976, Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Gunson and Clevenger 2003) even when accounting for different levels of animal density (Joyce and Mahoney 2001). Therefore, if the timing of daily animal activity and traffic patterns are known, it should be possible to calculate a collision potential that reflects the likelihood of a wildlife-vehicle collision (WVC) occurring during the day using the activity levels of animals and the traffic volume.

In this study, I examined how fluctuating hourly traffic rates relate to the timing of mule deer and mesocarnivores activity around State Route 101 to better understand how changes in traffic volume throughout the day impact habitat use near the roadway. I chose to look at mule deer and mesocarnivores because these were the two taxa with the most detections on our remote camera stations and both have been known to be involved in fatal wildlife-vehicle collisions. I used multivariate logistic regression models to determine if there was a relationship between traffic volume and animal activity levels after controlling for day-period (dawn, day, dusk, night), day of the week (weekend vs. weekday) and season. I then used hourly mule deer and mesocarnivore detection numbers and traffic levels to calculate an hourly wildlife-vehicle collision potential value for deer and mesocarnivores separately.

METHODS

Study Area

The study took place along an 11.9 mile section of State Route 101 between San Luis Obispo and Atascadero, in central California, USA. This area has a cool Mediterranean climate with cool wet winters and hot dry summers. The road way climbs up and over the Santa Lucia Mountains and crosses the Los Padres National Forest and a large mammal movement (Thorne et al. 2006) and ecological connectivity corridor (Spencer et al. 2010). The study area began just northeast of San Luis Obispo at the base of the Santa Lucia Mountains and extended into the southern edge of Atascadero. The vegetation types varied across the study sites and included grazed grassland (mainly *Avena* spp. and *Bromus* spp.), cultivated crops, coastal scrub, chaparral (*Ceanothus* spp.), mixed evergreen forest (*Querus* spp.), riparian woodland (*Platanus racemosa*), oak woodland (*Quercus agrifolia* and *douglasiana*), and oak savannah (*Quercus lobata*). San Luis Obispo and Santa Margarita Creek run along portions of the highway and in three locations crossed under the highway. State Route 101 is a divided highway, the northbound and southbound lanes are separated by a center median barrier, with two lanes of travel in both directions and the speed limit is 65 mph for this entire section of roadway.

Traffic Volume

I estimated hourly traffic volume for the period of the camera study (May 1st, 2009 to June 30th 2010) from data provided by the California Department of Transportation (Caltrans), which was collected using a Peek Traffic ADR-1000 permanently installed near the Highway 58 junction. The traffic counter provided the number of vehicles that passed in both lanes in both directions of travel on State Route 101 in 15 minute intervals. For analysis I averaged the

number of vehicles traveling in both directions for each hour of the day across the length of each camera survey.

Camera Stations

Animal activity near the roadway was documented using Cuddeback Capture IR cameras (NonTypical Inc., Park Falls, WI) with a motion sensor activated trigger and infrared flash. There were three survey periods: summer 2009, fall 2009 and spring 2010. The goal was 42 survey days per period per camera station; however, cameras were often deployed longer to account for days lost due to camera malfunction or dead batteries.

The camera stations were established around the roadway between the bottom of Cuesta Grade and the southern edge of Atascadero (Figure 2.1). The locations and number of stations varied between surveys due to the number of functional cameras available and the level of animal activity documented in the previous survey (Table 2.1). Five stations were placed along game trails, four of which were within 50m of the roadway (N2.8, N4.1, N6.3 and N7.6). The fifth station was placed on a game trail along east Cuesta Ridge of the Santa Lucia Mountains (EC03) which was greater than 50m from the roadway but close enough (1,500m) that the home range of the mesocarnivores and large mammals documented likely include the highway. These five stations were baited with canned cat food to attract nearby animals to be photographed. Six stations were established on underpasses, structures that could be used by animal to cross under the roadway (OSCR, Ov-S, Ov-N, N58, N8.5, N10.0 and S1.9). These stations were not baited, therefore only those animals using the underpass as part of their normal activity were documented. Cameras were not placed at all stations during each season.

The cameras were mounted on T-posts or trees and aimed so that mesocarnivores and large mammals would activate the trigger. The cameras were programmed with a 30-second delay between triggered events. The cameras were checked weekly to exchange memory cards and refresh batteries and bait. Photographs were reviewed and the following information recorded: date, time, species and number of individuals photographed. A photograph with a picture of an animal was called a detection. Often multiple photographs of the same individual were obtained due to the 30-second delay. In these situations the first photograph of the individual was recorded as a detection and all successive photographs were ignored. Because it was not always possible to determine if it was the same individual in successive photographs, any photograph of the same species within 15 minutes was ignored. Instances where the animal photographed could not be identified to a specific taxon were not included in the analysis.

Road Avoidance Behavior Analysis

To determine if traffic volume and animal activity were correlated I used multiple logistic regression and assigned a binomial response to two different outcomes: 1) target animal detected, and 2) target animal not detected. I defined a detection as at least one target animal was documented by one or more camera stations during that hour period. Each hour of the camera survey was the unit of measure. I analyzed mule deer and mesocarnivores separately to determine if these taxa demonstrated a difference in their sensitivity to traffic. This analysis was completed using JMP Pro 11.

To control for other factors that might influence the activity pattern of the animals or the traffic I included four other terms in the model: DAYPERIOD, WEEK (day of the week),

SEASON and an interaction between DAYPERIOD and SEASON (Table 2.2). DAYPERIOD controlled for differences in animal activity due to time of the day. I divided each day into four periods, DAWN, DAY, DUSK and NIGHT, based on the timing of sunrise and sunset for each day. Sunrise and sunset times were obtained from the NOAA Sunrise/Sunset Calculator (www.esri.noaa.gov/gmd/grad/solcalc/sunrise.html). DAWN included the hour before and after sunrise. DUSK included the hour before and after sunset. DAY included the hours between DAWN and DUSK. NIGHT included the hours between DUSK and DAWN. I excluded DUSK from the mesocarnivore model to improve the fit because no mesocarnivore detections occurred during DUSK. Instead I divided each day into three periods: DAWN, DAY and NIGHT. DAWN was the same as above. DAY included the hour before sunset and the hour after sunset was included with NIGHT.

WEEK was a term that identified whether it was a weekday or a weekend. The road experienced different traffic patterns on weekends when compared to weekdays (Figure 2.2). SEASON was a term that identified during which season the camera survey occurred. Each of the three camera survey periods occurred during different seasons. Animals exhibit different activity patterns associated with time of year. The interaction term between DAYPERIOD and SEASON controlled for the differences in the timing of sunrise and sunset and the length of the day and night periods due to the time of year.

Wildlife-Vehicle Collision Potential

I calculated the potential for wildlife-vehicle collision by hour of the day for each camera survey by multiplying the total number of target animals detected during that hour by the average traffic volume for that hour. I then standardized this value by dividing all hourly values

by the largest value, which gave me a range of values from 0.0 to 1.0. A value of 0.0 meant there was no collision potential during that hour while a value of 1.0 meant that hour had the greatest potential of a collision occurring. I calculated collision potential for the mule deer and mesocarnivores separately.

RESULTS

Traffic Volume

Traffic volume was greatest during the summer with an average of 46,636 ± 569 (SE) vehicles per day (VPD) (Figure 2.2). Spring was second with 42,688 ± 636 VPD and fall was third with 42,052 ± 712 VPD. Traffic volume was bimodal during the week in all three seasons with a major peak in the evening between 16:00h and 17:00h and a minor peak in the morning between 07:00h and 08:00h. The afternoon peak was the highest in the summer with 4177 ± 32 vehicles per hour (VPH), followed by spring (3967 ± 35 VPH) and lowest in the fall (3910 ± 42 VPH). The morning peak was highest in the fall with 3073 ± 33 VPH, followed by spring (3015 ± 38 VPH) and finally summer (2970 ± 34 VPH). Traffic volume remained high during the day, dropping slightly an hour after the morning peak and then steadily climbing until the afternoon peak. Traffic volume dropped off sharply the two hours after the afternoon peak and then decreased steadily until 23:00h. Traffic volume remained low between 23:00h and 04:00h (summer 313 ± 12 VPH, fall 253 ± 9 VPH, spring 239 ± 8 VPH) and then began increasing rapidly until the morning peak.

Unlike weekday traffic weekend traffic volume experienced only one peak beginning midday (12:00h) and continued until 16:00h in all seasons. It was greatest in summer (3334 ± 43 VPH), followed by spring (3080 ± 35 VPH) and then fall (3001 ± 31). After this peak traffic

volume decreased steadily until 23:00h. From 23:00h till 04:00h traffic volume remained low (summer 355 ± 23 VPH, fall 287 ± 23 VPH, spring 268 ± 13 VPH) and after 04:00h it steadily increased until it reached its peak at 12:00h.

Camera Detections

Mule Deer

Across all three seasons deer were detected by the cameras 289 times (Table 2.3). The greatest number of detections occurred in fall with 0.43 detections per survey day, followed by summer (0.27) and then spring (0.11) (Table 2.3). In all three seasons the most deer detections occurred at the camera station located at Santa Margarita Creek (N58). In the fall this station accounted for 76% of all detections, 72% in spring and 37% in summer (Table 2.4). The majority of detections were of a single animal (75%), followed by two animals (9%), with at most four individuals detected in one photograph.

The activity pattern based on camera detections was crepuscular in all three seasons with a morning and evening peak in activity (Figure 2.3). The morning peak occurred at 05:00h in summer, 06:00h in the fall and between 06:00h and 7:00h in the spring. The summer peak occurred two hours before the peak in morning traffic, one hour before in fall and overlapped in spring. The evening peak occurred at 19:00h in summer, between 16:00h and 18:00h in fall and 17:00h in spring. The summer evening peak occurred after the evening traffic peak and overlapped with it in fall and spring.

Mesocarnivores

Mesocarnivores were detected 275 times with 286 individuals in total belonging to six species: bobcat, coyote, gray fox, red fox, opossum and raccoon (Table 2.3). The most mesocarnivores were detected in spring with 0.41 detections per survey day, followed by fall (0.28) and summer (0.13). Bobcat was the most common species detected accounting for 28% of mesocarnivore detections; next was gray fox with 24%. Coyotes accounted for the fewest detections overall (8%). The majority of detections were of a single individual (99%). There were four occasions were two or more animals were detected together; two of these were of a mother with offspring, a bobcat with two kittens and an opossum with 8 kits. The camera station with the most detections was different in each season; the East Cuesta Ridge station (EC03) in summer (32%), N6.3 in fall (33%) and N8.5 in spring (33%) (Table 2.4).

In general mesocarnivores displayed a nocturnal activity pattern with the majority of detections occurring at night in all three seasons with the exception of a spike in activity at 11:00h during summer (Figure 2.4). In summer the night peak in activity was between 21:00h and 04:00h, 18:00h and 06:00h in fall and 19:00h and 05:00h in spring. In all three seasons animal activity began after sunset and ended before dawn. Mesocarnivore activity increased between one and three hours after the evening traffic peak and decreased one to two hours before the morning traffic peak.

Road Avoidance Models

Both the mule deer and mesocarnivore models were significant ($p < 0.0001$) (Table 2.5). Deer and mesocarnivore activity varied significantly by day period ($p < 0.0001$). Deer activity also varied significantly by season ($p < 0.0001$) and mesocarnivore by the interaction term

between season and day period (p = 0.0002). However, the predictor TRAFFIC was significant only in the mesocarnivore model (p = 0.0135) (Table 2.5 and Fig. 2.5, 2.6, 2.7 and 2.8). This suggests that traffic volume was an important predictor in determining mesocarnivore detectability but not for deer (Figure 2.5 and 2.6). Mesocarnivore detections were negatively related to traffic volume suggesting that the probability of detecting a mesocarnivore decreased with increasing traffic (Fig. 2.6 and 2.8).

Wildlife-Vehicle Collision Potential

Mule Deer

In summer 2009 collision potential was trimodal with the major peak at 13:00h, followed closely by a peak between 06:00h and 8:00h (ranged from 0.94 – 0.86) and another peak at 20:00h (0.93) (Figure 2.5). In fall 2009 there were two peaks in collision potential during the day, one between 16:00h and 18:00h (0.73 – 1.0) and a second between 06:00h and 0:700h (0.70 – 0.78). Collision potential in spring peaked in the evening at 17:00h, with a secondary peak between 07:00h and 08:00h (ranged from 0.53 – 0.59). In all three seasons collision potential was almost non-existent between 23:00h and 04:00h (≤ 0.07) because traffic volume was so low at night (<500 VPH) compared to during the day (2154 – 3893 VPH). Collision potential was also very low (0.00 – 0.17) during the middle of the day in fall (12:00h – 15:00h) and spring (09:00h – 15:00h).

Mesocarnivores

In summer 2009 collision potential was greatest in the morning at 07:00h, followed by a secondary peak at 11:00h (0.69) (Figure 2.6). There were also two lower peaks in the evening at 19:00h (0.38) and 21:00h (0.46). During fall and spring collision potential was greatest in the evening. In fall there were two peaks in the evening, the major peak was at 18:00h and the secondary peak was at 21:00h (0.98). Collision potential peaked in the spring at 19:00h. There were two smaller peaks in fall, one in the morning between 05:00h and 06:00h (0.39 – 0.44) and another at 12:00h (0.37). In all three seasons collision potential was low (0.00 – 0.20) between 00:00h and 04:00h.

DISCUSSION

Mule Deer and Traffic Volume

Deer activity around the roadway did not show any relationship to changes in traffic volume suggesting that mule deer around this section of SR 101 are not exhibiting road avoidance behaviors due to traffic (Table 2.5, Fig. 2.5 and 2.7). This pattern contrasts with studies of elk in Arizona and Canada (Gagnon et al. 2007a, Alexander et al. 2005). The study in Arizona found that the probability of detecting an elk within 200 m of a highway was approximately 40% at <100 VPH and less than 20% at 600 VPH (Gagnon et al. 2007a). The study in Canada found that crossing rates of ungulates (elk, moose, sheep and deer) decreased significantly between 5000 and 14,000 VPD. The daily traffic volume along SR 101 during the study was on average 44,000 vehicles a day, much greater than in the elk studies, yet we did not detect road avoidance behaviors.

A possible explanation could be that mule deer have a greater tolerance for high traffic volume than larger ungulates. Though deer were a part of the ungulate guild in the Alexander et al. (2005) study, if there was a difference in deer behavior it could have been obscured by the behavior of the other ungulate species. In Colorado, 70% of deer crossing attempts occurred when traffic was present implying that deer do not display traffic induced road avoidance (Reed and Woodard 1981), however traffic volume on this road was lower, between 5706 and 6483 VPD. A telemetry study of elk and deer in Oregon observed that deer were located closer to open roads than elk (Ager et al. 2003). However, a study in Colorado using pellet count densities found that deer more strongly avoided roads than elk (Rost and Bailey 1979). The authors in this study suggested that this response might have been a behavior more likely to be seen in a hunted population.

Another explanation could be that deer along SR 101 have become habituated to the traffic levels along this roadway. Chruszcz et al. (2003) found that habituated grizzly bears were located closer to roads than were wary bears. The authors suggested that given the high traffic volume in their study area traffic noise would be relatively constant and predictable resulting in habituation by the bears to the traffic noise. During the day traffic volume along SR 101 is consistently high with between approximately 2500 to 4000 vehicles passing by each hour. A study of underpass use by elk in Arizona found that during low, intermittent traffic volumes elk passage rate was lower than during high traffic volume (Gagnon et al. 2007b). The authors suggested that during low traffic volumes a single passing vehicle could be more of a shock to an animal than a continuous stream of passing vehicle during high traffic volumes (Gagnon et al. 2007b). Also, traffic volume along SR 101 is consistent throughout the year, unlike in Alexander et al. (2005) study where there were pronounce differences in seasonal traffic volumes: Trans-

Canada Highway had 5,000 VPD in winter vs. 14,000 VPD annually and Banff National Parkway had 300 VPD in winter vs. 3,000 VPD annually.

The lack of road avoidance could also be a result of the deer using the underpasses to cross safely under the roadway. The camera station at Santa Margarita Creek had the greatest number of deer detections in all three seasons. This underpass allows deer to cross safely under the roadway, avoiding interactions with traffic. Studies on elk in Arizona documented road avoidance behaviors in response to traffic along a section of roadway without wildlife underpasses but did not observe road avoidance along a section with underpasses (Gagnon et al. 2007a and 2007b). Along the section with underpasses elk were observed successfully using these underpasses even when traffic volume was at its peak (Gagnon et al. 2007a and 2007b). The authors suggested that wildlife underpasses could be used to mitigate sections of roads where wildlife exhibited road avoidance behaviors.

Mesocarnivore and Traffic Volume

Unlike mule deer, mesocarnivores did avoid the roadway during periods of high traffic volume even when controlling for time of day (Table 2.5, Fig. 2.6 and 2.8). This suggests that mesocarnivores along this section of road were more sensitive to traffic than deer. A study on ungulates and carnivores observed a similar pattern in crossing rates of ungulates and carnivores along roads in Canada (Alexander et al. 2005). They observed a significant decrease in the crossing rates of carnivores at traffic volumes between 300 to 500 VPD while ungulates did not show a significant decrease until traffic volumes were between 5,000 and 14,000 VPD. SR 101 experiences daily traffic volume well above that in the Alexander et al. (2005) study with 44,000 VPD.

In all three seasons mesocarnivore activity was highest at night, peaking after sunset and remaining high until just before sunrise. While many carnivores normally display nocturnal behavior, observable shifts in their activity patterns in response to human disturbances have been documented. Mountain lions impacted by human disturbances have been found to shift their activities from mid-evening hours and around sunset to after sunset, and are inactive instead of active at sunrise (Van Dyke et al. 1986). Waller and Servheen (2005) observed that grizzly bears in Montana crossed a highway more often at night but often outside their normal periods of activity, likely because it was when traffic volume was at its lowest.

Whether or not this road avoidance behavior will negatively impact mesocarnivore populations is unclear. This behavior could result in fewer individuals attempting to cross the roadway, which might result in population fragmentation, isolating the individuals on either side of the roadway from each other genetically. A study of bobcats and coyotes in Southern California found that even though individuals were crossing one of the busiest highways in the USA, the populations on either side of the freeway were genetically differentiated (Riley et al. 2006).

If mesocarnivores are displaying road avoidance behaviors along this section of SR 101 then it is likely that large carnivores are as well because they also are sensitive to road related human disturbances (McLellan and Shackleton 1988, Mace et al. 1996, Thiel 1985, Mech et al. 1988). I was unable to determine if large carnivores were displaying road avoidance because there were not a sufficient number of detections for analysis. During the entire study only one mountain lion was detected and this occurred at the station on east Cuesta Ridge, which was the farthest station from the road (1,500m). There were a total of ten black bear detections during the study, seven of which were at the station on east Cuesta Ridge. The other three were at N6.3 which was set back from the highway 85m. The small number of detections of large

carnivores might just be a result of them having lower population densities than mesocarnivores, but it could also suggest that they were displaying road avoidance behaviors even more intensely than mesocarnivores.

Wildlife-Vehicle Collision Potential

The collision potential for mule deer was high in the morning and late afternoon to evening in all three seasons with peaks occurring sometime between 06:00h – 08:00h and 16:00h – 20:00h. Despite likely displaying traffic-caused road avoidance, peaks in collision potential for mesocarnivores was only shifted an hour earlier in the morning (05:00h) and two hours later in the evening (18:00h – 21:00h) than collision potential for deer. This pattern was similar to the timing of wildlife-vehicle collisions observed in Europe, where collisions with red deer, roe deer and wild boar in eight European countries peaked at 07:00h and between 22:00h – 23:00h (Groot Bruinderink and Hazebroek 1996). A review of the timing of wildlife-vehicle collision for several locations in the USA found that the majority occurred between 18:00h and 00:00h (Kattack 2003). In Arizona 67% and 64% of elk- and deer-vehicle collisions, respectively, occurred within three hours after sunset (Dodd et al. 2006). A study of the roadside behavior of white-tailed deer in Illinois, USA found that deer utilized roadside habitat between 17:00h and 07:00h, but crossed the road between 15:00h and 22:00h (Waring et al. 1991). Other studies have noted that wildlife-vehicle collisions are high between sunset and midnight. Gunson and Clevenger (2003) observed that wildlife-vehicle collisions along the Trans-Canada Highway in Alberta, Canada were higher between 17:00h and 00:00h with a peak between 21:00h and 00:00h. Joyce and Mahoney (2001) documented a similar pattern with moose in Newfoundland with 60% of moose-vehicle collisions occurring between sunset and midnight. They also noted

that accidents in the morning (between 00:00h and 06:00h) were common, particularly during the summer months.

CONCLUSION: MANAGEMENT IMPLICATIONS

Traffic volume has been steadily increasing nationwide and will likely continue to increase. My results suggest that current traffic volume levels along SR 101 are negatively impacting habitat use around the roadway by mesocarnivores and future increases in traffic volume will likely exacerbate these road avoidance behaviors. Deer, however, did not, which suggests that current traffic volume levels are not negatively impacting their habitat use. It is possible, though, that in the future traffic volume will reach a level that could cause road avoidance behaviors in deer.

Steps should be taken to reduce the road avoidance behaviors in mesocarnivores in order to maintain viable populations around SR 101 in the face of increasing traffic volumes. The combination of wildlife fencing and wildlife crossing structures has been shown to mitigate traffic induced road avoidance behaviors in elk along a highway in Arizona especially when wildlife crossing structures are placed in areas with quality habitat for the species concerned (Gagnon et al. 2007a and 2007b). Wildlife fencing would also prevent deer from crossing the road at grade reducing future wildlife-vehicle collisions. The current activity patterns of deer place them and motorist at risk of colliding during the busier times of day. Wildlife fencing has been shown to be effective at substantially reducing wildlife-vehicle collisions. Dodd et al. (2007a) documented an 86% reduction in ungulate-vehicle collisions after a highway in Arizona was fenced.

TABLES

Table 2.1. Camera station locations and set up information (Su = Summer, Fa = Fall, Sp = Spring)

Station ID	Postmile	Bait	Seasons	Location notes
EC03	n/a	Yes	Su, Fa, Sp	Atop East Cuesta ridge, along fire road
N2.8	33.2	Yes	Su, Fa, Sp	Roadside along game trail
N4.1	34.6	Yes	Su, Fa, Sp	Roadside along game trail
N58	38.0	No	Su, Fa, Sp	Santa Margarita Creek underpass
N6.3	36.7	Yes	Su, Fa, Sp	Along game trail near train tracks
N7.6	38.1	Yes	Su	Roadside
N8.5	38.9	No	Sp	Drive-through underpass
N10.0	40.5	No	Su	Roadside at small dual concrete culvert
OSCR	32.8	No	Su	Streamside near culvert under bike path
Ov-N	35.6	Yes	Su, Fa, Sp	Under N-bound overpass over train tracks, along game trail
Ov-S	35.5	Yes	Su, Fa, Sp	Near S-bound overpass over train tracks, along game trail
S1.9	40.4	No	Sp	Drive-through underpass

Table 2.2. Predictors used in the animal activity and traffic volume analysis.

Variable	Description	Type
WEEK	Binary predictor denoting whether the day was a weekday or a weekend.	Categorical
DAYPERIOD	Predictor with 4 levels identifying time of day: **DAWN**: Includes the hour before and after sunrise **DUSK**: Includes the hour before and after sunset **DAY**: The hours between dawn and dusk **NIGHT**: The hours between dusk and dawn	Categorical
SEASON	Predictor with 3 levels identifying the camera survey **SUMMER**: May 16, 2009 to July 26, 2009 **FALL**: October 10, 2009 to November 22, 2009 **SPRING**: February 13, 2010 to April 18, 2010	Categorical
TRAFFIC	Number of vehicles that passed in both direction of the highway during that hour period. Scaled to 1000 vehicles.	Continuous

Table 2.3. Results of camera surveys. A survey day equals each day a camera was operational (e.g. one day with eight operational cameras equals eight survey days). For deer and mesocarnivores the numbers are detections/individuals. More than one individual can be documented by one detection.

	Summer	Fall	Spring	Total
Survey Days	443	298	317	**1058**
Deer	121/155	129/179	36/51	**286/385**
Mesocarnivores	59/67	84/86	132/133	**275/286**
Bobcat	20/20	18/20	40/40	**78/80**
Coyote	2/2	7/7	12/12	**21/21**
Gray fox	19/20	27/27	19/20	**65/67**
Red fox	0/0	19/19	20/20	**39/39**
Opossum	18/25	8/8	14/14	**40/47**
Raccoon	0/0	5/5	27/27	**32/32**

Table 2.4. Proportion of total detections by camera station. Values are comparable within seasons but not between seasons because survey effort differed between seasons. The symbol "–" indicates that the camera station was not used or did not record any detections during that season.

	Deer			Mesocarnivores		
Camera Station	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**	**Spring**
EC03	0.01	0.00	0.00	0.32	0.14	0.12
N2.8	0.12	0.05	0.06	0.08	0.01	0.02
N4.1	0.15	0.09	0.08	0.00	0.21	0.02
N58	0.37	0.76	0.72	0.15	0.14	0.13
N6.3	0.09	0.05	0.06	0.15	0.33	0.25
N7.6	0.01	–	–	0.00	–	–
N8.5	–	–	0.00	–	–	0.33
N10.0	–	–	0.00	–	–	0.04
OSCR	0.00	–	–	0.00	–	–
Ov-N	0.14	0.03	0.03	0.29	0.14	0.05
Ov-S	0.12	0.02	0.06	0.00	0.01	0.05
S1.9	–	–	0.00	–	–	0.00

Table 2.5. Results of animal activity and traffic volume models for deer and mesocarnivores.

	Deer	**Mesocarnivores**
P-value	**< 0.0001**	**< 0.0001**
DF	13	10
Chi Square	175.433	247.789
Log-likelihood	859.881	845.073
R Square	0.0926	0.1279
AICc	1747.87	1712.21
BIC	1835.82	1782.23
Predictors P-values		
DAYPERIOD	**< 0.0001**	**< 0.0001**
WEEK	0.0781	0.8539
SEASON	**< 0.0001**	0.1216
SEASON*DAYPERIOD	0.1939	**0.0002**
TRAFFIC	0.5575	**0.0135**

Table 2.6. Results of deer activity and traffic volume model. The reference levels are; WEEK: weekend, SEASON: fall, DAYPERIOD: night.

	β	P-value	Odds Ratio	Lower CI	Upper CI
Intercept	-2.3147	**< 0.0001**			
WEEK					
WEEKDAY	-0.1268	0.0748	1.29	0.97	1.70
SEASON		**< 0.0001**			
SPRING	-0.7744	**< 0.0001**	3.99	2.69	6.05
SUMMER	0.1656	**0.1096**	1.56	1.15	2.12
DAYPERIOD		**< 0.0001**			
DAWN	0.8490	**< 0.0001**	0.16	0.10	0.25
DAY	-0.6268	**< 0.0001**	0.71	0.40	1.26
DUSK	0.7459	**< 0.0001**	0.18	0.10	0.34
SEASON*DAYPERIOD		0.1939			
SPRING*DAWN	0.2451	0.2644			
SPRING*DAY	-0.0300	0.8878			
SPRING*DUSK	0.0579	0.8017			
SUMMER*DAWN	-0.3825	**0.0365**			
SUMMER*DAY	0.1778	0.2635			
SUMMER*DUSK	-0.1749	0.3514			
TRAFFIC	-0.0579	0.5577	0.74	0.27	2.02

Table 2.7. Results of mesocarnivore activity and traffic volume model. The reference levels are; WEEK: weekend, SEASON: fall, DAYPERIOD: night.

	β	**P-value**	**Odds Ratio**	**Lower CI**	**Upper CI**
Intercept	-12.9547	**< 0.0001**			
WEEK					
WEEKDAY	0.0135	0.8542	0.97	0.73	1.30
SEASON		0.1216			
SPRING	-0.1730	0.3817	1.72	0.91	3.39
SUMMER	-0.1939	0.2622	1.75	0.99	3.09
DAYPERIOD		**< 0.0001**			
DAWN	0.1447	0.4885	2.27	1.34	4.26
DAY	-1.1106	**< 0.0001**	7.98	4.35	15.45
SEASON*DAYPERIOD		**0.0002**			
SPRING*DAWN	-0.3442	0.2852			
SPRING*DAY	-0.2200	0.4588			
SUMMER*DAWN	-0.3980	0.1727			
SUMMER*DAY	0.7283	**0.0028**			
TRAFFIC	-0.2196	**0.0165**	0.80	0.67	0.96

FIGURES

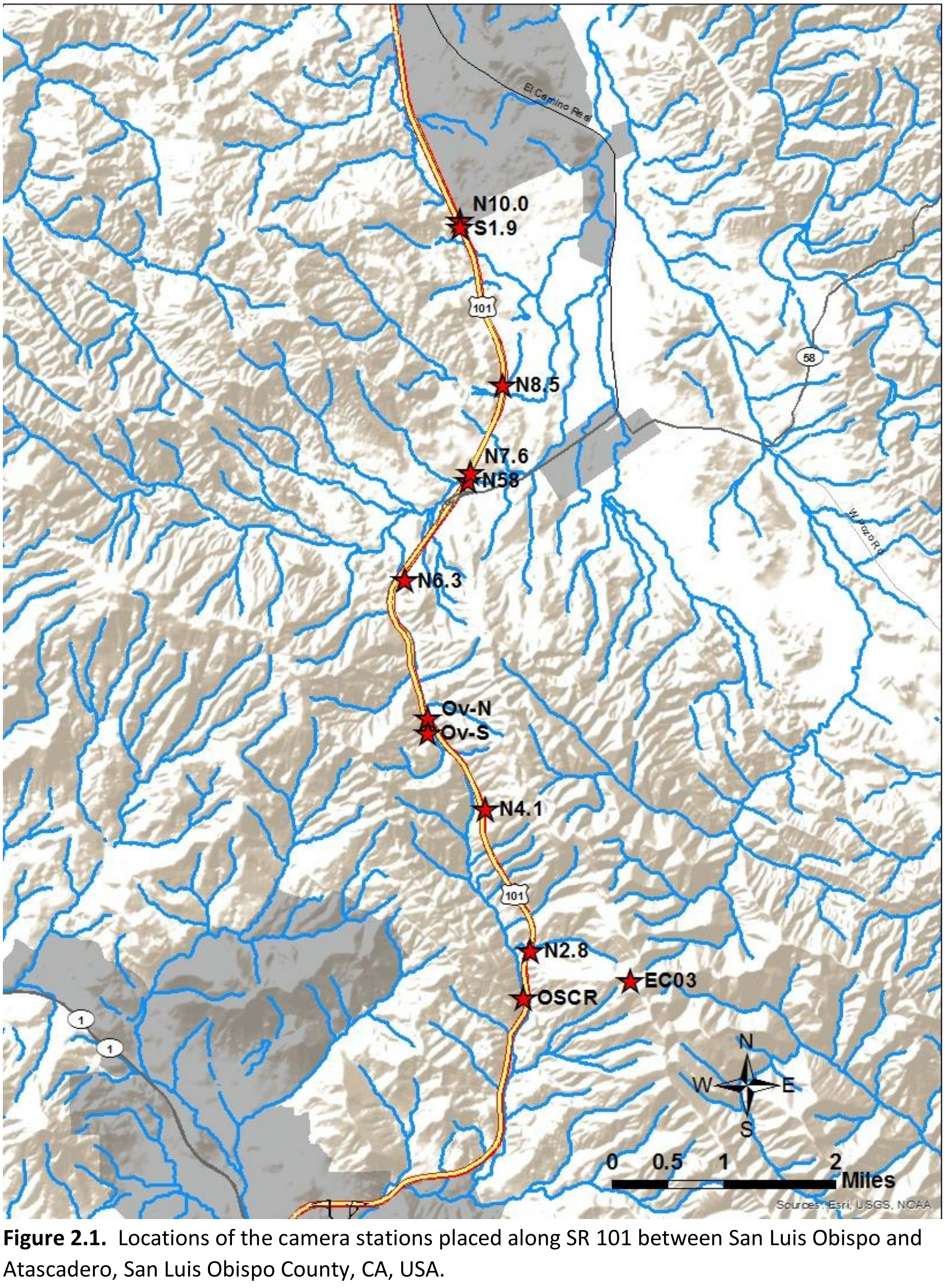

Figure 2.1. Locations of the camera stations placed along SR 101 between San Luis Obispo and Atascadero, San Luis Obispo County, CA, USA.

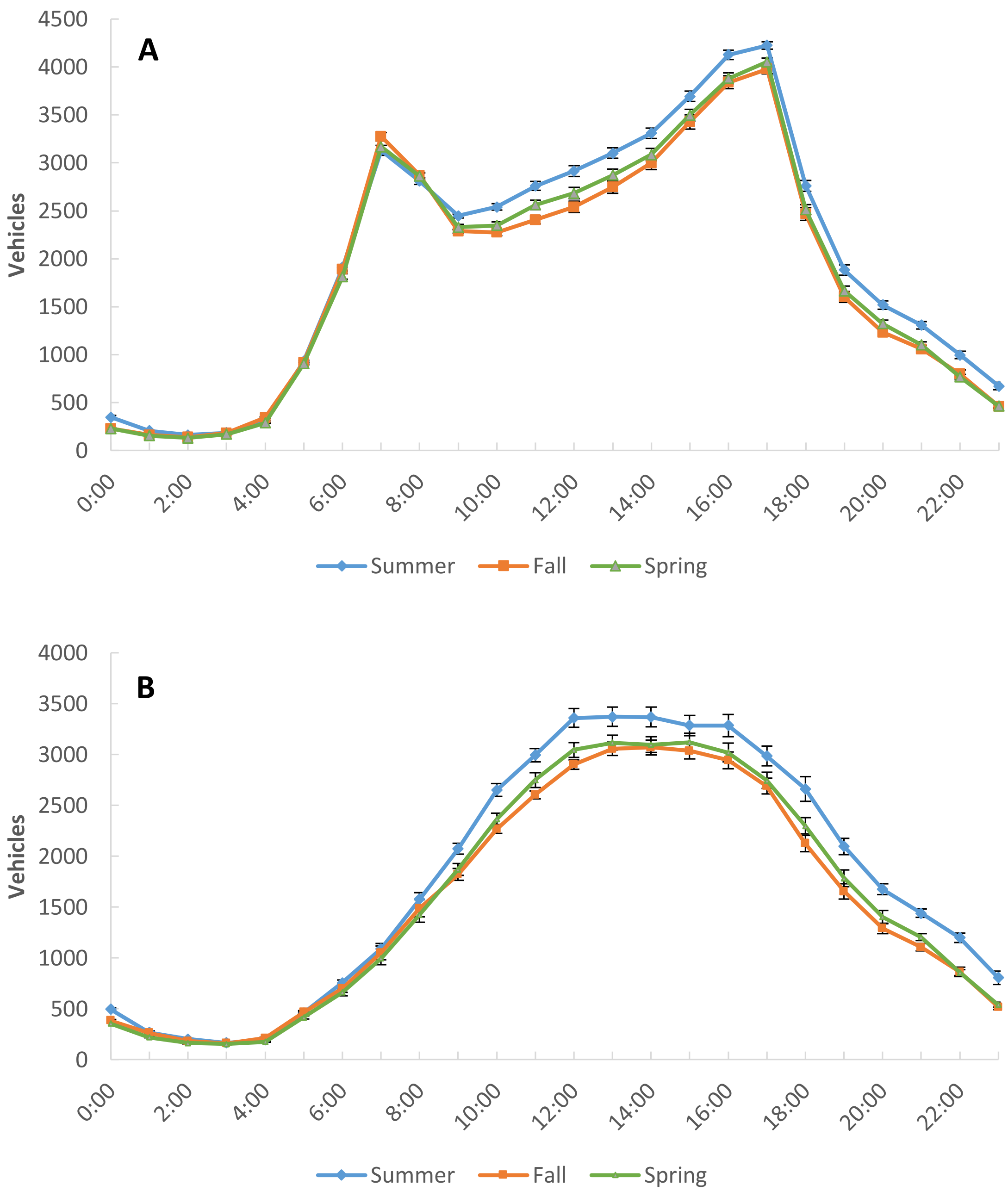

Figure 2.2. The average hourly traffic volume on weekdays (A) and weekends (B) during the three camera surveys.

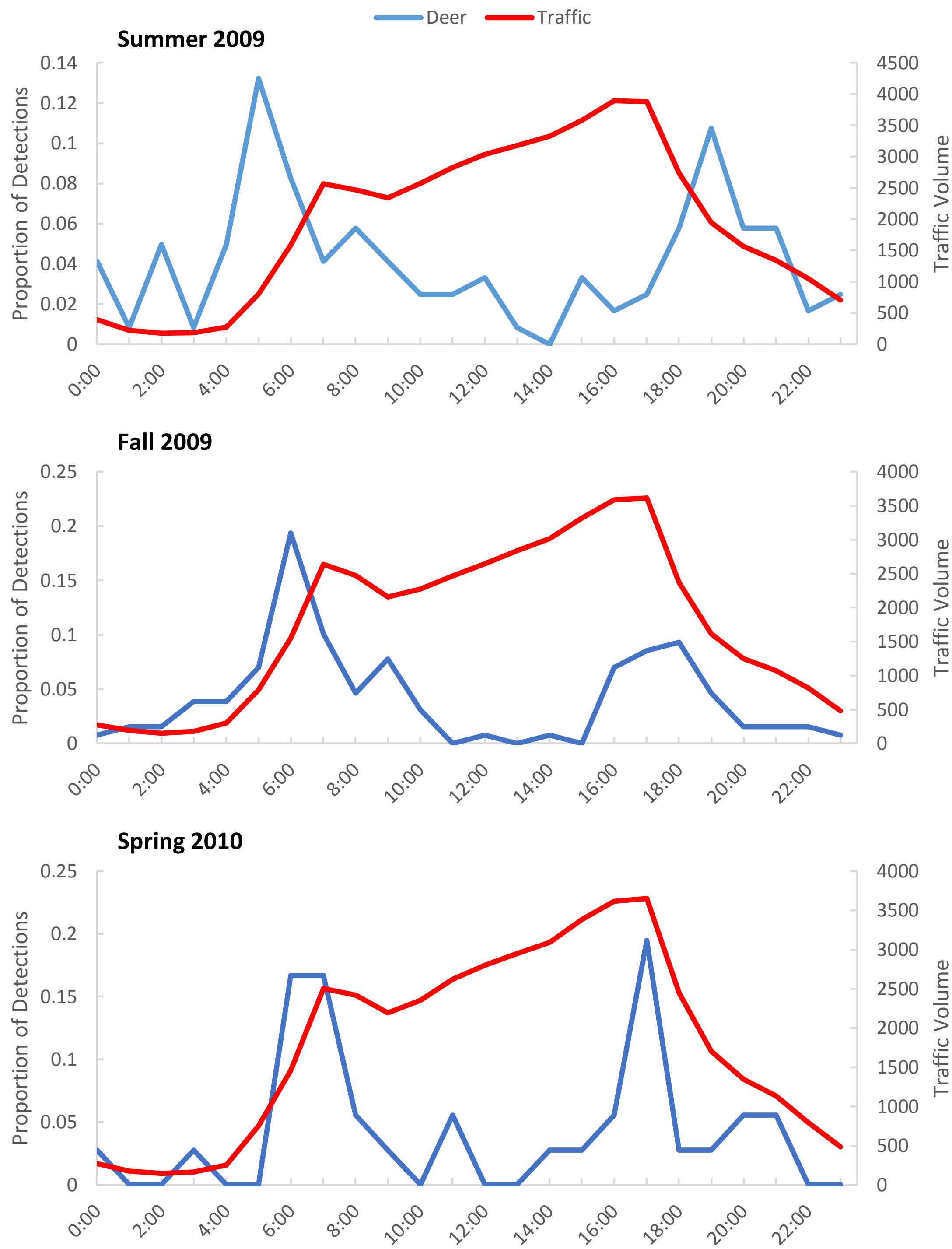

Figure 2.3. Proportion of total deer detections and traffic volume per hour for each season. Traffic volume is the average hourly traffic volume during the time of the camera survey.

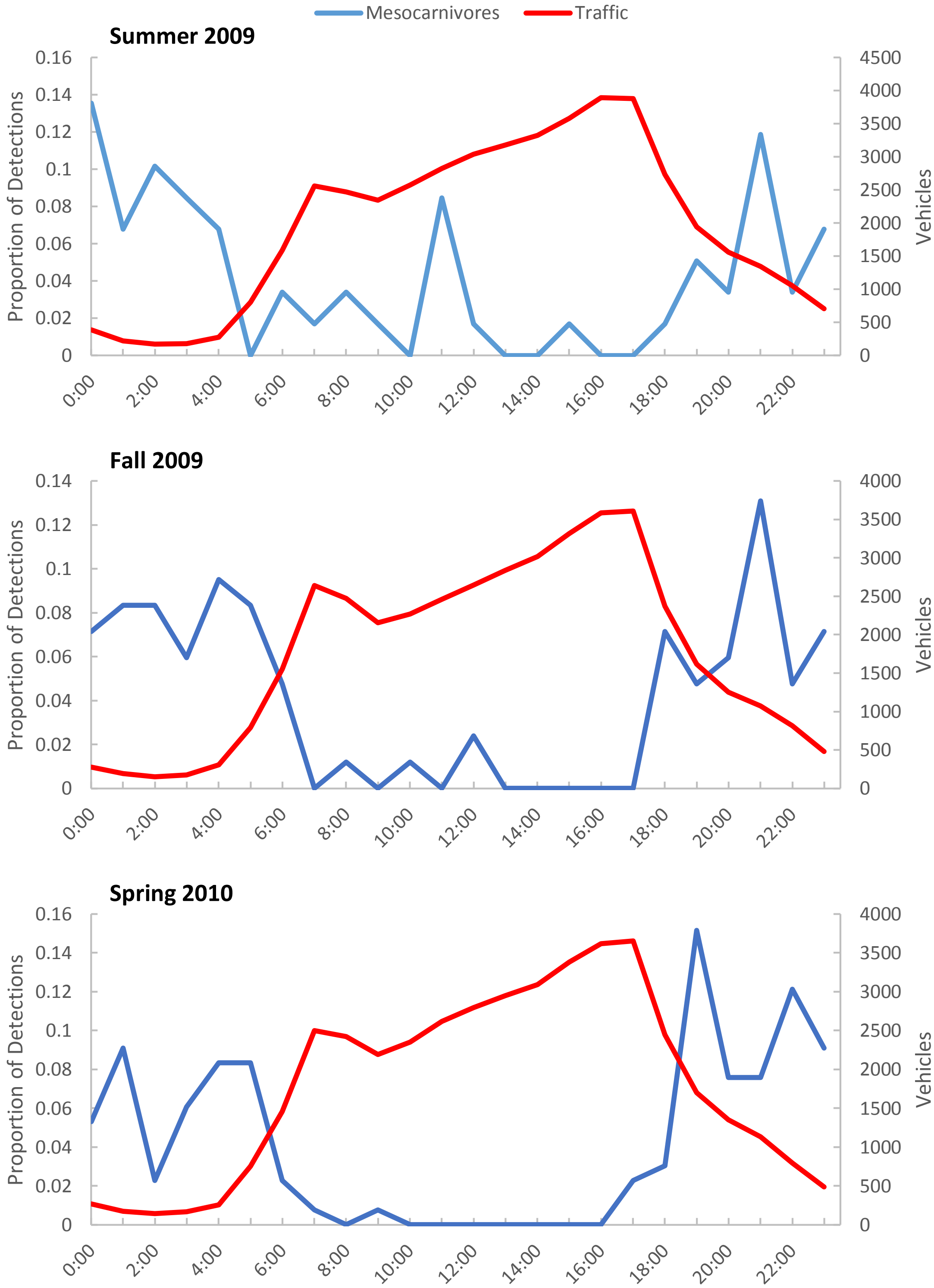

Figure 2.4. Proportion of total mesocarnivores detections and traffic volume per hour for each season. Traffic volume is the average hourly traffic volume during the time of the camera survey.

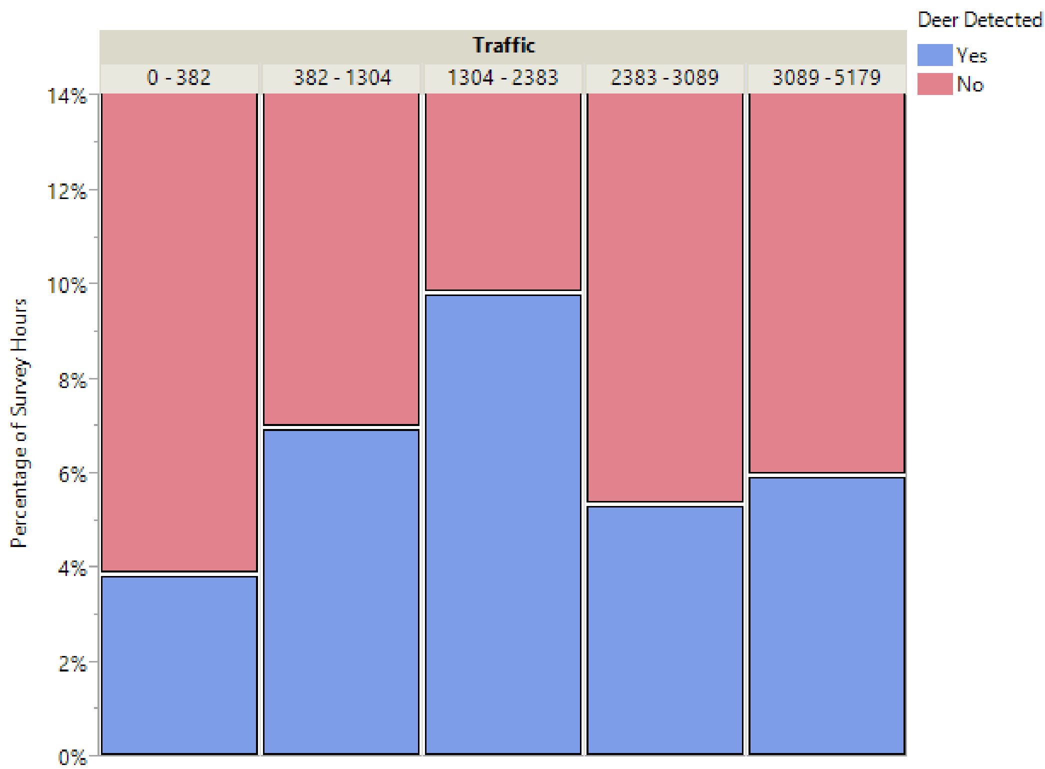

Figure 2.5. The percentage of total survey hours during which a deer was detected depending on traffic volume.

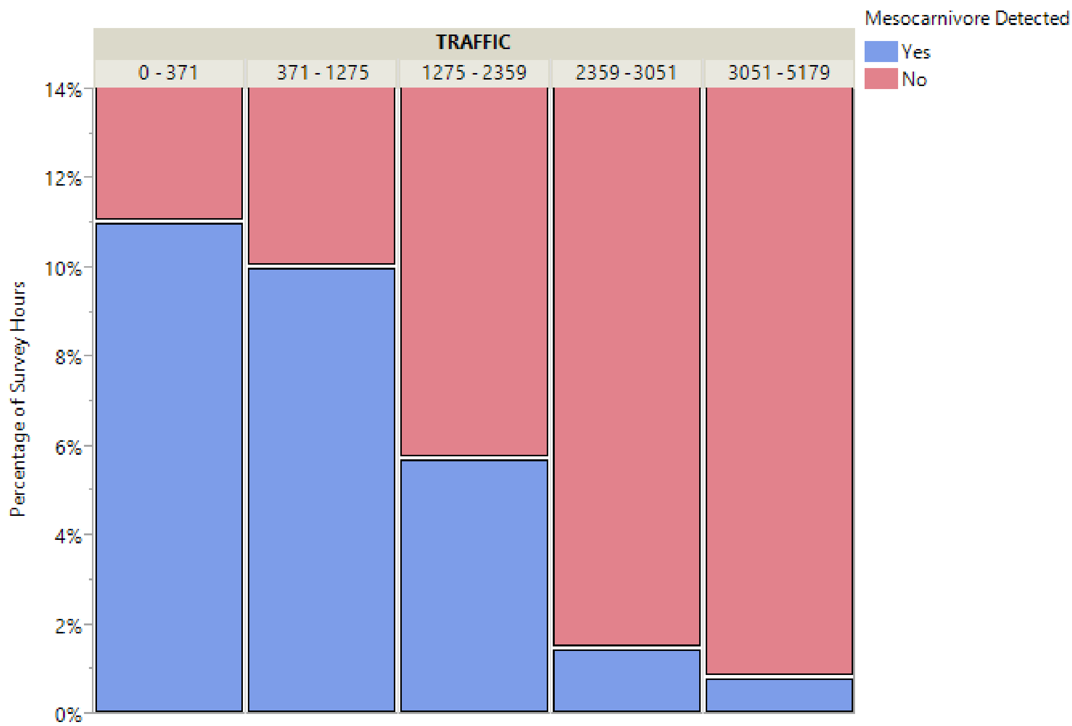

Figure 2.6. The percentage of total survey hours during which a mesocarnivore was detected depending on traffic volume.

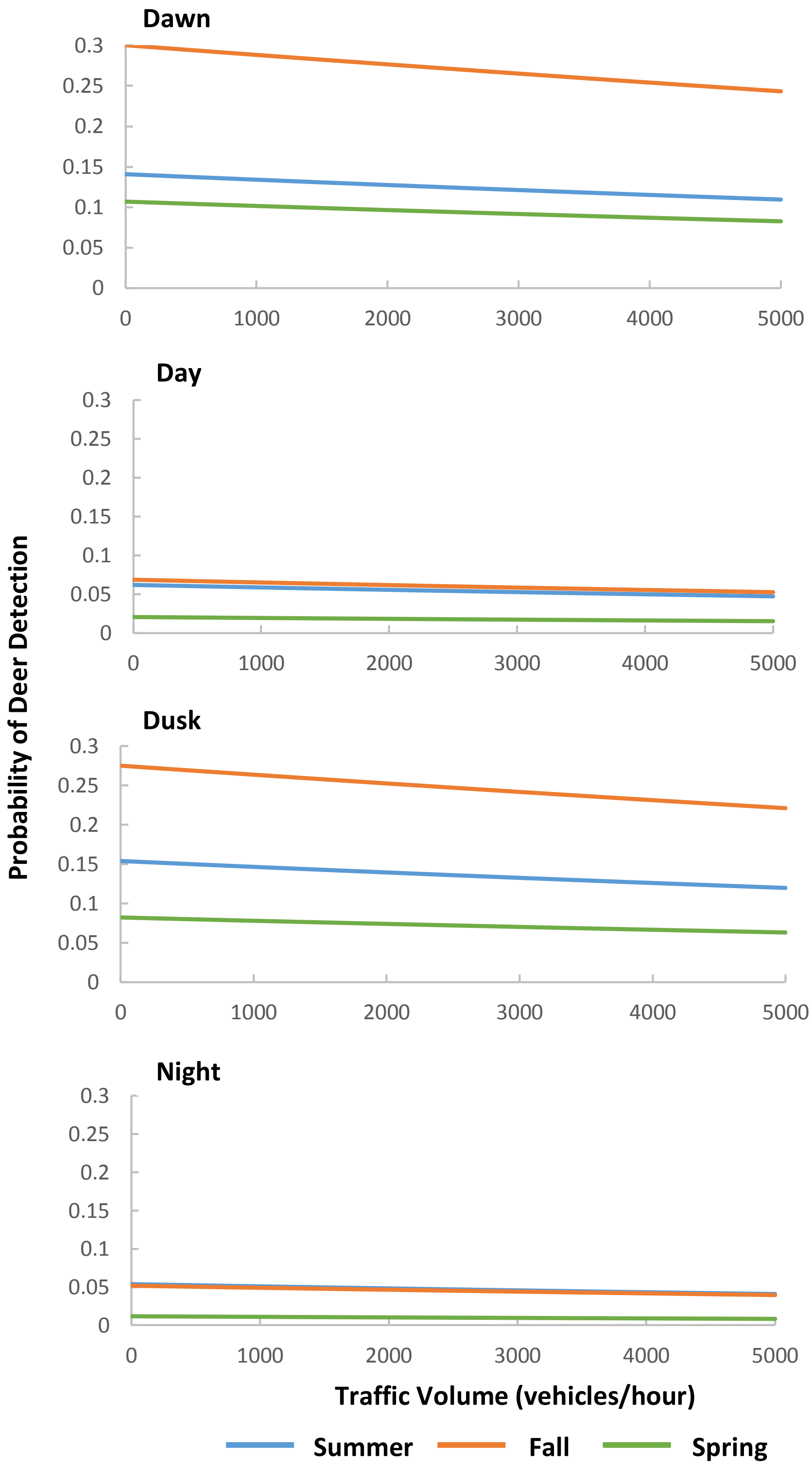

Figure 2.7. The probability of detecting a deer depending on day period (DAWN, DAY, DUSK, NIGHT), season and traffic volume for weekdays. These probabilities were determined using the deer model. Traffic volume was not a significant predictor for detecting deer. The line for summer is under fall in the graph for Night.

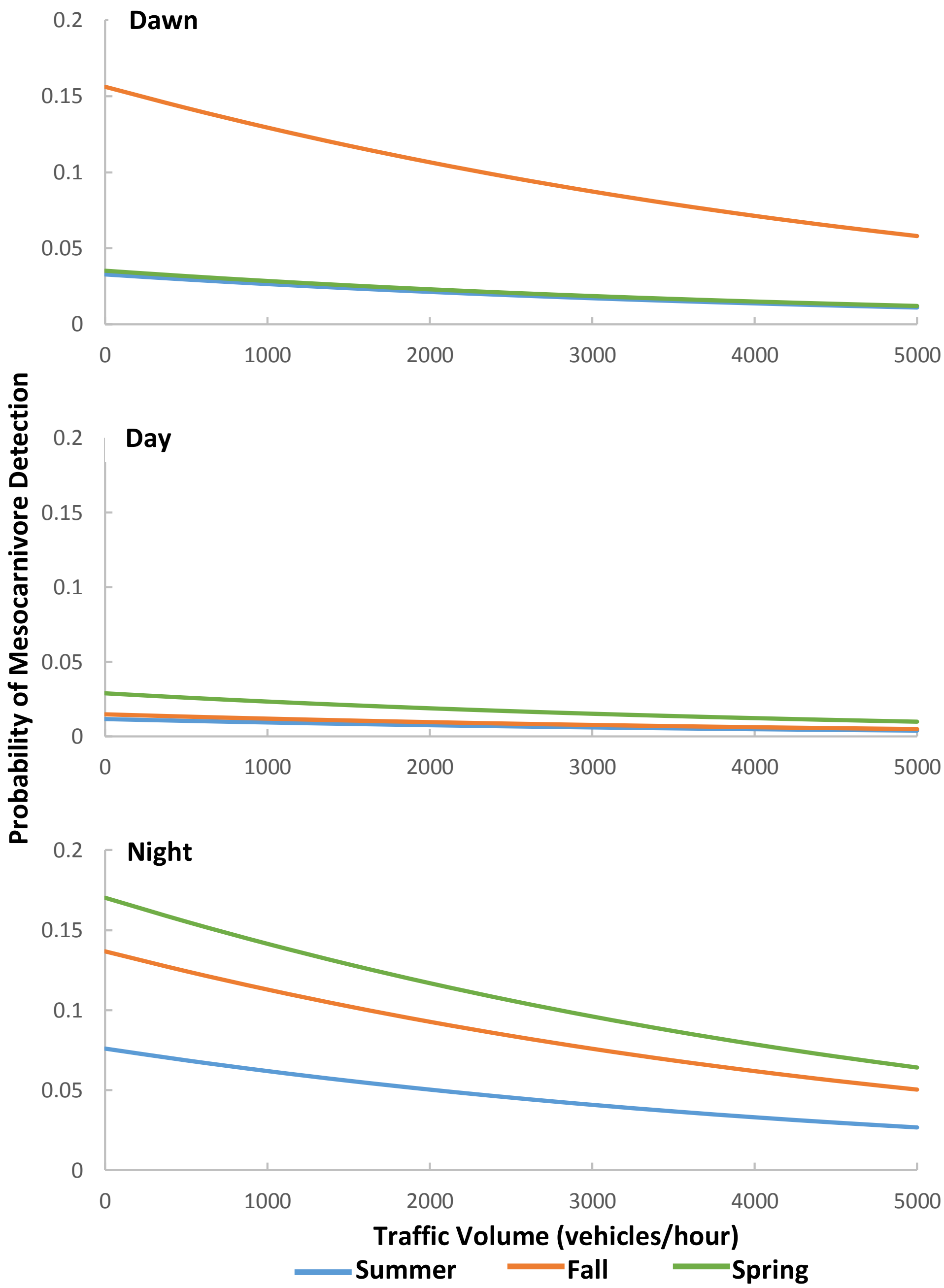

Figure 2.8. The probability of detecting a mesocarnivore depending on day period (DAWN, DAY, NIGHT), season and traffic volume for weekdays. These probabilities were determined using the mesocarnivore model. Traffic volume was a significant predictor for detecting mesocarnivores.

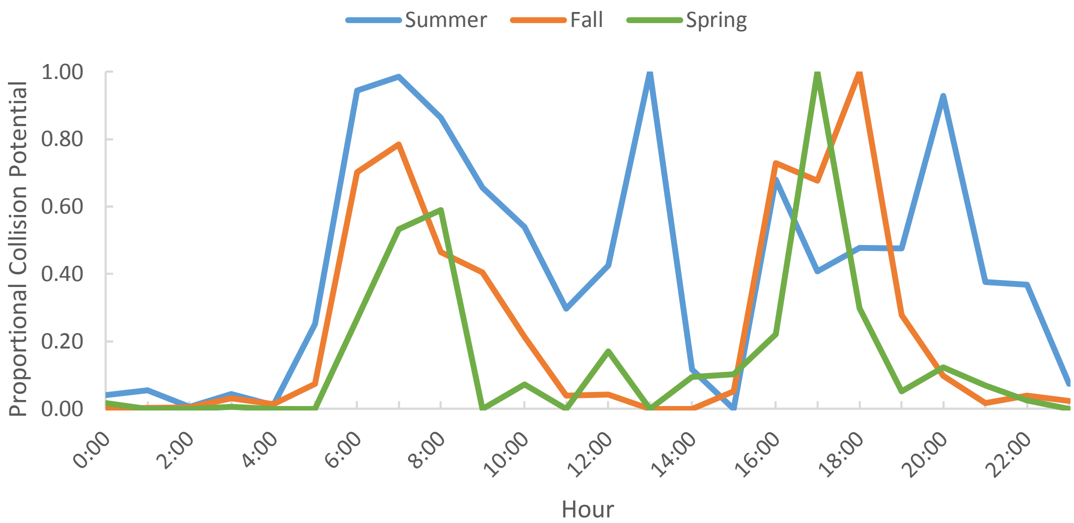

Figure 2.9. Collision potential of mule deer by hour for each season. Potential was calculated by multiplying the total number of deer detected during each hour of a season by the average number of vehicles detected during each hour of a season.

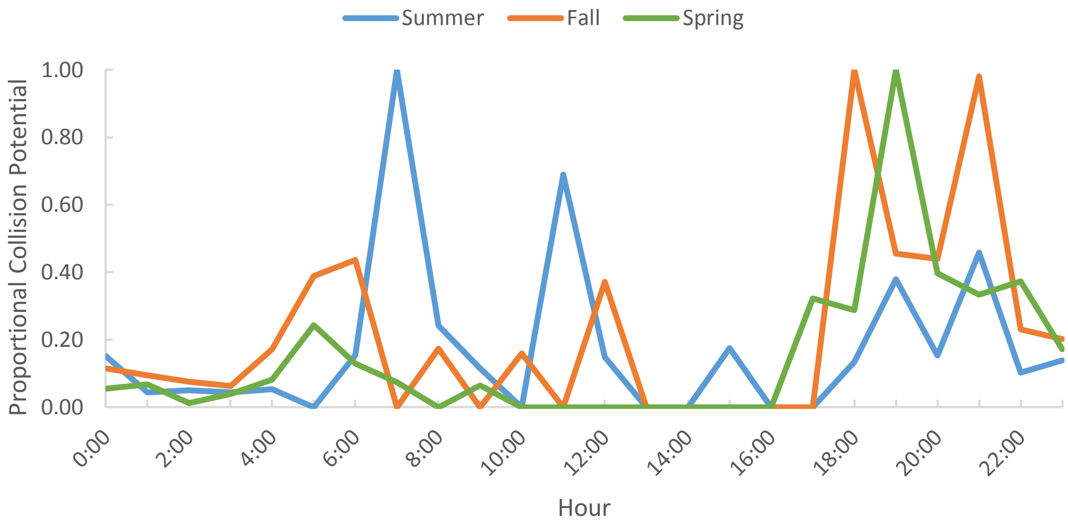

Figure 2.10. Collision potential of mesocarnivore by hour for each season. Potential was calculated by multiplying the total number of deer detected during each hour of a season by the average number of vehicles detected during each hour of a season.

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APPENDIX: GIS METHODS FOR LANDSCAPE VARIABLES

Polygons used for the predictors SLOPE and HABITAT

I obtained the geographic coordinates for the northbound and southbound postmile locations from Caltrans and the highway layer through ArcGIS online. I created a buffer around the northbound and southbound sides of the highway at 100m and 250m using the 'Buffer' tool in ArcMap 10.0. I used the 'Perpendicular to Polyline' tool in the program ET GeoWizard 10.1 (http://www.ian-ko.com/ET_GeoWizards/gw_demo.htm) to create lines beginning at, and perpendicular to the 250m line and ending at each postmile location along the roadway. I then created a point where each perpendicular line intersected the 100m buffer using the 'Intersect' tool in ArcMap 10.0. I created a 50m buffer around each of these points to make a circular area 100m in diameter at each postmile location.

SLOPE

I used the 'Slope' tool in ArcMap 10.0 to create a slope raster layer in degrees from the 1/3 Arc second (~10m) digital elevation model (DEM) for San Luis Obispo County, obtained from SLO Datafinder (http://lib.calpoly.edu/collection/gis/slodatafinder/). I used the ArcMap 10.0 'Zonal Statistics' tool to calculate the mean slope within each 100m circular polygon. I then used the ArcMap tool 'Extract Value to Points' to assign the average slope for each polygon to the corresponding postmile. The value for the northbound and southbound polygons were averaged to create one slope value for each postmile location.

HABITAT

I created the HABITAT predictor from the California Wildlife Habitat Relationship (CWHR) Vegetation Classification raster layer. First I created polygons for each vegetation type from the CWHR raster layer using the 'Raster to Polygon' tool in ArcMap 10.0. I then intersected the vegetation polygons with the 100m circles using the 'Intersect' tool in ArcMap 10.0 to determine the area of the different habitat types within the 100m circles.