CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

HOTSPOT ANALYSIS OF ROAD KILL

IN SOUTHERN CALIFORNIA: A GIS APPROACH

A thesis submitted in partial fulfillment of the requirements
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By

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ABSTRACT

HOTSPOT ANALYSIS OF ROAD KILL

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Areas of high probability for road kill hotspots were identified and land cover patterns that best distinguished where wildlife crossed road networks were measured to examine relationships between road kill and landscape/road variables in eight counties in Southern California from 1994-2012. The spatial association of road kill hotspots with specific land cover types was assessed using several geospatial analysis techniques. The Point Density analysis determined that there were eight hotspots for road kill in three counties for Southern California. Four hotspots were in San Diego County, two were in Los Angeles County, and two were in Ventura County. The habitat characteristics for the three counties indicated that road kill occurred in highly urbanized locations with 61% in urban land cover, while the remaining 39% of road kills were unevenly distributed between eleven other land cover types. For this study, there were a variety of species affected by road kills, from very small to very large animals including birds and reptiles. Rabbits were the most frequently killed animals followed by snakes, birds, squirrels, and coyotes.

The landscape metrics were measured with FRAGSTATS (version 4.0). The FRAGSTATS results computed a multiplicity of landscape metrics for the categorical map patterns by quantifying the spatial configuration of patches near the roads. The analysis identified a difference in the recognized hotspot areas for the patches of land cover. While road kill incidents, the majority of the time, occurred in urban areas in seven out of the eight hotspots, urban land cover was the dominant type for only three of the eight hotspot locations; two in central San Diego on the coast and the other in southern Los Angeles County. Spearman's rho analysis revealed that the density of road kill is strongly correlated with the number of land cover patches and patch richness. As the number of patches (NP) and the number of patch types in each area (PR) increase, road kill events also increase. This may be due to a fragmented landscape in which wildlife have a variety of patch types they must navigate, thus increasing the need for them to move across the landscape and the probability of being hit on a road.

Although road mortality may not affect large and fecund populations, it can have a significant impact on small populations and threatened or endangered species. The outcome for the hotspot analyses clearly showed urban land cover type as the highest among road kill sites. The results suggest that wildlife are crossing roads at distinct locations in the landscape. Measures can be taken to improve the chances for survival of many animals in the future such as, constructing wildlife crossings like overpasses and underpasses for future road constructions in identified hotspot areas. As the population in Southern California continues to increase so does the need to identify and protect critical habitats for wildlife.

Chapter 1 -- Introduction

1.1 Background

Roads can be a network of nuisances that fragment wildlife habitat and degrade the natural environment. The physical footprint of the nearly 4 million miles of roads in the United States is relatively small, however, the ecological footprint of the road system goes much farther (Beier, et al. 2008). With the current rate of population growth, the demand for human development has increased significantly. This increased development is invading sensitive wildlife habitat and altering their environment. Furthermore, habitats are becoming fragmented as urbanization continues and roads are constructed. Roads can cause direct loss of habitat, change the quality of adjacent habitat, impede animal movements, and lead to road kill (Forman, et al. 2003). Species are forced to cross-busy roads intersecting their environment. Consequently, road kill is a major threat for wildlife as well as an increasing hazard to drivers on American roadways. Most threatened are large mammals, such as carnivores and ungulates that regularly move over great distances (Ng, et al. 2004). Particularly, in rural and suburban areas road kill is a significant safety concern (Clevenger, et al. 2006).

As traffic volumes increase and roads extend to more and more natural areas, wildlife and vehicles collisions continue to intensify, resulting in a major socio-economic and traffic safety issue as well as a species conservation issue (Gunson, et al. 2010). To handle the increasing traffic volumes, American roads are altered and improved regularly. Widening and reconstructing existing roads can negatively affect the habitat of wildlife by either altering, fragmenting or reducing their natural environment. Consequently, animals that are roaming in their environment are having to traverse the newly modified roads in search of food, mates or even to relocate to new habitat for survival. As a result, the rate of success of road crossings on altered or newly constructed roads decreases significantly (Forman, et al. 2003). When roads are constructed in wildlife habitats, the connectivity is reduced resulting in significant habitat fragmentation. Additionally, the human populations spreading into the urban-wildland interface increases the interactions between animals and humans. However, little research has been done to identify where these interactions are most likely to happen. As such, hotspots for road kill need to be identified to insure the safety of both the public and wildlife and to provide opportunities for policy change to address these problem areas.

1.2 Purpose Statement

The aim of this study is to determine the spatial patterns of road kill by using geospatial analysis techniques and a Geographic Information System (GIS) to analyze the geography of road kill in Southern California. The specific objectives are (1) to identify areas with a high probability of road kill through a hotspot analysis; (2) to use spatial statistics to measure relationships between road kill and landscape/road characteristics, and (3) to establish what species are routinely affected. The results of this study will help to identify the unique environmental factors at road kill hotspots in an effort to provide information to planners that can be used to reduce this hazard to both wildlife and humans.

1.3 Research Questions and Hypothesis

Many studies have found that as the connectivity of road networks continues to increase, natural populations of plants and animals are becoming increasingly isolated and their habitats are decreasing (Clinton, et al. 2005). Therefore, the primary research questions for this study are: 1) where are the road kill hotspots in Southern California; 2) what are the landscape patterns adjacent to the hotspot areas, and 3) which species are most commonly impacted in the identified hotspot areas.

The results of the hotspot analysis will help to identify where wildlife crossings that end in road kills cluster spatially, and why these locations are unique. The expected outcome of this study is to find that the hotspots for road kills are related to patterns of landscape composition (land cover matrix) and spatial arrangement (size, connectivity, and intermixing of land cover types). By establishing the relationship between patterns and processes in landscapes near road kill sites, recommendations can be made to construct wildlife crossings, such as overpasses and underpasses, and to warn motorists of wildlife crossings with wildlife signage, and a reduction of speed limits.

1.4 Significance of the Study

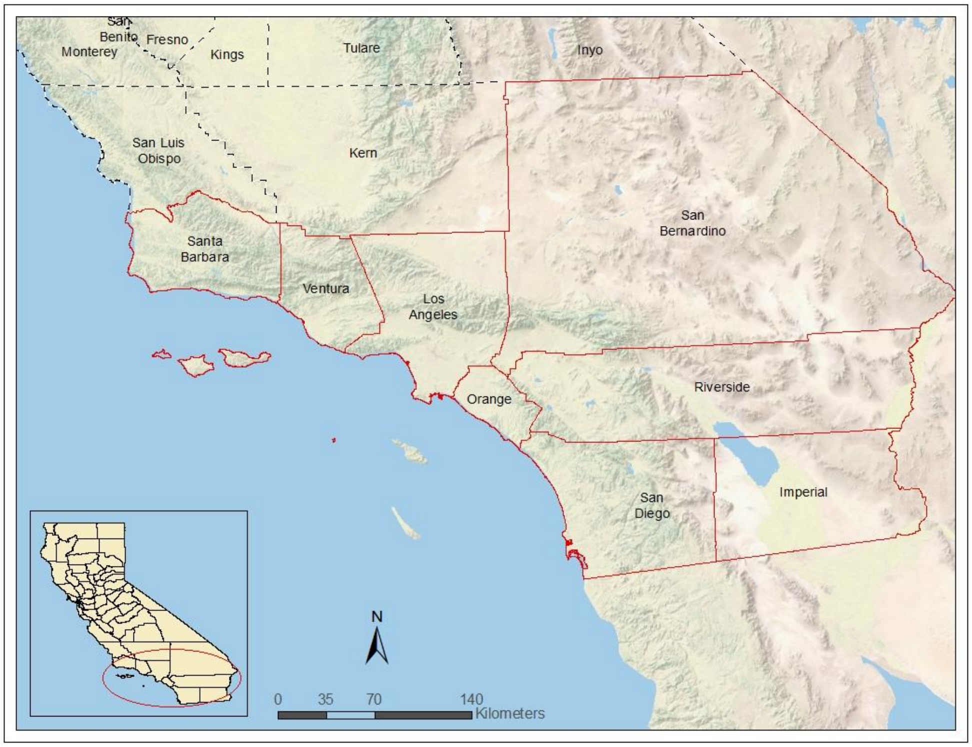
Roads can negatively influence wildlife in many ways. Vehicle-induced fatalities are one of the most obvious impacts of road networks. Yet there is little understanding of the patterns and rates of road mortality for mammals (Barthelmess and Brooks, 2010). Determining where wildlife movement and highway operation conflict is an essential first step in making highways safer for motorists and animals, especially those animals of conservation concern (Lloyd and Casey, 2005). Hotspot analyses for road kill data are a cost effective technique for identifying sensitive wildlife areas (Lowery and Grandmaison, 2009). So far, little research has been done regarding where the hotspot areas are, especially in Southern California. Systematic record keeping of wildlife road mortality on U.S. roads is nonexistent for many species (Forman, et al. 2003). Therefore, this study will aid in the data collection concerning wildlife vehicle collisions in Southern California. The data acquired can aid agencies in future transportation projects in areas where wildlife vehicle collisions are a major concern. In addition, by studying road kill data using GIS, areas of concern will be identified allowing for recommendations in transportation corridor design and planning.

Chapter 2 – Study Area

2.1 Location

The initial study took place in Southern California, extending from Santa Barbara to San Diego, and eastward to the Arizona border. The counties in the generalized study area were Santa Barbara, San Bernardino, Ventura, Los Angeles, Orange, Riverside, San Diego, and Imperial (Figure 1). The region through which these roads pass is a complex of mountains to low hills and valleys. Elevation ranges from 10,068 ft. Mount San Antonio in Los Angeles County down to below sea level in Imperial County. However, after the hotspot analysis was completed in ArcGIS, the focus was narrowed to San Diego, Los Angeles, and Ventura Counties. The study area included the road networks through San Diego County where hotspot locations were found. In addition, the road networks for the hotspot of road kills identified in Los Angeles and Ventura Counties were a focus as well. The landscape of San Diego, Los Angeles, and Ventura Counties incorporates a variety of fauna and flora, which had an important role in this study for analyzing the environments around the road networks. Flora includes coastal beach and dune habitats, coastal and interior sage scrub, chaparral, woodlands, grasslands, riparian woodlands, and wetlands all contribute unique variety of landscapes to Southern California (Rundel and Gustafson, 2007). For this study, all mammals, reptiles, and birds impacted by vehicles within the study area were examined, along with the flora in the landscapes adjacent to the determined cluster locations.

Figure 1: Southern California Study Area Boundary (red).



2.2 Population

The Southern California population is increasing along with the demand for development and more roads. Southern California consists of multiple metropolitan areas as well as smaller cities and towns. According to the U.S. Census Bureau, Southern California's total population as of 2000 was 19,753,736 and in 2010 was 21,570,742, while the state of California in 2010 was 37,253,956 (Table 1). In ten years, Southern California's population has increased by 1,817,006 (9%). This increase in population will have a major impact on wildlife and their environment, as housing and road construction will continue to invade these habitats.

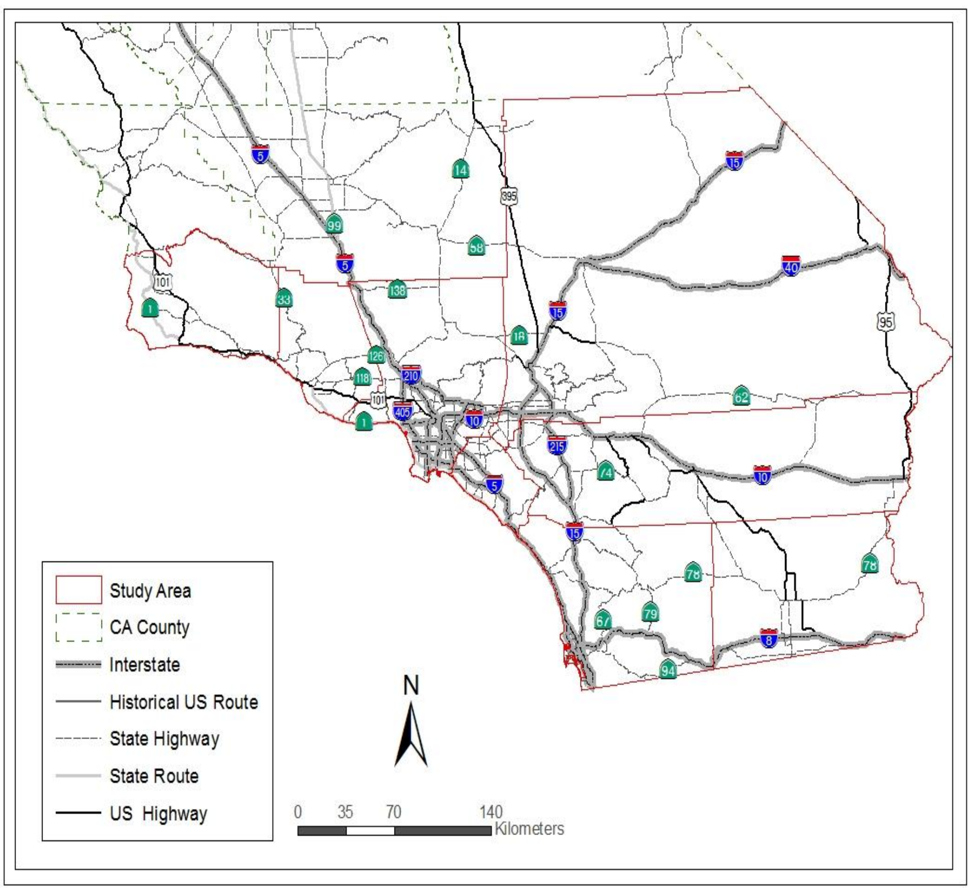
Table 1: Southern California Population by County, 2000 and 2010.

County	**2000**	**2010**
Los Angeles County	**9,519,338**	**9,818,605**
Orange County	**2,846,289**	**3,010,232**
San Diego County	**2,813,835**	**3,095,313**
Riverside County	**1,545,387**	**2,189,641**
San Bernardino County	**1,709,434**	**2,035,210**
Ventura County	**753,197**	**823,318**
Santa Barbara County	**399,347**	**423,895**
Imperial County	**142,361**	**174,528**

2.3 Road Networks

Southern California is a maze of road networks with additional ones added each year as populations increase and development continues. In Southern California, there are 13 interstate highways, one U.S. Highway system (U.S. 101), and 56 California state route freeways (Figure 2). In addition, there are thousands of surface streets and rural roads traversing through Southern California; consequently, all of these roads affect wildlife. Many of them cut through critical habitat, which can be a threat to the survival of wildlife in their environments. The construction of freeways, highways, and roads, or the altering of existing ones, will have an effect on animals navigating through their surroundings. Since the focus for this study included the areas of San Diego, Los Angeles, and Ventura Counties, the major landscape studied was centered on the roads within these counties.

Figure 2: Major Roads Networks in Southern California.



Chapter 3 – Literature Review

3.1 Human Development of Road Networks

Humans have constructed vast networks of roads traversing lands all over the world. These road networks are a characteristic of almost all of the earth's landscape and they are increasing in length and area at a rapid pace (Forman, et al. 2003). According to a study by Ree, et al. (2011), there are an estimated 750 million vehicles worldwide traveling on approximately 50 million kilometers of public road and the network and traffic volumes are still increasing. Almost all human communities are connected by road networks (Lloyd and Casey, 2005). Both roads and vehicles affect the mobility and survival of wildlife across an environment, which has led to not only habitat destruction, but also population fragmentation (Orth and Riley, 2005).

3.2 Impact of Road Networks on Wildlife

Roads, especially large highways, have been found to have significant impacts on wildlife movement and survival (Ng, et al. 2004). There are many direct effects on wildlife including death, habitat fragmentation, habitat loss, and reduced habitat connectivity. Road networks that have been studied are known to cause habitat fragmentation by breaking large areas into small, isolated habitat patches. Forman and Alexander (1998), showed that the ecological effect of road barriers might emerge as the greatest ecological impact of roads on wildlife. Many people do not think of roads as causing habitat loss. However, a study found that a single freeway with a typical width equaling 50 meters, including median and shoulder, crossing diagonally across a 1-mile section of land results in the loss of 4.4% of habitat area (Beier, et al. 2008). Roads alter an animal's habitat by limiting access to other areas within their environment. Equally, there is a high rate of mortality incurred by individual animals that attempt to cross roads to move among remaining patches of habitat (Lloyd and Casey, 2005). Species of varying sizes are impacted by roads and highways cutting through their environment. Many states are experiencing infrastructure expansion that has led to greater safety concern and the need to develop effective countermeasures to mitigate wildlife vehicle collisions (Clevenger, et al. 2006). Many species, especially larger exploratory ones such as mountain lions, coyotes, and bobcats, will travel miles crossing roads and highways in search of food, mates, and shelter (California Biodiversity, 1997). Alternatively, some wildlife choose to avoid roads altogether, which have resulted in the isolation of their populations. Smaller wildlife species may view roads as barriers rather than something to cross, resulting in confinement in their habitats and ultimately seclusion. Additionally, roads have been found to pose additional wildlife habitat threats such as increased ambient noise levels and vibrations that could interfere with the ability of reptiles, birds, and mammals to communicate, detect prey, or avoid predators (Beier, et al. 2008). As habitats become more fragmented with human development and road networks are continually added to the landscape, wildlife populations will continue to decrease. Therefore, determining where the most vulnerable habitat areas are is vital to the future of many species.

3.3 Wildlife Vehicle Collisions – Road kill

Road kill locations along roadways act as reliable indicators of wildlife crossing areas (Lowery and Grandmaison, 2009). A study done in northwestern Oregon found that hotspots generally were associated with topographic features that directed animals towards highways, the presence of habitat adjacent to highways, or food resources that attracted animals (Lloyd and Casey, 2005). Estimates of road kills throughout the world show the impacts on wildlife from road networks; 159,000 mammals and 653,000 birds in The Netherlands; seven million birds in Bulgaria; five million frogs and reptiles in Australia, and an estimated one million vertebrates per day are killed on roads in the United States (Forman and Alexander, 1998). Direct road kill affects most species and the impacts on wide-ranging predators such as the cougar in southern California, the Florida panther, the ocelot, the wolf, and the Iberian lynx have been well-documented (Beier, et al. 2008). In a study conducted in Canton, New York focusing on road kill rates for local mammal species, it was discovered that at least 50% of the mammals in the study area were impacted by road mortality, representing 21 species from 5 mammalian orders. The outcome of the study also showed that carnivores were found less often than medium-sized mammals. On average, 3.8 mammals were killed per 100 km of road (Barthelmess and Brooks, 2010). Anyone who has watched an animal try to cross a busy road, or seen the remains of one that did not make it, can imagine the diverse effects of road kill (Forman, et al. 2003). Consequently, as many road segments are improved to accommodate greater traffic volume, the chances of wildlife crossing these roads successfully declines. As the volume of traffic increases so does the amount of road kill.

3.4 Wildlife Crossing Structures

It is evident that the best way to protect wildlife from dangerous road crossings is to not construct roads in the first place. However, where there are overriding reasons to build or expand roads, wildlife-crossing structures can facilitate wildlife movement (Beier, et al. 2008). Though no single crossing structure will accommodate all wildlife, many can benefit from these structures. Numerous structures already exist that will aid the growing concern for wildlife crossing roads that run through their environment. Many of these structures were not initially intended for wildlife movement, but have become de facto road cross corridors, such as drain culverts and tunnels. The results of a study done in Bow River Valley along the Trans-Canada transportation corridor found that for many small and medium sized mammals, drainage culverts mitigated the potentially harmful effects of busy transportation corridors (Clevenger, et al. 2001). For larger animals, wildlife overpasses (Figure 3) also improve the chances of safely crossing busy highways. Approximately fifty overpasses have been built in the world, with only six of these occurring in North America (Forman, et al. 2003).

Figure 3: Wildlife overpass crossing (Bissonette and Cramer, 2008).

Wildlife underpasses on many roads and highways such as viaducts, bridges, culverts, and pipes already exist for medium to smaller animals (Beier, et al. 2008). A study conducted along three major highways located on the eastern edge of Ventura County, California, just west of the San Fernando Valley and adjacent to the Los Angeles metropolitan area demonstrated regular use of underpasses and drainage culverts beneath highways by wildlife (Ng, et al. 2004). Numerous methods exist that will allow wildlife to cross highways safely, ranging from relatively inexpensive efforts to modify the behavior of motorists to building more complicated structures for wildlife corridors (Lloyd, et al. 2005).

3.5 Landscape Ecology

Some wildlife requires specific vegetation in their habitat for survival. However, if critical habitat is intersected by roads, then the composition and spatial properties of vegetation patches near roads will influence wildlife, as such, the pattern of the landscape, for many species influences its ability to persist in particular locations. Landscape ecology is a discipline that focuses on the shared interactions between spatial pattern and ecological processes (Turner, 2005). It is a field that has grown rapidly in the past fifteen years and continues to be employed to make contributions to understanding wildlife-landscape interactions. Landscape ecology studies the spatial patterns of landscapes, including the distribution of species and habitat on local to regional scales (MacDonald, 2003). A landscape is an area of land containing a mosaic of patches or environmental elements that is not defined by its size instead, it is defined by an interacting variety of patches relevant to the phenomenon under consideration (McGarigal, et al. 2002). The structural characteristics of a landscape, such as patch size, edge length, and configuration are the framework for landscape patterns, however over time these complex spatial designs tend to change (Franklin and Forman, 1987). Until recently, it was not possible to study the spatial pattern of ecological resources and human environments at a variety of scales. However, advances in computer technology and development of new databases, have made it possible to analyze spatial patterns at scales ranging from communities to the entire globe (EPA, 2012).

Within the last century, significant changes in land-use practices combined with increasing levels of habitat fragmentation have made the landscape an important and relevant scale for studies of wildlife ecology and management (Rodewald, 2003). The expansion of road networks in the Mojave and Sonoran Deserts has reduced connectivity among populations of flora and fauna (Epps, et al. 2005). Roads can alter the landscape and have harmful effects on the environment resulting in obstacles that may prevent landscape connectivity and can eventually affect wildlife populations (Bennett, 1991). Another study found that for some species, habitat type influenced where carcasses were located. Specifically, carnivores were found predominantly in rural habitats, while other species, such as Virginia opossums, domestic cats, and rats, carcasses were located in both rural and suburban landscapes (Caro, et al. 2000). Landscape ecology provides a strong conceptual and theoretical foundation for understanding landscape structure, function, and change (Berry, et al. 2011). It is fundamental for the survival for many wildlife to relate landscape patterns, human development, and ecological processes.

Chapter 4 – Methodology

4.1 Data Collection

Road kill occurs when vehicles collide with, or run over, wildlife resulting in millions of animals killed each week on roads in the U.S. (Wildlife and Roads, 2011). The prevalence of road kill and lack of available data led to creation of a website that allows the public to report road kill (California Road Kill Observation System (CROS)). This website records observations from reporters out in the field that come across identifiable road killed wildlife. The system then displays a summary of this information for different animal groups across the state (CROS, 2012). Road kill location data were provided from the CROS website for this study (Shilling, 2012). However, there are limitations with this data such as many of the road kill incidents that were reported are in well-traveled areas, so prejudices have to be considered with this data. Additionally, the data are from observations on a website, which allows anyone to report a road kill; however, the majority of the reporters are scientists from many accredited affiliations. Road kill data were provided in ESRI shapefile format and included information on road kill events from 1994 to present (February 2012). The shapefile consisted of 1637 road kill points. Road kill attribute data included name of species, species category, observer, zip code, date, latitude and longitude, street and road type. This data was used in ArcGIS to perform the hotspot analysis, Tabular summary of habitat characteristics, and the Spearman's rho analysis. To study the patterns in the landscape, land cover data from the U.S. Geological Survey (USGS) Seamless server was downloaded. An additional shapefile consisting of the South Coast Missing Linkages Networks was downloaded and overlayed on top of the results of the hotspot analysis.

4.2 Hotspot Analysis Using GIS

A GIS approach based on spatial autocorrelation analysis of road kill data for the identification of critical hotspots was used in this study. Spatial autocorrelation is the relationship of a variable within its surroundings or space. If that variable has an orderly pattern then it is spatially autocorrelated. Likewise, if the variable exhibits random patterns then there is no spatial autocorrelation. Spatial analysis tools, such as a Geographic Information System (GIS) provides tools that allow for the analysis of spatial information to describe wildlife movement through the landscape and identify spatial patterns and correlations (Bram, 2005). These tools can be an effective way for determining road kill hotspots, which are identified as the spatial clustering of road kills. Simple plotting of animal-vehicle collisions can be done in a variety of GIS formats. For example, ArcView or ArcGIS currently are being used by many transportation agencies (Clevenger, et al. 2001). A cluster analysis is a way of indentifying clusters of features with values in similar magnitude. One of the most popular approaches for the detection of hotspots is the cluster analysis, which can be an effective method for determining areas exhibiting elevated concentrations of road kills (Grubesic n.d.). An example of how GIS was used to protect wildlife is documented in a 2003 Before-After-Control-Impact (BACI) study. This study took place in San Diego County, as part of a road-widening project, and used mobile GIS, statistical analyses, and ArcView to collect and analyze wildlife data. The results of the study determined that there were notable hotspots of road kill and that the road-widening project would further influence wildlife, leading to the installation of undercrossings for wildlife movement in the project plan (Orth and Riley, 2005). Another study used GIS to perform a hotspot analysis using carcass data from wildlife killed on roads to investigate several hotspot identification techniques within a GIS framework that can be used in a variety of landscapes. The data from this study aided transportation managers in increasing motorist safety and habitat connectivity for wildlife by providing safe passages across busy roadways (Bissonette and Cramer, 2008).

This thesis project used GIS to identify road kill hotspots. First, a point pattern analysis was created that involves the ability to describe patterns of locations of point events. This analysis employed the Average Nearest Neighbor Analysis tool. This tool calculated the observed mean distance between each road kill event. The Average Nearest Neighbor tool measures the distance between the center of each feature and the center of its nearest neighboring feature. It then averages all these nearest neighbor distances.

After calculating the nearest neighbor distances, the greatest densities of points were determined for the road kill data. For this analysis, the Point Density Tool was utilized. This tool calculates a magnitude per unit area from point features that fall within a neighborhood around each cell (pixel) (ESRI, 2012). For this study, the neighborhood was set to circle, the radius was set to 8 cell units, and the area units used was square kilometers. This tool has a “population field” to weigh each point based on a particular observation, such as number of deaths at a specific location. However, for this study each point was treated as an individual death instead of multiple deaths at one site. Therefore, the population field was set to none and each point was only counted once. The result was raster data layer that illustrated the greatest density of road kill points. Raster datasets represent geographic features by dividing the world into discrete square or rectangular cells laid out in a grid. Each cell has a value that is used to represent some characteristic of that location.

A shapefile from the South Coast Missing Linkages Project was then added to the identified hotspot analysis to determine whether identified road kill hotspots were within the critical wildland networks. The shapefile delineated the outer-boundaries of 12 critical landscape linkages identified by the South Coast Missing Linkages Project. The South Coast Missing Linkages project was established to identify and conserve the highest priority linkages in the South Coast Ecoregion. The project designed landscape linkages that encompassed 19,435,105 acres, 94% of which are already protected lands. The linkages stitched together over 18 million acres of already protected lands such as national forests, state and national parks. The Linkage Design addresses the potential movement needs for several focal species. The project gathers the most current biological data for each linkage design to ensure the viability of the full complement of species native to the region (South Coast Wildlands, 2008).

4.3 Land cover types

To determine what type of land cover is most associated with road kill hotspots, a tabular summary of habitat characteristics was performed. The Extract Values to Points tool was used along with the Summarize tabular function to perform this analysis. The Extract Values to Points tool extracts the cell values of a raster based on a set of point features and records the values in the attribute table of an output feature class. The Summarize function calculates summary statistics, including mean, maximum, and minimum values, for numeric fields within a table. The input data used for this analysis were the raster vegetation layer and the road kill points shapefile. In addition, the land cover raster was used to generate tables to show the value of cells used to represent the characteristics of land cover for a given location.

4.4 Landscape Metrics

Landscape metrics are used in landscape ecology to measure, analyze, and interpret spatial patterns (Turner, 2005). These metrics have been used for analyzing the historical range of variability in the landscape, monitoring change, and comparing landscapes (Nonaka and Spies, 2005). Landscape metrics include indices developed for categorical map patterns, which are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (McGarigal, et al. 2002). Landscape metrics were used in this study to quantify the characteristics of landscape patterns where high-density road kill occurred. FRAGSTATS, a pattern analysis software program, was used to measure landscape patterns in the identified hotspots. FRAGSTATS is designed to compute a wide variety of landscape metrics for categorical map patterns by quantifying the areal extent and spatial configuration of patches within a landscape. FRAGSTATS computes three groups of metrics: 1) patch level metrics which look at each patch in the mosaic, 2) class level metrics which look at each patch type in the mosaic, and 3) landscape level metrics which look at the landscape mosaic as a whole.

To analyze the landscape pattern at both the class and landscape levels at road kill hotspot locations, this study focused on the land cover within each identified hotspot. This was achieved by clipping the land cover layer to the boundaries of the hotspots. For these analyses, the following variables were measured, 1) at the class level: Class Area (CA), Largest Patch Index (LPI), Percent of Landscape (PLAND), Number of Patches

(NP), Patch Density (PD), Interspersion and Juxtaposition Index (IJI), and Cohesion, and 2) the landscape level: Number of Patches, Patch Density (Mean Patch Size), Interspersion and Juxtaposition Index, Patch Richness (PR), and Simpson's Evenness Index (SIEI).

Using the results from the landscape metrics analysis, The Spearman Rank Correlation Coefficient was employed to evaluate the relationship between density of road kill and each mosaic. Spearman Rank Correlation Coefficient (rs) is non-parametric; it uses ranks to calculate correlation. It assesses the correlation between two variables with resulting correlations ranging in value from -1 to +1. If rs = 1.0 then there is a perfect positive correlation, however a -1.0 means there is a perfect negative correlation. When no association exists between variables, rs = 0.0 (McGrew, et al. 2000). A perfect positive correlation means that the two variables tend to increase or decrease together. While a perfect negative correlation means one variable increases as the other decreases. This study uses non-parametric analysis because the observations are not normally distributed, meaning the road kill points do not have the same variances. Instead, the road kill points are independent.

The following information for each metric description was obtained from the UMass Landscape Ecology Lab website (McGarigal, et al. 2000). The first is the Class Area (CA). The CA equals the sum of the areas (m^2) of all patches of the corresponding patch type. This metric is a measure of landscape composition; specifically, how much of the landscape is comprised of a particular patch type. PLAND equals the percentage of the landscape comprised of the corresponding patch type. This metric quantifies the proportional abundance of each patch type in the landscape. NP equals the number of patches of the corresponding patch type (class). This metric counts the number of patches for every class type. LPI metric quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance. The fifth metric is the Interspersion and Juxtaposition Index (IJI). IJI is measured as a percentage and is the observed between patch types interspersion over the maximum possible interspersion for the given number of patch types. This metric measures the extent to which patch types are interspersed. The sixth metric, Cohesion measures how connected patches are to one another. PD is calculated as the number of patches in the landscape, divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). PD has the same basic utility as NP as an index, except that it expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. The eighth metric is Patch Richness. PR equals the number of different patch types present within the landscape boundary divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). The final metric is Simpson's Evenness Index (SIEI). SIEI is equal to zero when the landscape contains only 1 patch (no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven (dominated by 1 type). SIEI equals one when the distribution of area among patch types is perfectly even (proportional abundances are the same). These metrics were chosen for this study to determine the landscape patterns for road kill in the identified hotspot locations. In addition, these metrics determined how the landscape patterns were arranged in the eight hotspots such as being adjacent to like patches, the connectivity of like patches, land cover types scattered evenly or poorly, and the number of patches for each land cover type.

Chapter 5 – Results

5.1 Average Nearest Neighbor Summary

The Average Nearest Neighbor Summary analysis evaluated, quantified, and compared the spatial distribution of road kill sites within a fixed study area, in this case Southern California. The results from this analysis are the calculated mean distances. The observed mean distance is the actual average distance between each point and the closest neighboring point (Table 2). The data used to create the Nearest Neighbor calculation was the road kill shapefile. Euclidean distance was used for the method and the study area is a rectangle that encompasses all of the road kill points in each county (Table 3). The observed mean distances for each of the counties are: 1) Los Angeles County 2038.54 in an area of 13289052573.15 meters, 2) San Diego County 416.46 in an area 12127969499.25 meters, and 3) Ventura County 1450.74 in an area of 2901836508.93.

Table 2: Average Nearest Neighbor Summary.

Observed Mean Distance	
Los Angeles County	**2038.54**
San Diego County	**416.46**
Ventura County	**1450.74**

Table 3: Size of each county in meters.

Study Area in meters	
Los Angeles County	**13289052573.15**
San Diego County	**12127969499.25**
Ventura County	**2901836508.93**

5.2 Point Density

A map of San Diego, Los Angeles, and Ventura Counties was created displaying road kill points prior to the Point Density analysis (Figure 4). The map clearly illustrates high concentrations of road kill in San Diego County, Los Angeles, and southern Ventura County. To confirm this observation, the Point Density Analysis was performed. The raster-based surface result of the analysis displayed confirmation of where point features are clustered and where the density of road kill is greatest in the study area (Figure 5). In specific, eight significant hotspots were detected. A ninth hotspot near the eastern border of San Diego County was not included as the majority of the cluster stretched into areas with largely private federal lands and rural roads, therefore outside the study area for this project. Of note, San Diego County exhibited the greatest density of clustering across the study area (Figure 6). The most concentrated areas in San Diego County involved three major Interstate Highways (Interstates 15, 8, and 5), three California State Highways (CA 67,163, and 94), in addition to numerous minor road networks. For this study, the hotspot in western San Diego Counties were selected for the subsequent land cover analysis. The results for Los Angeles and Ventura Counties show a high concentration of road kill points near the 14 freeway, State Highway 1 and 126 and U.S. Highway 101 (Figure 7). The hotspots range in area size (Table 4) from the moderate, as in central San Diego County near Interstate 5 (Hotspot 6 -256.68 km^2) to the very large, as with the hotspot in south central San Diego County (Hotspot 8 – 967.67^2 km). Additional hotspot sizes include, Hotspot 1 near Highway 126 at 406.48 km^2, Hotspot 2 near the 101 freeway at 346.13 km^2, both in Ventura County, Hotspot 3 near Highway 14 at 369.07 km, and

Hotspot 4 at 281.18 km², both in Los Angeles County, and Hotspot 5 at 376.69 km², and Hotspot 7 at 805.68 km² in San Diego County.

Table 4: Hotspot area size comparisons.

ID	**Description**	**Area Size (km^2)**
1	**Western Ventura County**	**406.48**
2	**Southern Ventura County**	**346.13**
3	**Northern Los Angeles County**	**369.07**
4	**Southern Los Angeles County**	**281.18**
5	**Northern San Diego County**	**376.69**
6	**Central San Diego County**	**256.68**
7	**South Central San Diego County**	**967.76**
8	**Southern San Diego County**	**805.68**

Figure 4: Road kill points in Southern California.

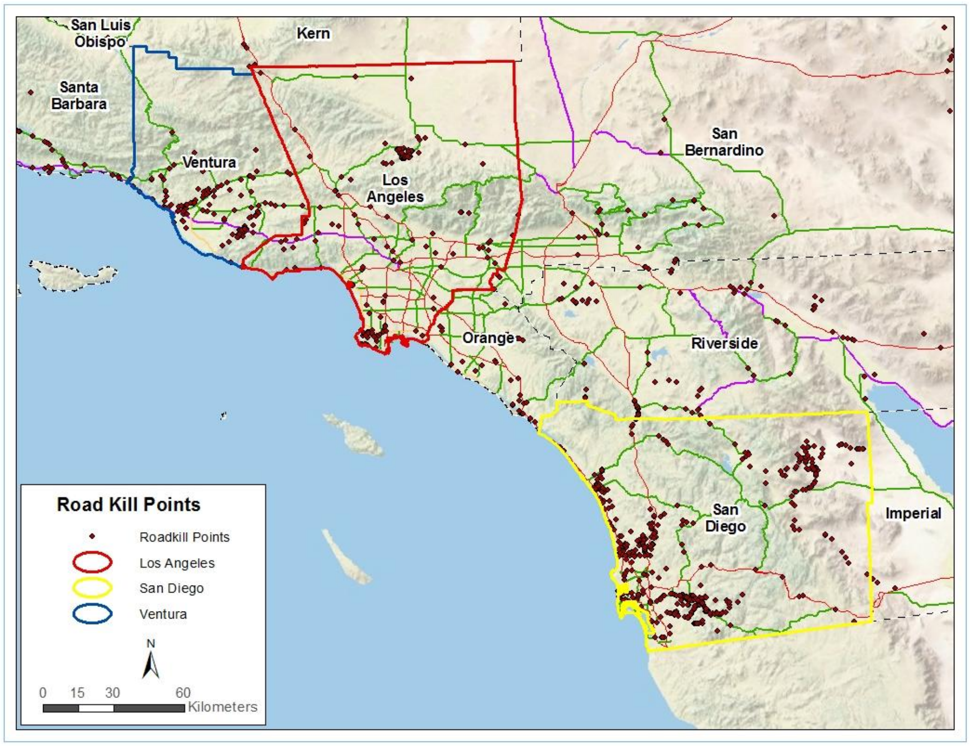


Figure 5: Results from the Point Density tool showing areas of high concentration of road kills.

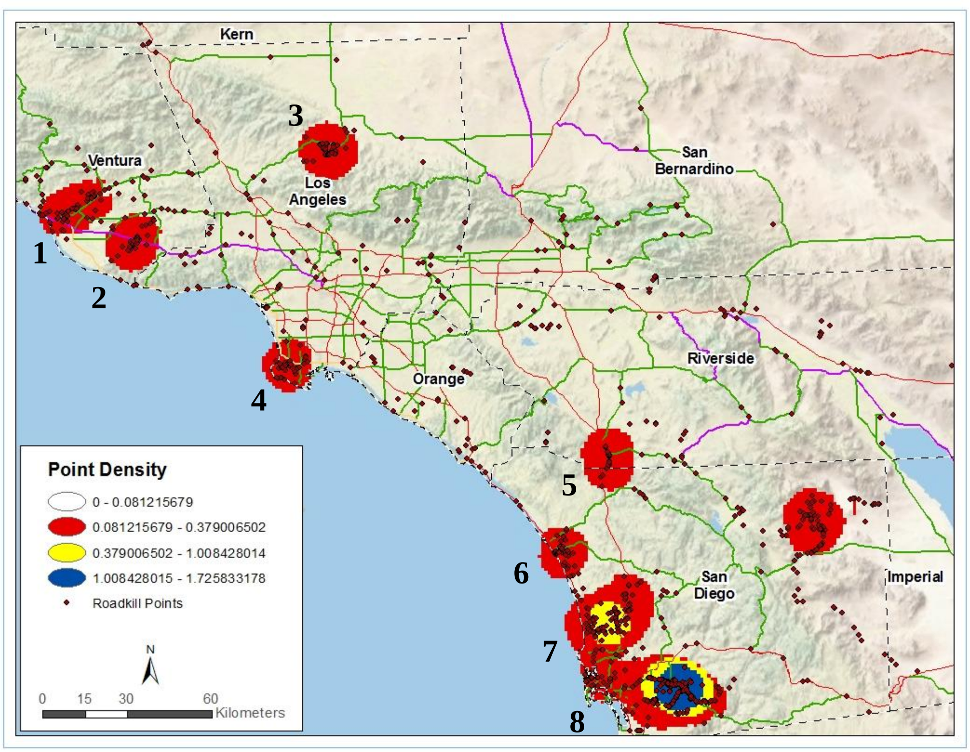


Figure 6: Point Density Results for San Diego County.

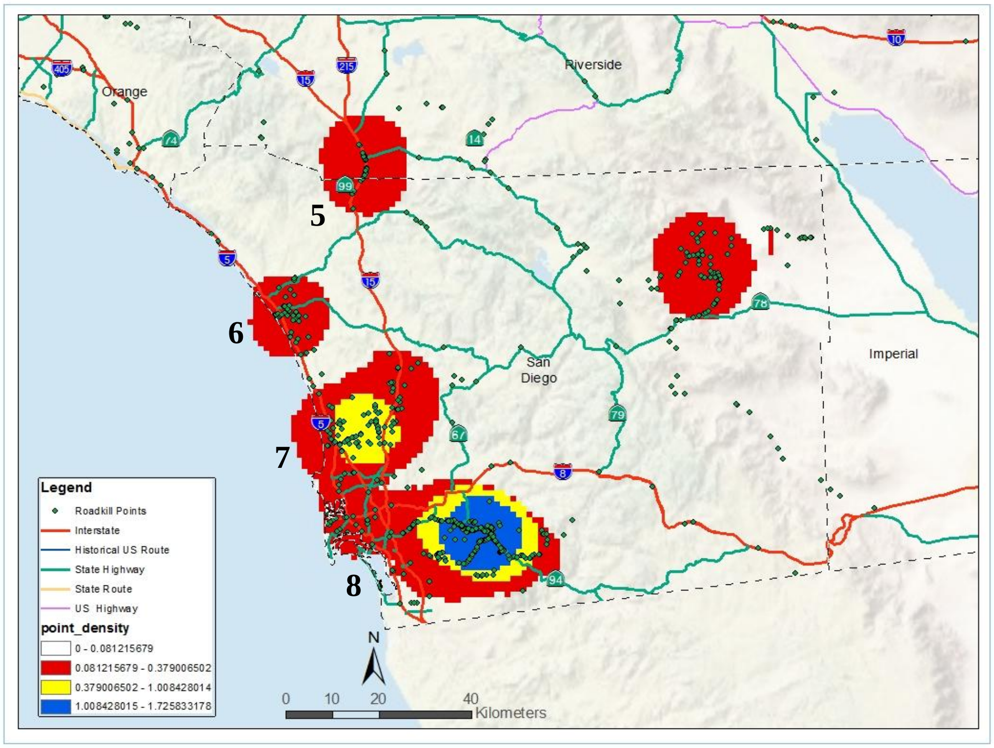
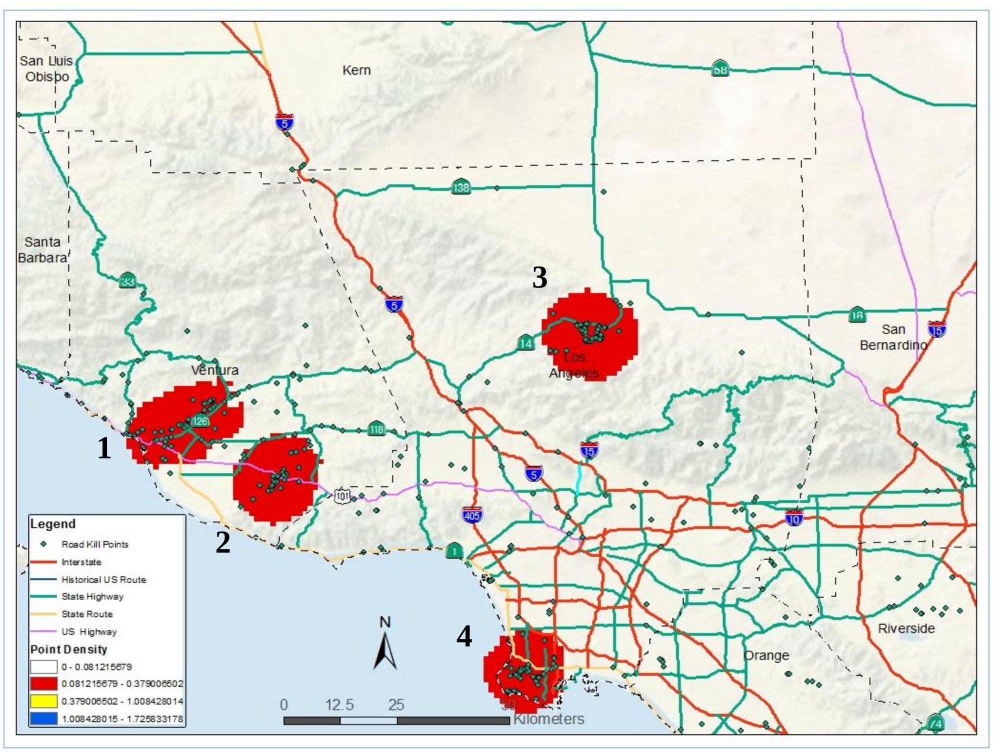


Figure 7: Point Density results for Los Angeles and Ventura Counties.



5.3 Tabular summary of habitat characteristics

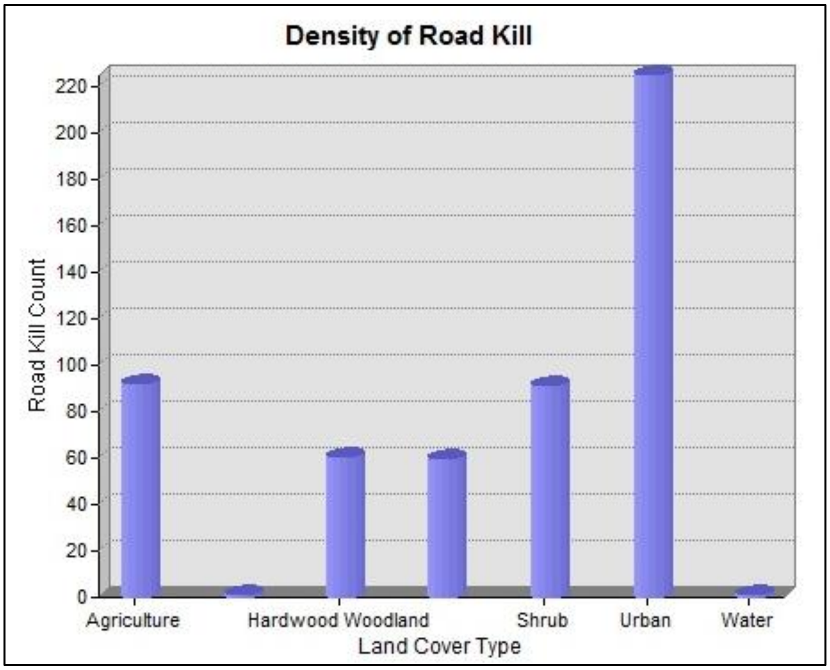
The results from The Extract values to Points tool is a point feature class that contains the values for each raster cell where a point is present coincidentally in space, appended to the attribute table as a land cover attribute field. By summarizing this field, the number of road kill in each land cover type was determined (Table 5). The results show the land cover types in each of the eight hotspots and then depict the amount of road kill per land cover type. There are 1,105 road kills in the eight hot spot locations. The highest concentration of road kill are in the urban areas with 676 (61%) followed by 128 (12%) incidents in the agricultural locations and 126 (11%) in shrub. The rest of the points are distributed unevenly throughout the other land cover types. The identified hotspot in southern Ventura County is the exception compared to the seven other hotspots. Here the majority of the road kill occurred in the agriculture land cover type. Hotspot 7 also shows a high number of road kill events in agriculture areas, however the highest number of incidents in this location occurred in the urban areas.

Table 5: The number of road kills per land cover type.

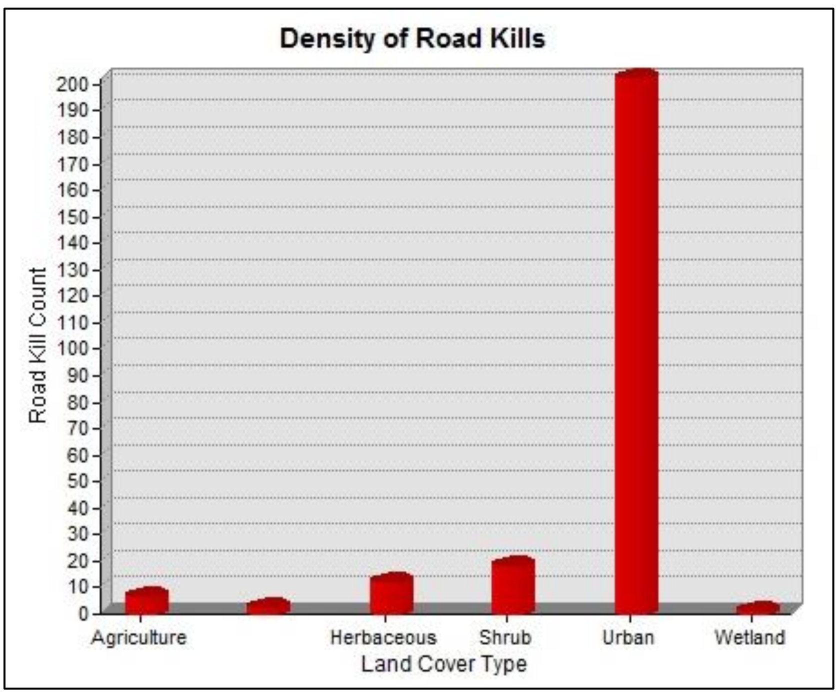
	Agriculture	Barren/ Other	Conifer Forest	Desert Shrub	Hardwood Forest	Hardwood Woodland	Herbaceous	Shrub	Urban	Wetland	Water	Total
Hotspot 1	**x**	**x**	**x**	**x**	**x**	**x**	**2**	**5**	**64**	**x**	**x**	**71**
Hotspot 2	**2**	**x**	**x**	**x**	**x**	**1**	**1**	**1**	**32**	**x**	**2**	**39**
Hotspot 3	**6**	**x**	**x**	**x**	**x**	**2**	**12**	**18**	**202**	**1**	**x**	**241**
Hotspot 4	**92**	**x**	**1**	**x**	**x**	**60**	**59**	**91**	**225**	**x**	**1**	**529**
Hotspot 5	**x**	**x**	**6**	**21**	**x**	**x**	**x**	**3**	**48**	**x**	**x**	**78**
Hotspot 6	**x**	**x**	**x**	**x**	**x**	**x**	**1**	**2**	**40**	**x**	**x**	**43**
Hotspot 7	**3**	**x**	**x**	**x**	**1**	**x**	**x**	**3**	**44**	**x**	**x**	**51**
Hotspot 8	**25**	**1**	**x**	**x**	**2**	**1**	**x**	**3**	**x**	**x**	**x**	**32**

Using the information from (Table 5), graphs were created for each of the eight hotspots to summarize results for road kill in specific land cover types. There are four hotspots within San Diego County. The largest of these hotspots, Hotspot 8 in southern San Diego County, contained 529 road kill incidents (Graph 1). The land cover with the highest road kill events in Hotspot 8 was urban with 225 road kill incidents (43%), followed by agriculture with 92 road kill (17%). The next hotspot , Hotspot 7, contained a total number of road kill incidents of 241 (Graph 2). Again, the highest concentration of road kills at this location were in urban landscapes and accounted for 202 road kill sites (84%). Hotspot 6, also located on the coast in central San Diego County, had 39 road kill incidents (Graph 3). Like the other centrally located hotspot in San Diego County, urban was the main land cover type in Hotspot 6, consisting of 32 total incidents (82%). The final hotspot, Hotspot 5, had 71 road kill incidents incorporating only three land cover types (Graph 4). Once more, like the other three hotspots in San Diego County, the highest concentrations of road kill were predominately in the urban land cover type (64 total incidents, 90%).

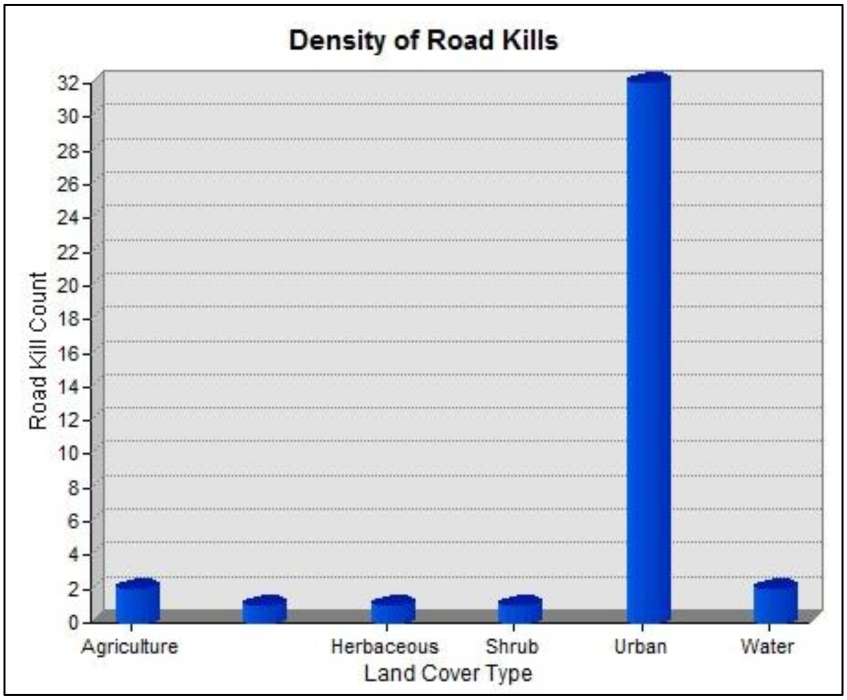
Graph 1: Land cover composition at Hotspot 8



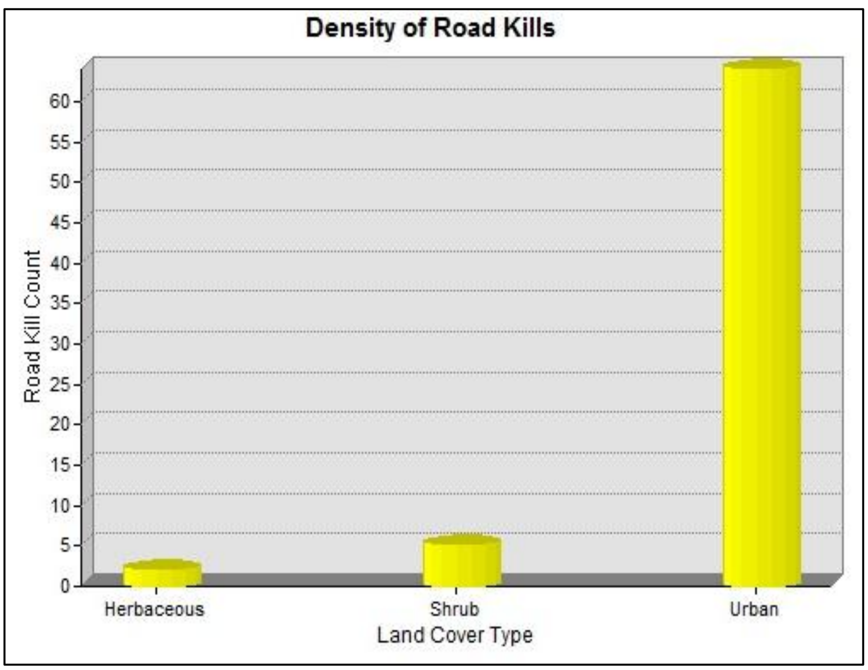
Graph 2: Land cover composition at Hotspot 7.



Graph 3: Land cover composition at Hotspot 6.

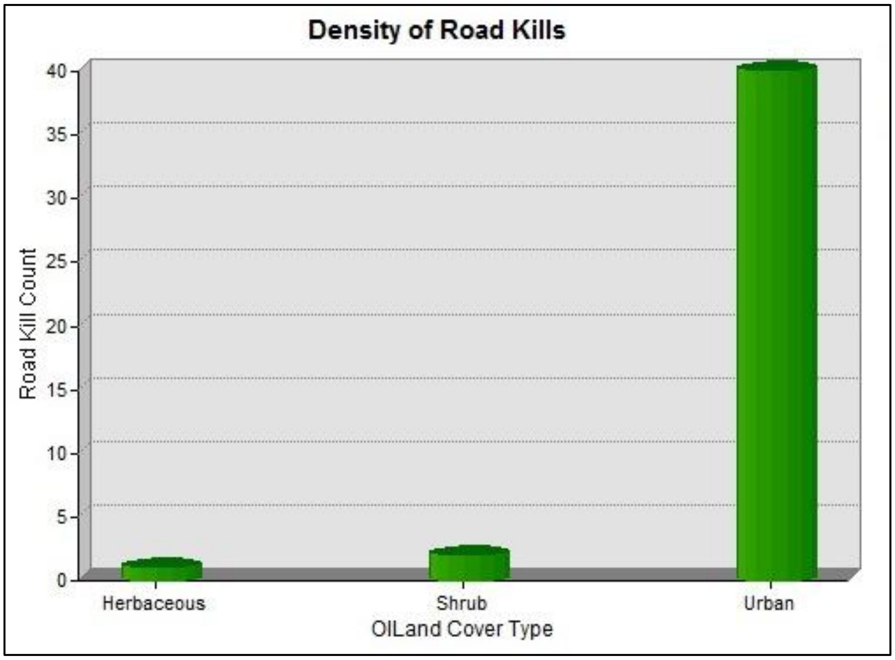


Graph 4: Land cover composition at Hotspot 5.

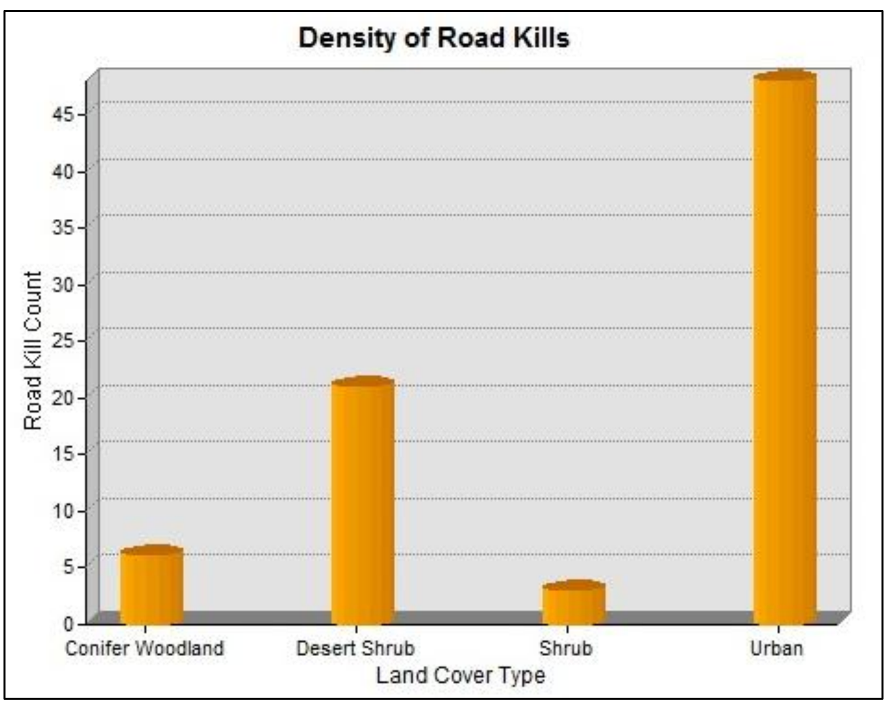


Looking at the results for Los Angeles and Ventura Counties, there are four hotspots, two located in Los Angeles County and two in Ventura County. Hotspot 4 in south Los Angeles County contained 43 road kill incidents, 40 (93%) of which occurred in the urban land cover type (Graph 5). this Hotspot 3 (Graph 6) there were 78 road kill incidents, most occurring in urban land cover (48 incidents, 62%). Hotspot 2 (Graph 7), in Ventura County near the busy 101 freeway, reported 44 (86%) road kill events in urban land cover. Conversely, Hotspot 1 (Graph 8) reported the highest concentrations of road kills not within the urban land cover type. Here, the highest road kill incidents were located in the agriculture land cover type (25 incidents, 47%), followed by 21 (40%) incidents in the urban land cover.

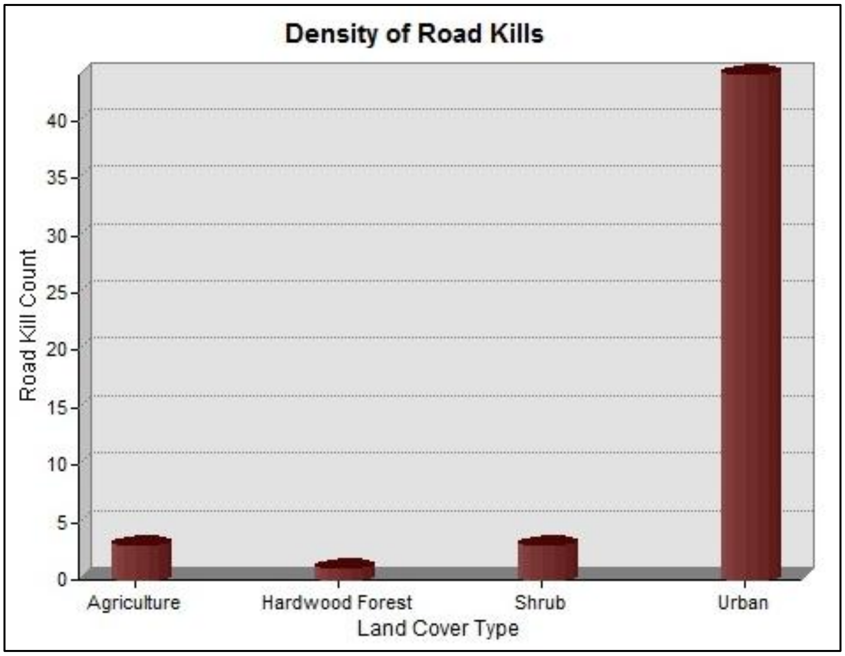
Graph 4: Land cover composition at Hotspot 4.



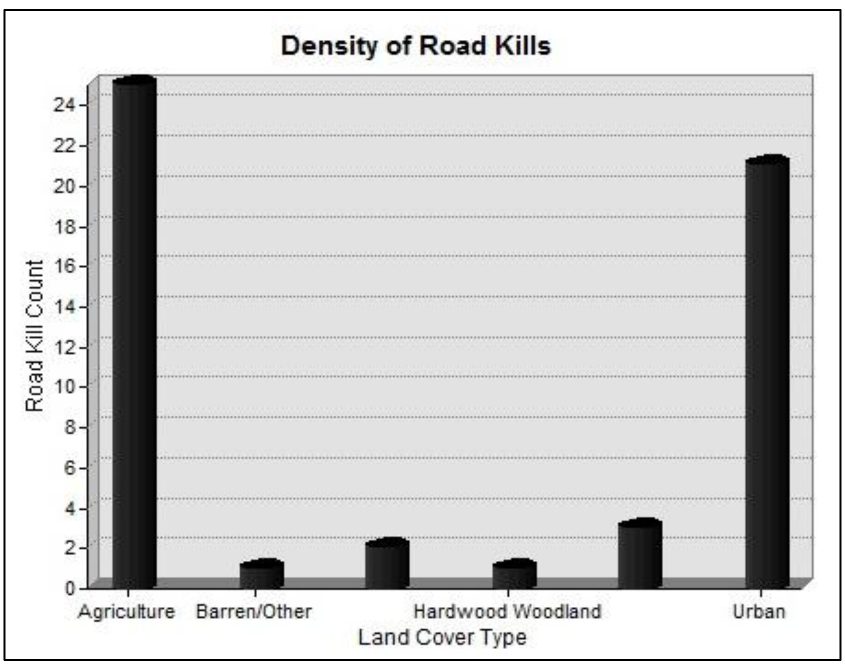
Graph 5: Land cover composition at Hotspot 3.



Graph 6: Land cover composition at Hotspot 2.



Graph 7: Land cover composition at Hotspot 1.



5.4 Class Level Metrics

To determine the type of landscape patterns in the identified hotspot areas, seven different metrics at the class level were studied. This was achieved by using the clipped land cover raster layers for the identified hotspot locations in San Diego, Los Angeles, and Ventura Counties. Eight tables were created displaying the results. The data are arranged in alphabetical order using the land cover type field.

The results for this analysis showed many similarities between the eight hotspots and some differences as well. The most common result among the hotspots was the high values for urban land cover. These data correlate with the density of road kill analysis (Graphs 1-8), finding that road kill occurs most often in urban areas. On the other hand, there are some differences especially in two hotspots. The first is in northern Los Angeles County near the 14 Freeway (Hotspot 3) and the second is in south Ventura County near State Highway 126 (Hotspot 1). First, the Hotspot 3 land cover is dominated by desert shrub and shrub. In addition, desert shrub and shrub land cover types tend to be highly connected and evenly scattered. Yet road kill events for this area were found to occur in the urban land cover 62% of the time. Urban land cover makes up only 16% in this hotspot while shrub and desert shrub make up 68% of the land cover types. Hotspot 1, however, is dominated by agriculture land cover (33%) Nevertheless, this is consistent with the density of road kill analysis (Graph 8).

5.4a San Diego County

Hotspot 7, in central San Diego County, reveals that percent of landscape (PLAND), largest patch Index (LPI), and cohesion (connectivity) have the highest values for the identified urban patches (Table 6). In this location, the number of patches (NP) is dominated by shrub and this is true for patch density (PD) as well. The interspersion and juxtaposition index (IJI) reveals that hardwood woodland has the highest value. This means that this patch type is scattered most evenly when compared to all the land cover types. Whereas the patch type with the lowest value is desert shrub, which indicates that this patch type is poorly interspersed. The other hotspot on the central coast in San Diego County, Hotspot 6, also has urban with the highest values for PLAND, LPI, and cohesion (Table 8). Again, the same results for NP and PD as Hotspot 7 reveal that shrub has the highest value. However, the difference between these two areas is in the value for IJI. Urban is more evenly scattered while barren/other has a value of 0, meaning there is no scattering with this land cover. Hotspot 5, in northern San Diego County near Interstate 15 (Table 7), shows that shrub has the highest value for PLAND, LPI, and cohesion in this area. The NP measures reveal that hardwood woodland has the highest value and the least NP is desert shrub. The IJI surprisingly reveals that water patches are scattered more evenly and wetlands are poorly interspersed. The results for Hotspot 8, located in southern San Diego County near California State Highway 94 (Table 9), shows that urban has the highest values for LPI, while shrub has the highest values for PLAND, IJI, and cohesion. Hardwood woodland has the highest values for NP and PD; however, hardwood woodland has the third lowest value for connectivity.

Therefore, most of the landscapes in the hotspots in central San Diego County (Hotspots 6 & 7) are comprised of urban patches. In addition, the urban patches in central San Diego County encompassed by the largest patch, which also is the most, connected land cover type. Although the data does not show urban as having the highest count for

NP and PD however, this could mean that there are smaller individual patches of shrub that do not cover as much land as urban patches. In the other two hotspot locations (Hotspots 5 & 8), one in northern San Diego County and the other in Southern San Diego County, reveal that shrub comprises much of the landscape. However, urban patches still comprise the second largest portion of the landscape in these hotspots. The amount of road kill events in all four hotspots in San Diego County are mostly occurring in urban areas (Graphs 1-4), this could be due to the uneven patch types in which wildlife have to navigate, ultimately increasing the chances of wildlife being hit on a road.

5.4b Los Angeles

The PLAND, and PD metrics reveal that desert shrub has the highest values for the identified patches in Hotspot 3 (Table 10). The highest value for NP for this hotspot area is conifer woodland and this is true for PD as well. For the patches that are most evenly scattered (IJI), shrub shows the highest values while desert woodland has the lowest value. Shrub has the highest values for LPI and cohesion as well. Most of the landscape in this hotspot is dominated by shrub patches, however, there are also many urban patches of land that encompass this area. Like the hotspots in San Diego, there are many different land cover types that make up this area and wildlife must navigate their way through, lowering their chances of doing so safely. Hotspot 4 shows that urban has the highest values for PLAND, LPI, IJI, and cohesion (Table 11). For the number of patches (NP) and patch density (PD), shrub is the dominant land cover. The results from this hotspot make sense as to why there are so many road kill incidents in urban land cover as this area is comprised mostly of urban patches. Not only is this hotspot made up of mostly urban, the urban patches are scattered evenly in this location (revealed by the IJI metrics).

5.4c Ventura County

The FRAGSTAT results for Ventura show that urban areas have the second highest values for PLAND, LPI, and cohesion. The land cover with the highest values for NP and PD is hardwood woodland. The results for Hotspot 1 reveal that for PLAND, LPI, and cohesion, agriculture has the highest values (Table 13). The land cover with the highest values for NP and PD is herbaceous. The IJI results show that barren/other are most evenly scattered in this hotspot location, while herbaceous is poorly interspersed. The data for this area coincides with the tabular characteristic charts, which show that road kill events occur in agricultural areas most and urban second (Graph 8). This location is dominated by agriculture but poorly scattered with urban patches; consequently, road kill incidents tend to increase as wildlife try to move through this complex landscape.

Table 6: FRAGSTATS results for Hotspot 7 in San Diego County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	**3261.78**	**3.9544**	**90**	**0.1091**	**0.759**	**61.1887**	**90.7712**
Barren/Other	**49.3319**	**0.0598**	**21**	**0.0255**	**0.01**	**53.945**	**36.0019**
Desert Shrub	**3.5237**	**0.0043**	**2**	**0.0024**	**0.0028**	**49.558**	**19.9811**
Hardwood Woodland	**1038.32**	**1.2588**	**235**	**0.2849**	**0.057**	**64.1607**	**60.616**
Herbaceous	**4812.21**	**5.834**	**239**	**0.2897**	**2.7938**	**56.7199**	**93.0603**
Shrub	**17127.6**	**20.7644**	**262**	**0.3176**	**5.5521**	**60.0331**	**96.7748**
Urban	**54891.1**	**66.5466**	**129**	**0.1564**	**63.1917**	**60.0132**	**99.7987**
Water	**794.008**	**0.9626**	**73**	**0.0885**	**0.3802**	**65.8496**	**84.5461**
Wetland	**454.558**	**0.5511**	**37**	**0.0449**	**0.215**	**80.3065**	**83.0203**

Table 7: FRAGSTATS results for Hotspot 5 in San Diego County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	**8988.15**	**23.8586**	**114**	**0.3026**	**6.9129**	**61.6383**	**97.1729**
Barren/Other	**100.946**	**0.268**	**16**	**0.0425**	**0.1462**	**69.5**	**75.6603**
Desert Shrub	**51.1286**	**0.1357**	**4**	**0.0106**	**0.1079**	**72.5071**	**84.7219**
Hardwood Woodland	**1571.22**	**4.1707**	**300**	**0.7963**	**0.254**	**56.1274**	**77.3836**
Herbaceous	**4399.68**	**11.6787**	**253**	**0.6716**	**3.0084**	**65.1274**	**94.3414**
Shrub	**15174.1**	**40.2787**	**197**	**0.5229**	**18.9275**	**66.6688**	**98.7068**
Urban	**7322.54**	**19.4373**	**207**	**0.5495**	**15.6598**	**63.3362**	**98.2655**
Water	**52.4396**	**0.1392**	**20**	**0.0531**	**0.0296**	**75.575**	**57.5894**
Wetland	**12.4544**	**0.0331**	**5**	**0.0133**	**0.0104**	**43.1913**	**49.8201**

Table 8: FRAGSTATS results for Hotspot 6 in San Diego County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	**1095.001**	**6.0648**	**33**	**0.1828**	**1.7084**	**58.9721**	**94.4456**
Barren/Other	**8.2658**	**0.0458**	**3**	**0.0166**	**0.0169**	**0**	**60.7925**
Desert Shrub	**1.3051**	**0.0072**	**2**	**0.0111**	**0.0048**	**41.721**	**20.0039**
Hardwood Woodland	**291.9132**	**1.6168**	**61**	**0.3379**	**0.1976**	**74.2157**	**78.5622**
Herbaceous	**706.9433**	**3.9155**	**69**	**0.3822**	**0.5373**	**59.7644**	**86.654**
Shrub	**1528.303**	**8.4647**	**77**	**0.4265**	**2.0023**	**68.1438**	**93.3248**
Urban	**13947.88**	**77.2517**	**16**	**0.0886**	**75.4662**	**77.1104**	**99.8696**
Water	**403.284**	**2.2336**	**22**	**0.1218**	**0.7879**	**59.9022**	**91.4461**
Wetland	**72.217**	**0.4**	**18**	**0.0997**	**0.1711**	**77.0273**	**77.6749**

Table 9: FRAGSTATS results for Hotspot 8 in San Diego County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	**4205.076**	**5.2207**	**68**	**0.0844**	**3.1561**	**58.5178**	**95.733**
Barren/Other	**19.0562**	**0.0237**	**7**	**0.0087**	**0.0063**	**21.4014**	**35.9527**
Conifer Forest	**1143.374**	**1.4195**	**45**	**0.0559**	**0.4621**	**1.4638**	**91.4051**
Desert Shrub	**175.3174**	**0.2177**	**2**	**0.0025**	**0.1451**	**63.0064**	**88.7052**
Hardwood Woodland	**2117.783**	**2.6293**	**326**	**0.4047**	**0.2776**	**43.481**	**73.3807**
Herbaceous	**3150.631**	**3.9115**	**174**	**0.216**	**0.7208**	**57.3252**	**85.9215**
Shrub	**34916.11**	**43.3488**	**101**	**0.1254**	**38.8095**	**77.002**	**99.5781**
Urban	**33688.89**	**41.8252**	**150**	**0.1862**	**39.1865**	**55.1849**	**99.2722**
Water	**1069.69**	**1.328**	**26**	**0.0323**	**0.5946**	**56.0193**	**92.1333**
Wetland	**60.98**	**0.0757**	**9**	**0.0112**	**0.0268**	**56.6855**	**65.7531**

Table 10: FRAGSTATS results for Hotspot 3 in Los Angeles County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	135.218	0.3664	12	0.0325	0.0996	66.0387	77.6186
Barren/Other	146.241	0.3963	42	0.1138	0.0577	66.2991	61.9543
Conifer Forest	974.452	2.6404	26	0.0704	1.5193	29.8743	95.0051
Conifer Woodland	6135.52	16.6249	189	0.5121	4.0562	46.0116	95.1881
Desert Shrub	12836.2	34.781	172	0.4661	17.2202	63.3413	98.7228
Desert Woodland	72.7532	0.1971	3	0.0081	0.1932	19.8003	89.6524
Hardwood Forest	631.997	1.7125	100	0.271	0.2668	53.6992	78.5222
Hardwood Woodland	162.409	0.4401	47	0.1274	0.0398	50.178	62.3934
Herbaceous	1277.22	3.4608	157	0.4254	0.7288	54.0897	84.2632
Shrub	12137.3	32.8873	166	0.4498	28.4329	69.4977	99.0807
Urban	2396.45	6.4934	110	0.2981	1.583	59.0377	91.6579

Table 11: FRAGSTATS results for Hotspot 4 in Los Angeles County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	14.3734	0.0767	5	0.0267	0.0329	64.1902	66.9645
Barren/Other	55.4402	0.2958	11	0.0587	0.1578	37.8844	77.252
Desert Shrub	88.2937	0.4711	14	0.0747	0.1643	61.6534	80.2405
Hardwood Woodland	80.491	0.4295	10	0.0534	0.1249	25.6856	81.2715
Herbaceous	523.602	2.7938	62	0.3308	0.4251	45.5845	86.6545
Shrub	735.917	3.9267	66	0.3522	0.8414	49.2169	89.431
Urban	17196.3	91.7565	13	0.0694	91.2197	66.3686	99.9413
Water	46.8162	0.2498	25	0.1334	0.1096	61.9871	65.5021

Table 12: FRAGSTATS results for Hotspot 2 in Ventura County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	**5987.32**	**17.2991**	**36**	**0.104**	**8.9743**	**66.7003**	**98.1793**
Barren/Other	**191.426**	**0.5531**	**50**	**0.1445**	**0.0624**	**41.8592**	**69.1184**
Hardwood Forest	**456.335**	**1.3185**	**95**	**0.2745**	**0.1142**	**60.8951**	**74.2623**
Hardwood Woodland	**855.243**	**2.4711**	**114**	**0.3294**	**0.6869**	**51.2036**	**84.4066**
Herbaceous	**1325.78**	**3.8306**	**105**	**0.3034**	**0.9117**	**65.2354**	**86.9871**
Shrub	**15047.3**	**43.4762**	**46**	**0.1329**	**41.8616**	**87.8419**	**99.6788**
Urban	**10649.5**	**30.7695**	**70**	**0.2023**	**17.4454**	**65.9007**	**98.6191**
Water	**97.5656**	**0.2819**	**13**	**0.0376**	**0.1963**	**72.2326**	**83.8947**

Table 13: FRAGSTATS results for Hotspot 1 in Ventura County.

TYPE	CA	PLAND	NP	PD	LPI	IJI	COHESION
Agriculture	**12806**	**33.4446**	**58**	**0.1515**	**13.2619**	**70.2027**	**98.5712**
Barren/Other	**667.272**	**1.7427**	**76**	**0.1985**	**0.5662**	**86.0115**	**85.7406**
Hardwood Forest	**652.574**	**1.7043**	**54**	**0.141**	**0.2802**	**84.3727**	**85.7435**
Hardwood Woodland	**1279.43**	**3.3414**	**154**	**0.4022**	**0.3224**	**59.5303**	**82.3541**
Herbaceous	**3114.42**	**8.1337**	**221**	**0.5772**	**1.7599**	**46.3909**	**92.837**
Shrub	**8942.03**	**23.3533**	**136**	**0.3552**	**8.7345**	**68.0207**	**98.039**
Urban	**10654.3**	**27.8251**	**57**	**0.1489**	**13.2351**	**65.1917**	**98.1899**
Water	**138.892**	**0.3627**	**19**	**0.0496**	**0.1075**	**71.9454**	**77.6314**
Wetland	**35.2743**	**0.0921**	**8**	**0.0209**	**0.023**	**71.0297**	**61.9796**

5.5 Landscape Level Metrics

FRAGSTATS was used to compare the correlation between the density of road kills in the identified eight hotspots to the land cover type at the landscape level metrics (Table 14). The results for the bivariate data between density and the five metrics determined the type of correlation between the two variables. NP and PR have a positive correlation with density while SIEI has a negative correlation with density. However, PD has no significant correlation with density. This is interesting because PD is usually correlated more strongly with NP, and NP and Density have high correlations in this dataset. This may be due to the fact that the total of landscape area in each of the hotspots differ, resulting in patch density conflicting between landscapes.

Table 14: Results from the FRAGSTATS density correlation analysis.

Hotspots	NP	PD	IJI	PR	SIEI	DENSITY
Hotspot 1	**783**	**2.0449**	**69.6033**	**9**	**1.125**	**53**
Hotspot 2	**529**	**1.5284**	**73.1903**	**8**	**1.1429**	**51**
Hotspot 3	**1024**	**2.7746**	**60.8338**	**11**	**1.1**	**78**
Hotspot 4	**206**	**1.0992**	**55.6599**	**8**	**1.1429**	**43**
Hotspot 5	**1116**	**2.9624**	**63.2659**	**9**	**1.125**	**71**
Hotspot 6	**301**	**1.6671**	**68.5862**	**9**	**1.125**	**39**
Hotspot 7	**1092**	**1.3239**	**59.9786**	**10**	**1.1111**	**233**
Hotspot 8	**908**	**1.1273**	**61.5065**	**10**	**1.1111**	**529**

The density of road kill is strongly correlated with NP, and PR (Table 15). Though these two metrics were moderately correlated with each other, they measure two different, but related aspects of landscape composition that may be affecting road kill occurrence. As the number (NP) and types of patches (PR) increase, road kill events also increase. This may be due to a fragmented landscape that wildlife have many patches of different types they must navigate, thus increasing the need for them to move across the landscape and the probability of being hit on a road. There is a complementary negative relationship between road kill density and landscape evenness (SIEI) (Table 15). As the number of patches and types of patches increase, a decrease in patch evenness might be expected as the landscape is increasingly fragmented. It becomes more likely that the landscape is unevenly divided amongst diverse types of land cover, typically with Urban land cover types dominating these landscapes of high road kill density. While the relationship is not strong, there is a weak negative relationship between patch type intermixing (IJI) and road kill density. Again, as landscapes are divided into more patches of differing types in primarily urban settings, those patches tend to be spatially segregated. In landscapes where many patches are segregated into separate areas, road kill may tend to increase as wildlife attempt to negotiate complex the landscape. On the other hand, if these patches are more evenly distributed and intermixed, road kill may be less likely.

Table 15: Spearman's rho results.

		NP	PD	IJI	PR	SIEI	DENSITY sq km
NP	Correlation Coefficient	1.000	.524	-.119	.642	-.642	.762*
	Sig. (2-tailed)	.	.183	.779	.086	.086	.028
	N	8	8	8	8	8	8
PD	Correlation Coefficient	.524	1.000	.429	.247	-.247	.000
	Sig. (2-tailed)	.183	.	.289	.555	.555	1.000
	N	8	8	8	8	8	8
IJI	Correlation Coefficient	-.119	.429	1.000	-.334	.334	-.310
	Sig. (2-tailed)	.779	.289	.	.419	.419	.456
	N	8	8	8	8	8	8
PR	Correlation Coefficient	.642	.247	-.334	1.000	-1.000**	.766*
	Sig. (2-tailed)	.086	.555	.419	.	.	.027
	N	8	8	8	8	8	8
SIEI	Correlation Coefficient	-.642	-.247	.334	-1.000**	1.000	-.766*
	Sig. (2-tailed)	.086	.555	.419	.	.	.027
	N	8	8	8	8	8	8
DENSITY	Correlation Coefficient	.762*	.000	-.310	.766*	-.766*	1.000
	Sig. (2-tailed)	.028	1.000	.456	.027	.027	.
	N	8	8	8	8	8	8

5.6 Species Categorized

Table 16 shows each species listed by their common name and number of incidents per species in Southern California. As the table indicates, there are a variety of road kill from very small to large animals as well as birds and reptiles. Rabbits were the most frequently killed animals (344, 21%) followed by snakes, birds, squirrels, and coyotes. Even though the data for smaller wildlife such as frogs and gophers is minimal throughout the region, however the data being reported is only what is observed. The information is particularly biased against the observation of these smaller species because fewer people would note them in the road compared to larger species as bear, sheep, or coyote.

Table 16: Road kill count by common name.

Common Name	**Number**
Badger	**3**
Black Bear	**2**
Big Horn Sheep	**1**
Bird	**127**
Bob Cat	**13**
Coyote	**81**
Deer	**11**
Fox	**52**
Frog	**5**
Gopher	**3**
Lizard	**36**
Mountain Lion	**3**
Mouse	**18**
Opossum	**111**
Rabbit	**334**
Raccoon	**102**
Rat	**26**
Skunk	**104**
Snake	**162**
Squirrel	**122**
Weasel	**6**
Unknown	**266**

5.7 Land Cover Results

The attribute table from the raster layer for each hotspot area was used to generate data to show the makeup of the landscape in each hotspot location (Tables 17). Three out of the eight hotspots show that the land cover types for urban has the highest number of cells. Two of these areas are located in San Diego County (Hotspots 7 & 8) and the other is near State Highway 1 (Hotspot 4) in South Los Angeles County. Four out of the eight hotspots show that the land cover type for shrub has the highest number of cells and the second highest raster count in three locations. Therefore, shrub is either the leading land cover type or the second dominant land cover in almost all of the hotspot areas. In Hotspot 1, agriculture land cover is the most abundant. However, comparing this with the landscape characteristic data (Graph 8), agricultural land was determined to be the land cover where road kill most often occurred. In addition, Hotspot 2, also in Ventura County, shows that agriculture is the third most abundant land cover type. Lastly, the land cover type in Hotspot 3 is dominated by desert shrub. In this area urban comes in forth for land cover but first in road kills (Graph 6).

Table 17: Land cover raster cell count.

	Hotspot 1	Hotspot 2	Hotspot 3	Hotspot 4	Hotspot 5	Hotspot 6	Hotspot 7	Hotspot 8
Agriculture	17426	9696	184	35	13712	2517	2777	3310
Barren/Other	908	310	199	135	154	19	42	15
Conifer Forest	x	x	1326	x	x	x	45	900
Conifer Woodland	x	x	8349	x	x	x	x	x
Desert Shrub	x	x	17467	215	78	3	3	138
Desert Woodland	x	x	99	x	x	x	x	x
Hardwood Forest	888	739	860	x	x	x	x	x
Hardwood Woodland	1741	1385	221	196	2397	671	884	1667
Herbaceous	4238	x	1738	1275	6712	1625	4097	2480
Shrub	12168	24368	16516	1792	23149	3513	14582	27484
Urban	14498	17246	3261	41874	11171	32061	46733	26518
Water	189	158	x	x	80	927	676	842
Wetland	48	x	x	x	19	166	387	48

The attribute table from the raster layer for each hotspot locations was also used to generate maps to show the makeup of the landscape in each of the hotspots (Figures 8-13). Hotspots 6 and 7 are dominated by 69% urban land cover type (Figure 8). As a result, this is where most of the road kill occur. Hotspot 8 is made up of mostly shrub (43%) and urban (42%) (Figure 9). However, as indicated in (Graph 1) road kill occur in the urban land cove 43% of time and agriculture land cover type 17% of the time. Hotspot 5 is dominated by shrub (40%) followed by agriculture (24%) and urban (20%). Most of the road kill in this area are along the 15 freeway in the urban patches of land cover (Figure 10). Hotspot 4 is almost entirely made up of urban land cover (92%) (Figure 12). Hotspot 3 is dominated by desert shrub (35%) and shrub (33%). However, most of the road kill is occurring in the urban patches (7%), most likely from wildlife entering into the urban areas that are in the middle of their habitats (Figure 11). Hotspots 1 and 2 in Ventura County are dominated by both agriculture and urban land cover types (Figure 13). Thirty-three percent of the area is agriculture, 27% urban and 23% shrub in Hotspot 1. Road kill are happening in the agriculture patches (47%) (Graph 8). Hotspot 2 consists of shrub (43%) urban (31%) and agriculture (17%). Road kill are more prevalent in the urban patches 62% of the time (Graph 7).

Figure 8: A map displaying the land cover types in Hotspots 6 and 7.

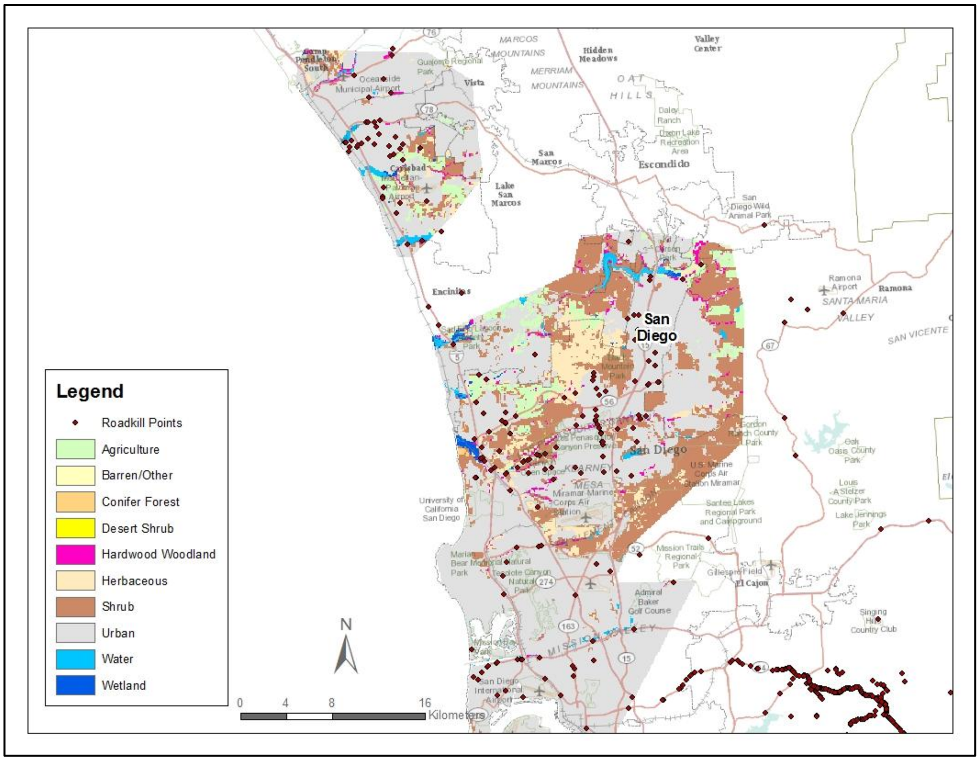


Figure 9: A map displaying the land cover types in Hotspot 8.

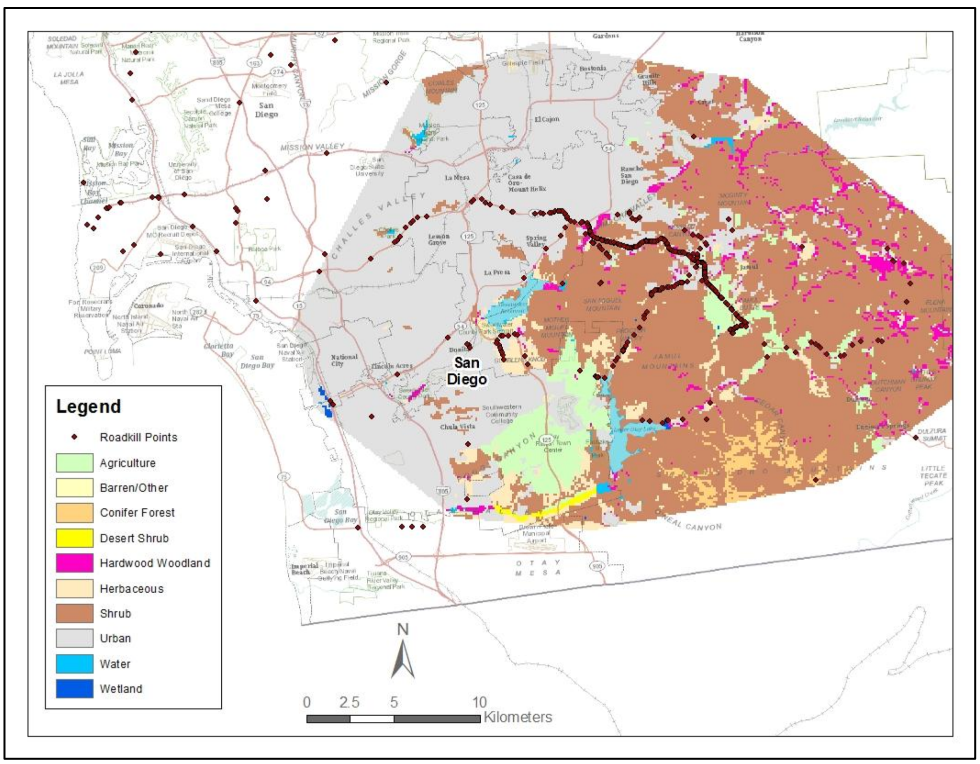


Figure 10: A map displaying the land cover types in Hotspot 5.

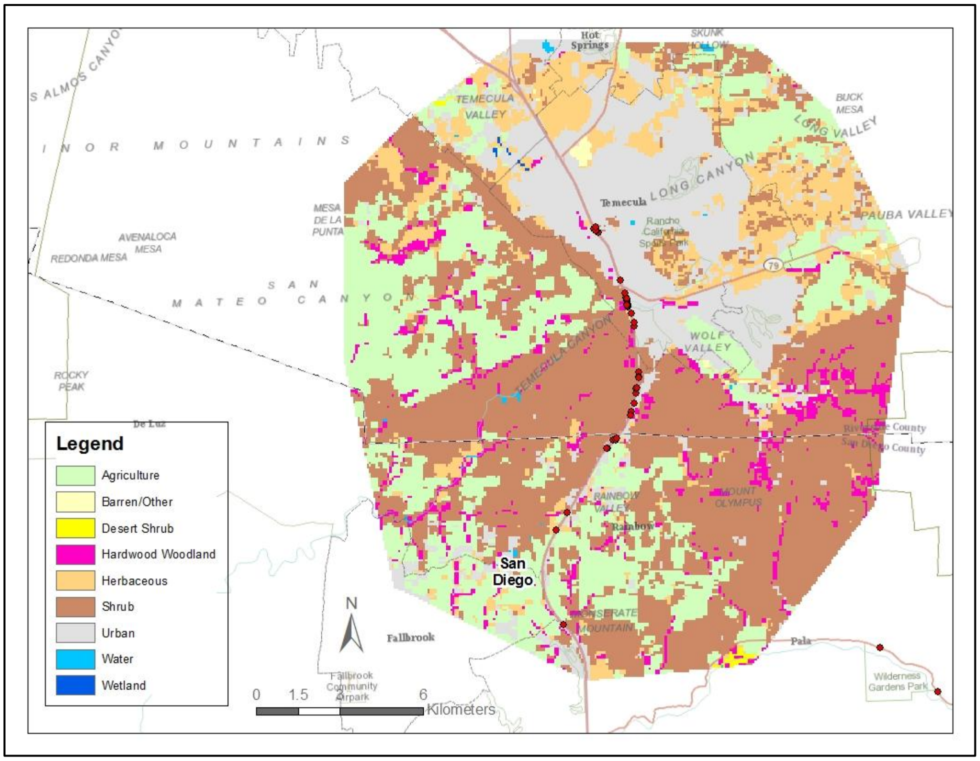


Figure 11: A map displaying the land cover types in Hotspot 3.

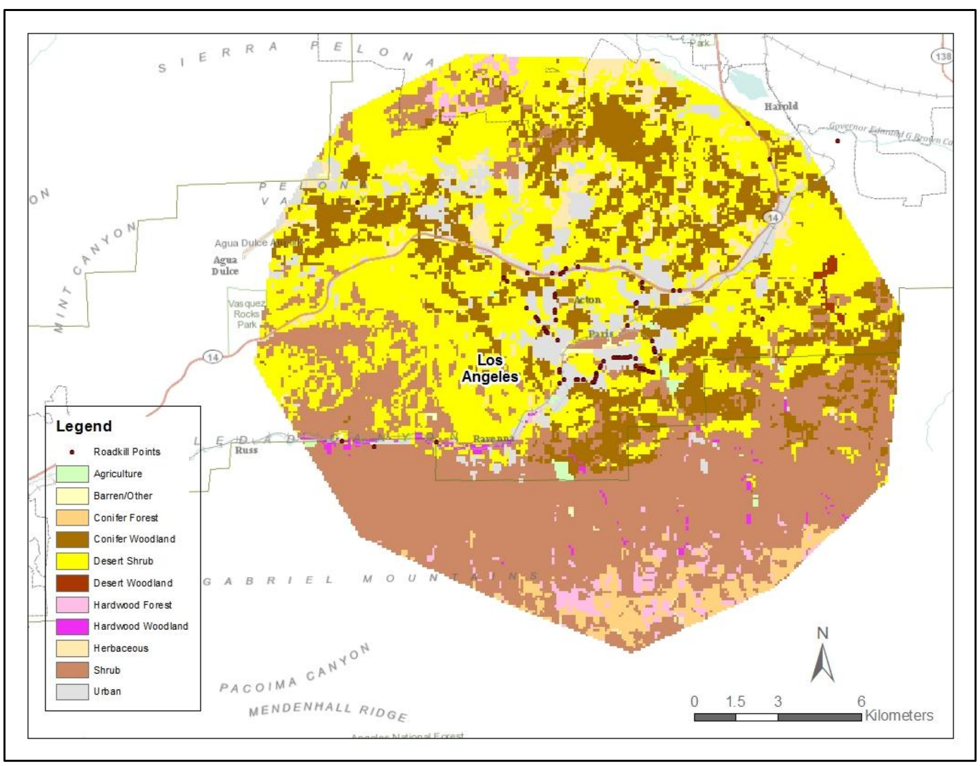


Figure 12: A map displaying the land cover types in Hotspot 4.

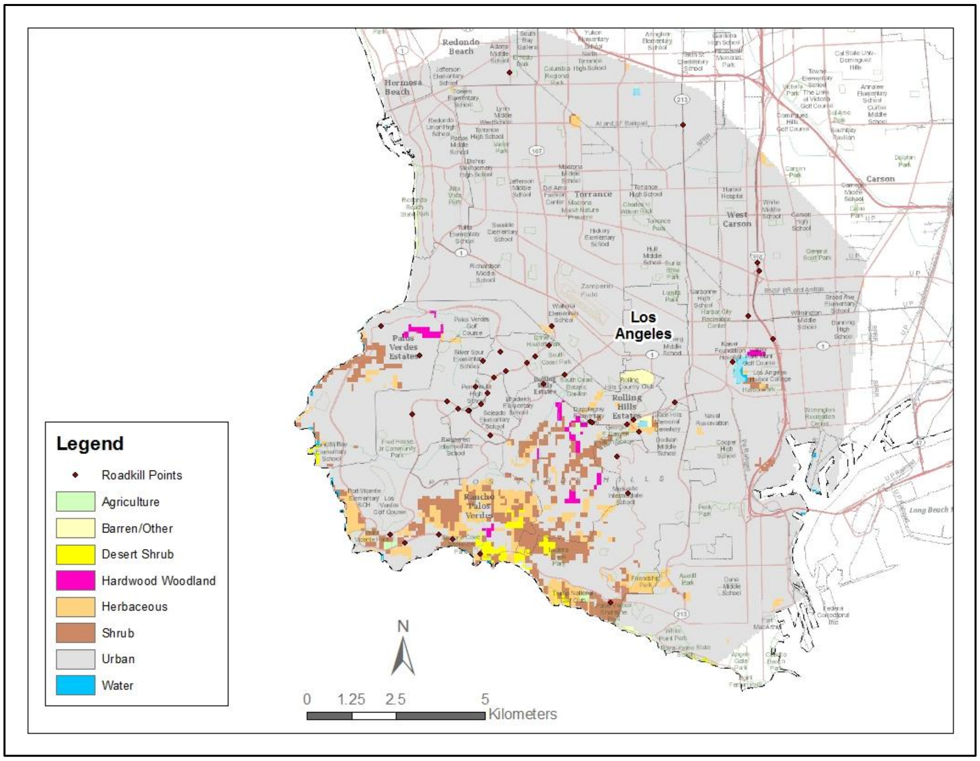
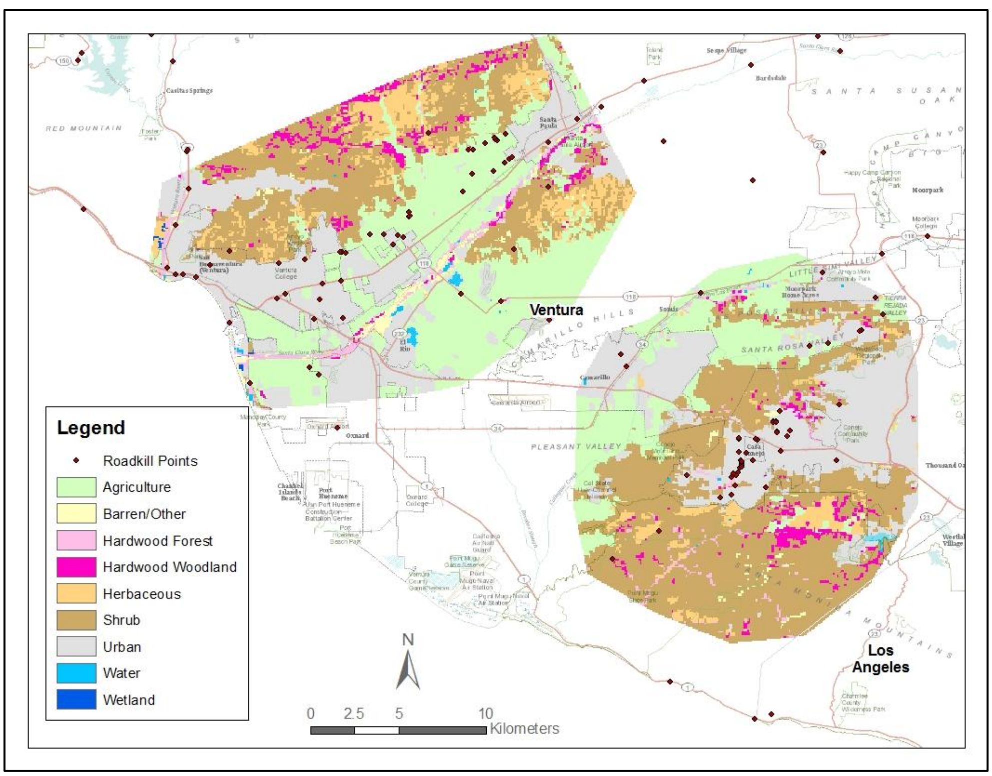


Figure 13: A map displaying the land cover types in Hotspots 1 and 2.



5.8 Wildland Networks

California along with other states and nations are becoming more aware of the importance of connected habitats to ensure the existence of wildlife and biodiversity. A map was created to display the identified hotspot locations as well as the South Coast Missing Linkages shapefile (Figure 14). Four of the identified hotspot areas are in a critical wildland network. Hotspot 3 is in the San Gabriel - Castaic connection. Hotspot 5 is the Santa Ana – Palomar connection. Hotspot 2 lies in the Santa Monica – Sierra Madre connection. Hotspot 1 is in Sierra Madre – Castaic Range connection. Out of the eight identified hotspots in Southern California, four are not located in or near a critical wildland network.

A final map was created to display all of the layers used for this research (Figure 15). These layers include the Point Density analysis, land cover feature class to raster layer, road kill points, counties shapefile, roads shapefile, and wildlife corridors. The map shows road kill points in dark red, the results from the point density test yellow circles and the corridors in dark green. As the map displays, Southern California contains a diversity of flora, however there are many highly populated areas intermingled within the landscape. The map clearly defines the hotspot areas for road kill located in or near urban landscapes, which are depicted in red. In addition, the hotspot areas for road kill are along major highways, which coincide with the other analysis done for this study.

Figure 14: Map showing wildland linkage networks in Southern California.

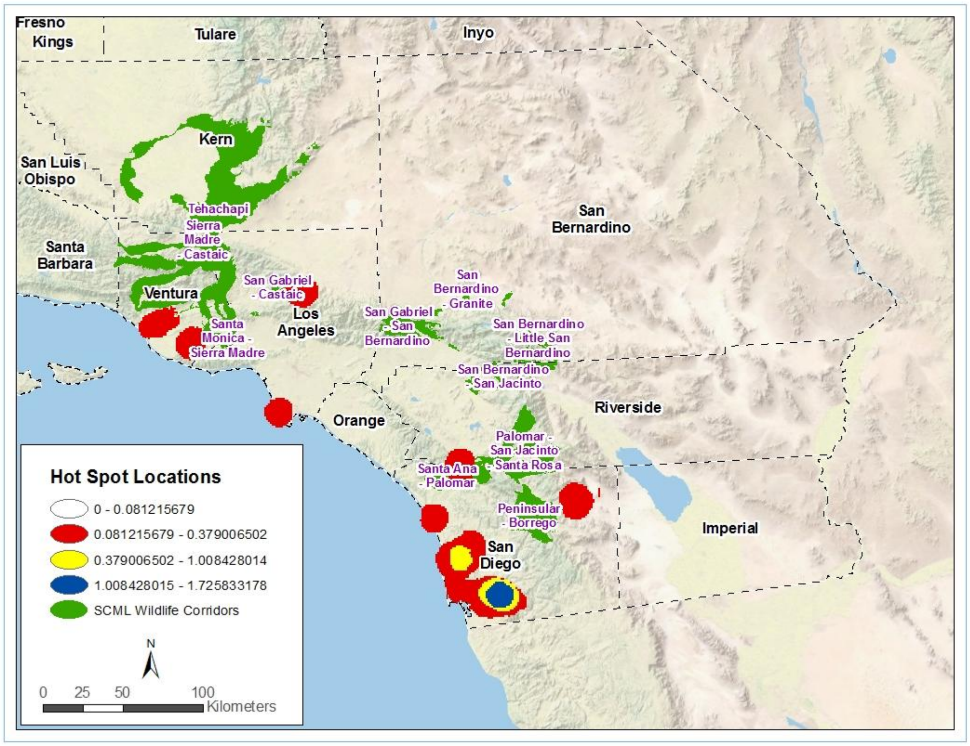
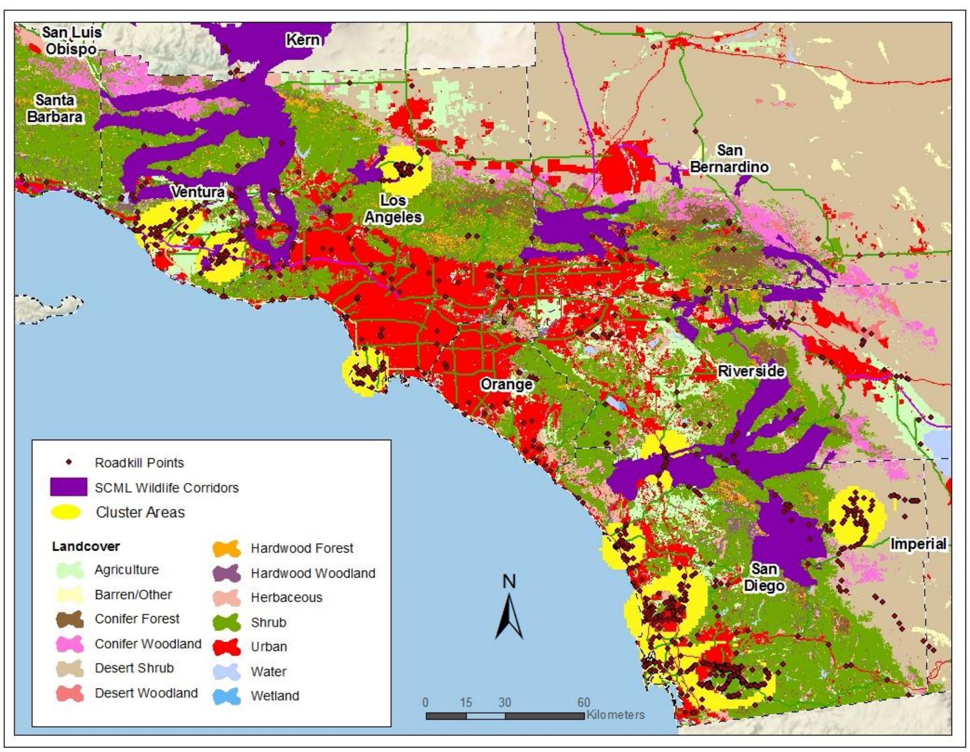


Figure 15: Final map displaying all layers.



Chapter 6 Discussion

Much can be interpreted from the results of this study. Coming from only one source, the data has limitations for further interpretation. However, there are enough road kill points in the sample to allow for the development of meaningful data on wildlife kill densities within the defined study area. Although there was variation in the results, there were some consistent findings regarding where and why road kills often occur. The road kill data for this study was reported over an18-year period with over 1600 road kills documented. Most of the identified species are not threatened or endangered, however they are the prey for the larger more endangered species such as the mountain lions, deer, bobcats, and coyotes (Table 16). As a result, the larger animals such as rabbits, opossums, raccoons, and squirrels, are being killed at a higher rate in highly urbanized areas with higher road densities compared to areas with fewer roads. In addition, larger animals require a greater habitat size to hunt, mate, and migrate. When their environments become fragmented, due to urban development, they have no choice other than to come into populated urban areas for survival (Ng, et al. 2004). It is evident that there is a high rate of mortality for animals that attempt to cross roads that are a direct result to habitat loss, to move among remaining patches of habitat as the results from this study suggests (Forman, et al. 2003).

Many studies have indicated that road kill are not random occurrences and that hotspots are prevalent (Hubbard, et al. 2000). The identified hotspot areas are near major freeways and are highly urbanized areas. As other studies suggest, wildlife movements tend to travel along a path of least resistance, therefore it is not surprising that this study showed the risk of road kill events increased when roads bisected urban areas in their habitat (Gunson, et al. 2010; Forman, et al. 2003). Equally, there is a high rate of mortality incurred by individual animals that attempt to cross roads within the remaining patches of natural habitat (Lloyd and Casey, 2005). Movement is essential to wildlife survival, whether this entails everyday movements of individuals seeking food, shelter, or mates, dispersal of offspring to find new homes, or seasonal migration to find favorable conditions (South Coast Wildlands, 2008).

Habitat loss and fragmentation are one of the leading threats to biodiversity worldwide, and nowhere is the risk more severe than in Southern California. It has only been a century since Southern California was a vast wildland that supported an abundance of habitats. However, much of this vast wildland has been lost to sprawling housing developments and freeways with drastic impacts to wildlife (South Coast Wildlands 2008). It has been shown that a mixture of land cover surrounding a road will increase the occurrence of road kill incidents (Finder, et al. 1999). The FRAGSTATS results for this study computed a variety of landscape metrics. The results clearly identified a difference in the recognized hotspot areas for the patches of land cover. As landscapes become more fragmented in urban settings, road kill may tend to increase as wildlife attempt to negotiate the landscape. On the other hand, if these landscapes are less fragmented and intermixed, road kill may be less likely.

Certain wildlife requires specific vegetation in their habitat for survival. However, if an animal's vital environment is intersected by roads, then the composition of vegetation near the roads will influence wildlife behavior. The patches identified at these hotspot locations show a diversity of patches. It may be difficult to distinguish why these results vary. In this study, it is possible that the identified relationships between road kill and land cover type were influenced by where road kill was being reported. Likewise, in less developed areas, there is more wildlife and therefore a greater likelihood of road kill compared to urban areas with less wildlife. The tipping point is most likely in areas where there is new urban development occurring or those places where urban sprawl is just beginning along the urban wildland interface.

At the landscape scale, the major ecological impacts of a road network are the disruption of landscape processes, loss of biodiversity and in many incidents, roads serve as barriers to some animal movement (Forman and Alexander, 1998). There are many challenges that threaten the natural environment, none more important than the ever-increasing human footprint. However, suggestions can be made on local development and land-management practices that would best preserve the landscape while accommodating economic development needs. The ecological footprint of a road network extends far beyond its physical footprint due to road mortality, habitat fragmentation, and numerous indirect impacts. The South Coast Missing Linkage Project connectivity analysis identified 552 pairs of Natural Landscape Blocks separated only by a road, and numerous roads cross essential connectivity areas (Spenser, et al. 2010). This analysis found that four hotspots for road kill are directly in one of the wildland networks. This suggests that identifying a critical habitat is not enough. Other measures need to be taken to ensure the safety of wildlife within these already vital areas. Although these areas are considered linked corridors, roads still intersect through them fragmenting the already disjointed habitats. Corridors provide important structural connectivity in habitats that have been fragmented by human activities, but work that is more practical is needed to identify the attributes of effective corridor design under a broad range of ecological conditions (McDonald and St. Clair, 2004).

Mitigation procedures could help to lessen the impacts of road kill for both wildlife and humans. Although many states use one or several management strategies to reduce mortality, few of these have been tested thoroughly. Of those that have, for example Swareflex reflectors, warning whistles, lighted and animated wildlife crossing signs, general highway lighting, many have been shown to be ineffective (Romin and Bissonette, 1996). This study has revealed that road kills are occurring where wildlife habitats are fragmented due to the increase in populations and housing and road development. Many studies demonstrated regular use of underpasses and drainage culverts beneath highways by wildlife, including species of conservation concern (Clevenger, et al. 2001; Ng, et al.; 2004; Beier, et al. 2008). It is critical to protect wildlife habitat where known hotspots for road kill have been identified. A combined one-hundred and twenty- eight focal species have been identified in The South Coast Missing Linkages Project. Although many of these identified critical corridors are not in the highly urbanized areas, except for four, however, they are near to populated locations. An increase in the human population is unavoidable. Nevertheless, how we handle these increases is key to the survival wildlife. Structures that allow wildlife to safely navigate through their habitat could help reduce the amount of road kill we see on road networks.

Studies have found that for many species, road mortality can serve as a population-limiting factor because their foraging and dispersal behaviors put them at risk of being struck on roadways (Glista, et al. 2007). Although road mortality may not affect abundant populations, it can have a significant impact on populations of threatened or endangered species. The outcome for the hotspot analyses clearly show urban land cover type as the highest among road kill sites. Consequently, the results of this study should be expected to have different outcomes. However, comparing all of the results of the analyses is an indication that the land cover types in the identified hotspot areas are extremely fragmented with urban areas mixed throughout and this may be an indication to why road kill is most often occurring in these highly populated areas.

In summary, wildlife have to negotiate the growing number of homes and access roads popping up across rural countryside’s nationwide (Dickson, 2010). Increases in population have a major impact on wildlife and their environment. With the population expected to increase, housing and road construction will continue to invade wildlife habitats. Roads are the largest human artifact on earth totaling, in the U.S., nearly 6.5 million kilometers occupying about 10.9 million hectares, approximately 1% of the U.S. land area (Forman, et al. 2003; Barthelmess and Brooks 2010). Both roads and vehicles affect the mobility and survival of wildlife across an environment, which has led to not only habitat destruction, but also population fragmentation as well.

Identifying and protecting large unfragmented areas in identified critical habitat and connecting them with corridors may be the best strategy to protect many species. If the identified areas are large enough, animals may be less likely to travel in areas of high human activity. Much of the analyses for this study showed that the hotspots for road kill occur most often in developed urban areas with busy road networks. This is a good indicator for where most road kills are taking place and suggests that road kill will become more prevalent in the future if actions are not taken in the present. As populations continue to increase so, too will the numbers and diversities of the CROS website. The results of this study display high statistics that there should be other monitoring systems in place for wildlife vehicle collisions. In addition, recommendations should be made to construct wildlife crossings, such as overpasses and underpasses for future road constructions in populated areas. The need and placement of wildlife friendly engineering designs that aid in maintaining wildlife connectivity is prevalent, as the results of this study support. Implementation strategies such as land bridges and/or large box culverts will be dependent on final roadway engineering plans and the biology of the species impacted by the roadway (Lowery and Grandmaison, 2009).

This study demonstrated that road kill is a major threat to wildlife. Overall, the information put forward may help to improve the understandings of why and where wildlife are most likely to be killed by vehicles. In addition, it will help other studies refine their road kill data collection and diagnostic methods in order to produce more precise and useful information that can be used to alleviate road impacts to wildlife and possibly improve highway safety.

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