Electrocution Risk to Three California Bird Species: Golden Eagle, Common Raven, and Turkey Vulture

by

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Dedication

I dedicate this document to my family: wife Adriana, daughters Katyana and Ariyana (in order of arrival), and mother Antonieta. Thank you for enduring the memorable and sometimes dizzying trips through California's backcountry and for your extraordinary patience on the many missed family events. May the completion of this thesis mark a new beginning for all of us and serve to inspire my beloved daughters to pursue their life goals by applying themselves, as always. I reserve one small section for the memory of my father; his passion for the natural world was enough to inspire me for a lifetime.

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Abbreviations

APLIC	Avian Power Line Interaction Committee
BLM	Bureau of Land Management
CDFW	California Department of Fish and Wildlife
CFR	Code of Federal Regulations
CNDDB	California Natural Diversity Database
DEM	Digital Elevation Model
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
GPS	Global Positioning System
ISO	Independent System Operator
IUCN	International Union for Conservation of Nature
kV	Kilovolt
MBTA	Migratory Bird Treaty Act
NOAA	National Oceanic and Atmospheric Administration
ROC	Receiver Operating Characteristics curve
SCE	Southern California Edison
TRI	Terrain Ruggedness Index
US	United States
USFWS	United States Fish and Wildlife Service
USC	University of Southern California
USGS	United States Geological Survey

Abstract

Bird mortality from electrocutions and interactions with utility transmission infrastructure totals into the hundreds of millions globally each year. Birds with large bodies and wingspans are especially susceptible, because they more easily span energized and grounded lines and pole hardware. Avian electrocutions compromise transmission delivery and occasionally cause wildfires; therefore, utility companies are pressured to study and prevent them. Studies designed to evaluate contributing factors to electrocution typically examine pole design and appliances, but fewer studies investigate environmental and physical factors like slope, topography, aspect, vegetation, and proximity to water. Yet these factors can influence bird species presence and behaviors that contribute to electrocution risk. This study examines the Southern California Edison bird mortality dataset (1988 to 2012) used in recent research from California, which considers pole design and the presence of unpaved roads in non-forest areas. The results have predicted risk well for most species, but poorly for Golden Eagles, Turkey Vultures, and Common Ravens. The electrocution dataset was re-examined using road density, human population density, proximity to water, topographic variation, and dominant vegetation. Exploratory data analysis visualized avian electrocution patterns. Clustering occurred. Relationships between dependent variables (electrocution events) and the explanatory variables were modeled using logistic regression. Golden Eagle electrocutions occur in areas with few roads and poles with multiple conductors and are on level to moderately rugged terrain with low-growing vegetation. Common Raven electrocutions occur on poles where jumpers outnumber conductors in areas of higher road and population density. Turkey Vulture electrocutions occur in flat to intermediately rugged lands with tall scrub, woodlands, and grassland/woodland mosaics.

Chapter 1 Introduction

Researchers estimate that hundreds of millions of birds die globally each year due to power line interactions, the second highest anthropogenic cause of bird mortalities (Rioux, Savard, and Gerick 2013; Longcore et al. 2012; Loss, Will and Marra 2012; Tinto, Real and Mañosa 2010; Rubolini et al. 2005; U.S. Fish and Wildlife Service 2002; Alonso, Alonso, and Muñiz-Pulido 1994). Although avian powerline interactions can involve collisions, electrocutions are of special concern to birds of prey and other large-bodied birds capable of making simultaneous contact with two lines or a line and a pole (American Bird Conservancy, 2013; Avian Power Line Interaction Committee, 2006; Dwyer et al. 2015; Tinto, Real, and Mañosa 2010; Lehman, Kennedy, and Savidge 2007). Increased energy demand and the resulting introduction of new power lines in rural and undeveloped areas exacerbate the problem (Manville 2005; Rubolini et al. 2005). Avian electrocutions also compromise transmission delivery and occasionally cause wildfires (Avian Power Line Interaction Committee 2012; Lehman and Barret 2002).

Environmental and operational concerns force US electric utility companies to analyze and mitigate factors that contribute to avian electrocutions (Tinto, Real, and Mañosa 2005; Bridges et al. 2004). To this end, utility companies working with resource agencies, land managers, researchers, and engineers have identified factors that contribute to avian mortality at power lines (Avian Power Line Interaction Committee 2012; Prinsen et al. 2012; Dwyer 2004). The results of this work indicate that biological, environmental, and utility distribution equipment design contribute to electrocutions (Harness, Juvvadi and Dwyer 2013; Manville 2005; Platt 2005). Most studies focus on analyzing the effects of tower designs and associated hardware (Dwyer, Harness, and Donohue 2014, Schomburg 2003; Mañosa 2001). Fewer studies look at physical and environmental factors, such as topography, vegetation, human presence and water proximity, in their analyses (Tinto, Real, and Mañosa 2010; Janss and Ferrer 2001). Yet, these factors, many of which have well-defined spatial boundaries, are important determinants of variation in bird diversity and abundance and influence the spatial distribution of avian electrocutions (Rappole 2013; Small 1994; Garrett and Dunn 1981; Grinnell and Miller 1944).

1.1. Basis for this Study

Dwyer et al. (2014) examined avian electrocutions in a portion of eastern, central and southern California and developed a model based principally on pole design. Figure 1 shows the study area. The purpose of the model was to identify pole designs most likely to electrocute birds and to use this information to retrofit target poles likely to pose an electrocution hazard for birds. The researchers identified four of fourteen candidate variables that distinguish electrocution poles from comparison poles: the number of jumpers, number of primary conductors, presence of grounding, and presence of un-forested unpaved areas as the dominant nearby land cover. The study's validation indicated that the model predicted risk well for American Crows (*Corvus brachyrhynchos*), Great-horned Owls (*Bubo virginianus*), Red-shouldered Hawks (*Buteo lineatus*), and Red-tailed Hawks (*Buteo jamaicensis*), but poorly for Golden Eagles (*Aquila chrysaetos*), Turkey Vultures (*Cathartes aura*) and Common Raven (*Corvus corax*).

Species for which the model in Dwyer et al. (2014) performed well are widespread and occupy many habitats in California, but those that performed poorly are at least seasonally tied to specific habitats or geographies. For example, all three species occupy areas with topographic variation. Golden Eagles and Turkey Vultures are obligate cliff nesters. Turkey Vultures nest in Tree cavities, bare ground and cliffs, while Common Raven is a facultative cliff nester that also nests in trees and sometimes on powerline poles and transmission towers (Thelander 1974,

Figure 1. Southern California Edison's service area and the study area used by Dwyer et al. (2014).

Grinnell and Miller 1944). In flat areas, power line poles may extend the usefulness of associated habitats to these species by offering elevation over surrounding terrain, a wide field of view, and a point for easy take off (Benson 1981; Stahlecker 1978; Nelson and Nelson 1976; Boeker 1972). For Golden Eagles, studies indicate that habitat heterogeneity, which is often influenced by landscape features, prey availability in specific vegetation types (i.e., differences in lagomorph abundance in native versus non-native grasslands and shrublands), and nesting substrates that are unfavorable for other species are important habitat components (Benson, 1981; Pearson, 1993, Stahlecker 1978; Thelander 1974). Terrain features affect migration patterns for bird species

(Rappole 2013; Goodrich et al. 2008; Mandel et al. (2008). Terrain ruggedness disrupts the structure of convective cells, decreasing the availability of thermal energy that Turkey Vultures use as an energy-conserving strategy during migration. The presence of human development and roads while beneficial to Common Ravens may be less attractive to Golden Eagles (Benson 1981; Boarman and Heinrich 1999; CDFW 2014; Pearson 1993). Terrain, vegetation, waterbodies and human development are factors that affect the distribution of species and their contribution to electrocution risk in conjunction with utility distribution design using spatial methods.

1.2. Objectives

The present study looks at the spatial distribution of electrocution events to discern Golden Eagle, Common Raven, and Turkey Vulture electrocution patterns within the Dwyer et al. (2014) study area, using an updated version of the same dataset employed in that study and spatial analysis techniques to examine how distribution pole design, topography, vegetation and land use contribute to electrocution for these three species. The objectives of this research are to:

1. Identify and evaluate factors that contribute to avian electrocution;
2. Determine if electrocution patterns in the three species are random or clustered within the study area and whether there are possible spatial explanations for their distribution;
3. Develop risk models for each species; and,
4. Use the information to develop recommendations on where to implement perching deterrents and other mechanisms to prevent electrocution.

1.3. Thesis Structure

The remainder of the thesis is comprised of four chapters. Chapter 2 highlights past relevant studies, summarizes the paper that influenced this thesis, and describes birds examined and their basic biology. Chapter 3 outlines methods employed for the analysis and discusses the study area, the SCE avian electrocution data, contributing factors examined, and field verification and data analysis methods. Chapter 4 presents the regression results of the analysis for each species and Chapter 5 discusses the results and offers alternative design and placement strategies.

Chapter 2 Background and Literature Review

Avian electrocution and factors that contribute to it are well-studied globally (Loss et al. 2013; Tinto, Real, and Mañosa 2010; Lehman, Kennedy, and Savidge 2007; Avian Power Line Interaction Committee 2006; Manville 2005; Rubolini, Gustin, Bogliani, and Garavaglia 2005; Lehman and Barret 2002). Most of these studies employ logistic regression to determine factors that alone or in combination influence electrocution.

2.1. Factors Implicated in Avian Electrocution

Three principal factors are: (1) pole design (including all appliances such as jumpers, insulators, transformers, etc.), (2) bird species and behavior, and (3) environment including habitat, road presence and open water.

2.1.1. Avian Electrocution and Pole Design

Dwyer et al. (2014) investigated design factors associated with avian electrocutions to determine design factors most likely to result in avian electrocution in California. These authors examined electrocution by voltage, month, and year to identify species most often killed within the study area. Red-tailed Hawks (n = 265) and American Crows were among the most electrocuted species, logically, given their year-round presence, distribution and abundance in the study area. Four of fourteen candidate variables distinguish electrocution poles: the number of jumpers (short wires connecting energized equipment), number of primary conductors, presence of grounding, and presence of un-forested unpaved areas as dominant nearby land. Similarly, Longcore et al. (2012) employed logistic regression to examine avian mortality associated with communication tower height for an estimate of avian mortality in the US and Canada.

Mañosa (2001) studied the presence of carcasses under poles to identify utility pole types likely to cause avian mortality. These were a priority for allocating mitigation resources. Employing logistic regression, the study revealed that geographical location and habitat setting were as important as technical design in determining the actual risk of electrocution. Similarly, Tinto, Real and Mañosa (2010) indicate that metal pylons with pin-type insulators or exposed jumpers, with connector wires, located on ridges, overhanging other landscape elements, and in open habitats with low vegetation cover pose the greatest risk of electrocution.

2.1.2. Avian Electrocution and Species, Age and Behavior

Sergio et al. (2004) published a review of twenty-five studies on the causes of mortalities in a top predator raptor and noted that: (1) electrocution was a major cause of death in many of the studies examined; (2) electrocution increased over three decades progressively and independently of other causes; and (3) caused breeding territory abandonment near utility infrastructure. The study also shows a temporal effect with mortalities spiking after juvenile fledging. Janss and Ferrer (2001) found a similar effect in their Golden Eagle study, where mortality from electrocution was higher in juvenile birds and attributed to inexperience in flying and more frequent pole use by birds in this age class (7.3 times more poles were present in immature bird territories). These studies emphasize how subtle anthropogenic disturbance can have incremental effects on top predators in each area.

Lehman et al. (2007) systematically reviewed the raptor electrocution literature and evaluated study designs and methods used in raptor electrocution research, mitigation, and monitoring. This effort represented a review of North American, western European, and South African data over 30 years. Based on the results of the review, few studies demonstrated the reliability of standardized retrofitting procedures or the effectiveness of monitoring techniques. Lehman et al. (2007) conclude that raptor mortality reduction on power lines will benefit from improved study design and thoughtful monitoring to evaluate electrocution minimization method effectiveness.

2.1.3. Avian Electrocution and Environment

Although comprehensive studies have examined how habitat (and vegetation, terrain, land use, and open water) influences mid-span avian collisions (APLIC 2012, 2008; and Heck 2007), fewer studies examine the effect of habitat and environment on avian electrocution. Biasotto et al. (2022) examined bird electrocutions in Brazil and found that 238 Pantanal species risk electrocution. Tinto et al. (2010) surveyed electrocutions on utility towers in Spain. Electrocutions were comprised of raptors and corvids and were associated with metal poles with exposed jumpers and wires, located on ridges and in open habitats with low vegetation cover. Janss and Ferrer (2001) assessed electrocutions in different habitat types in southwestern Spain to determine the effect that habitat had on pole design. Pin-type insulators in natural habitats accounted for the largest percentage (39%) of avian mortality. The researchers went on to quantify the effect of these types of poles in natural habitats for all birds, particularly for Spanish Imperial Eagle (*Aquila adalberti*), a highly imperiled species in the region.

2.2. Electric Utilities and Avian Electrocution Risk

This section describes electric utility transmission, its associated structures, and the design factors that cause avian electrocutions. The overview also provides visual and descriptive references for the terminology used in this thesis.

2.2.1. Transmission vs. Distribution

Overhead power lines are generally divided into three categories, transmission, subtransmission and distribution (Figure 2). Transmission lines move large quantities of electricity from generators to substations along lines mounted on large towers (Figure 3).

Voltages on transmission lines typically range from 161 kV to 500 kV (APLIC 2012). Subtransmission lines carry reduced voltages from transmission lines at voltages that range from 55 kV to 138 kV (Figure 4) (APLIC 2012). Distribution systems carry voltages from substations to businesses and residential areas. They typically operate at ranges between 4 kV to 46 kV (Figure 5) (US Department of Labor 2014). Avian electrocutions occur when birds make simultaneous contact with energized lines and grounded parts. High voltage lines require sufficient separation between individual transmission line components, so they do not typically pose an electrocution risk to birds (APLIC 2006). Smaller subtransmission and distribution lines typically pose a greater avian electrocution risk because energized and grounded components are spaced closer.

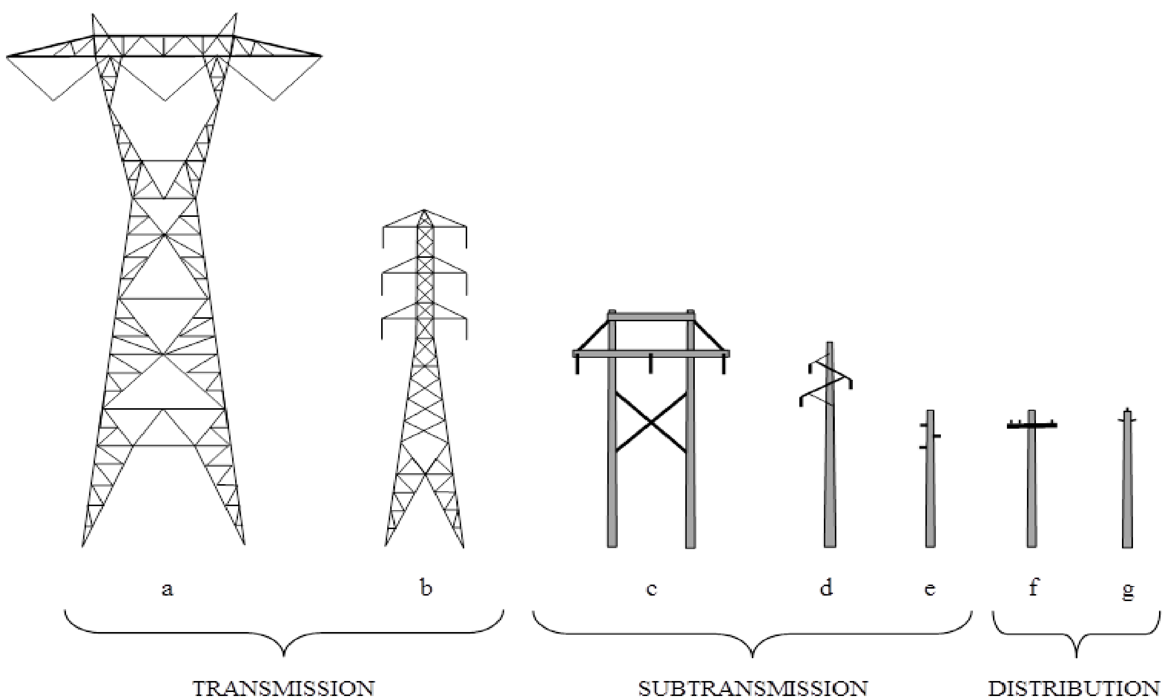

Figure 2. Transmission, subtransmission, and distribution tower and pole relative sizes are shown above. Representative voltages for each are: (a) 500 kV, (b and c) 230 kV, (d) 138 kV, I 69 kV, (f and g) 12 kV to 34.5 kV. Source: U.S. Department of Labor (n.d.).

Figure 3. Transmission lines near Rancho Cucamonga, California. Photograph by Author.

Figure 4. Subtransmission pole examples from within the study area. Photographs by Author.

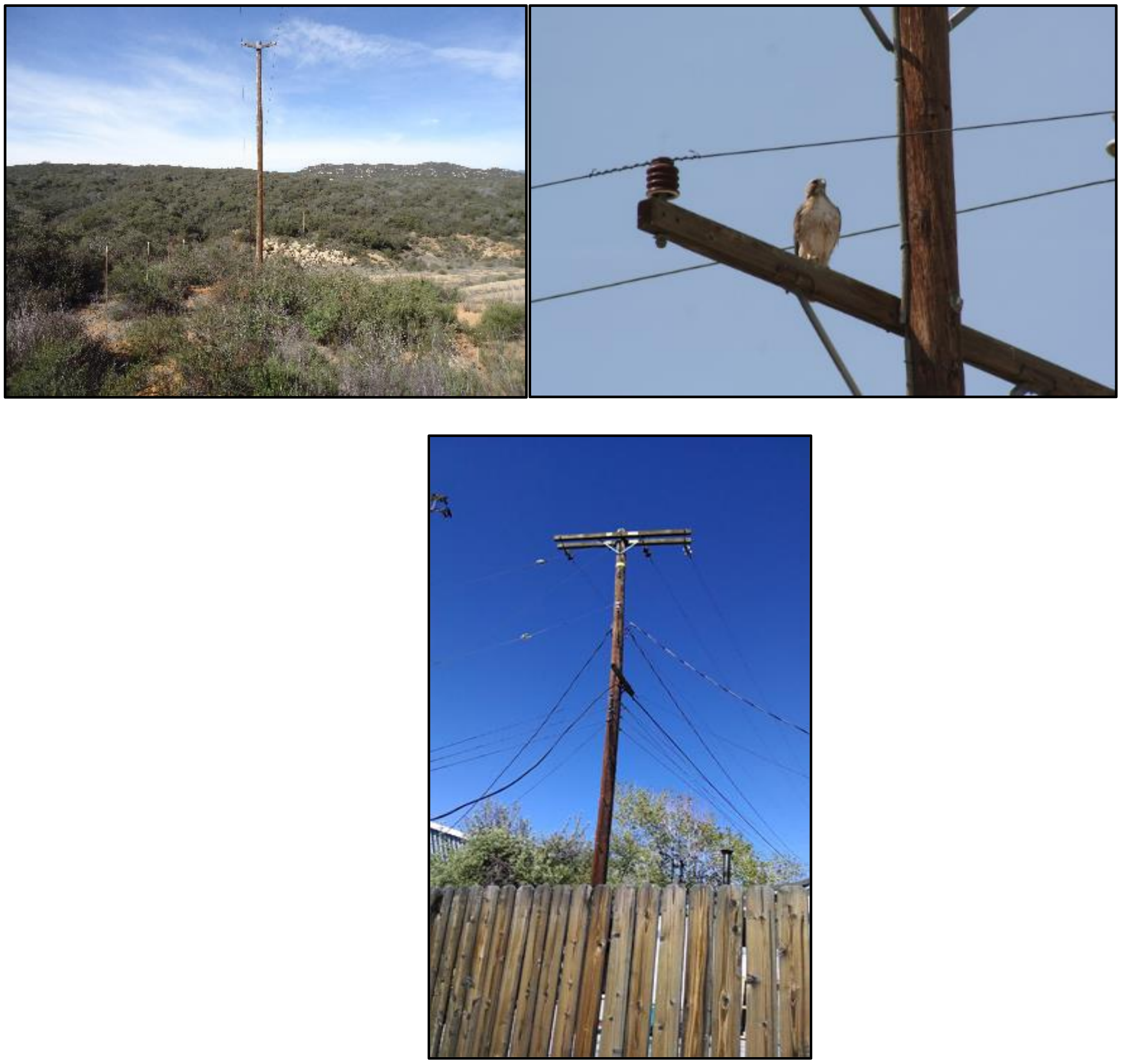

Figure 5. Distribution lines from Mono County (top left) the Antelope Valley in Northern Los Angeles County (top right) and eastern Los Angeles County (bottom center). Photographs by Author.

2.3. Species Overview

2.3.1. Golden Eagle

The Golden Eagle, the most widely distributed of all eagle species, occurs throughout the northern hemisphere (BirdLife International 2014; Watson 2010; Brown 1976). In North America, its distribution extends from Alaska, through the western states and Great Plains, and into Mexico (Kochert et al. 2002). In California, it occurs throughout the state (although infrequently in the Central Valley) as a permanent resident or migrant from sea level to over

3,500 m (0 to 11,483 ft) (Zeiner et al. 1990; Thelander 1972; Grinnell and Miller 1944). Golden Eagles occur throughout the project study area east and south of the Central Valley, except in heavily urbanized areas (CDFW 2014).

Golden Eagle territories include favorable nest sites, dependable food supplies, and broad expanses of open country for foraging (Johnsgard 1990). Preferred habitat typically consists of mountainous areas, foothills, juniper- and sagebrush-dominated scrubs, oak woodland savannahs and deserts, but wherever the species occurs it needs open terrain for hunting its preferred prey of rabbits, hares and squirrels (Families Leporidae and Sciuridae) (Kochert et al. 2002; Thelander 1972). Golden Eagle hunting strategy involves taking prey from perched or soaring positions; thus, hilly or mountainous country where takeoff and soaring are supported by updrafts is preferred to flat habitats, although manufactured structures in flat areas can serve a similar purpose (Watson 2010; Johnsgard 1990; Steenhof et al. 1993).

Golden Eagles often nest on rocky outcrop- or cliff-ledges and occasionally in trees from 3 to 30 m (i.e., 10 ft to 100 ft) up (Baicich and Harrison 1997). Nest sites selected offer shelter from inclement weather, prevailing winds, and solar exposure (Morneau et al. 1994; Watson and Dennis 1992; Polite and Pratt 1990; Poole and Bromley 1988; Eaton 1976; Mosher and White 1976). Golden Eagles maintain multiple nest sites and reuse nests (Kochert et al. 2002). Golden Eagle nest sites occur throughout the study area.

Within the study area, Golden Eagles do not migrate (Polite and Pratt 1990). Home range sizes vary according to Polite and Pratt (1990), with an average of 93 km^2 in southern California reported by Dixon (1937). Territory use intensity fluctuates from the breeding season to winter (Dunstan et al. 1978; Marzluff et al. 1997), but resident and migratory Golden Eagles show fidelity to wintering areas (Kochert et al. 2002).

2.3.2. Common Raven

The Common Raven occurs throughout the Northern Hemisphere and occupies a variety of habitat types (Madge and Burn 1994). It is a common year-round resident species over much of California, except the Central Valley, portions of the central coast, the Mojave Desert and cultivated valleys in the southeast (Boarman and Heinrich 1999; Small 1994). The species occurs at all elevations in California, in open and partially open habitats including desert tidal flats, agricultural fields and orchards, riparian forests, savannas, and suburban areas (California NatureMapping Program 2014; Grinnell and Miller 1944). Common Ravens occur throughout the study area and have increased their populations and expanded their range over much of this area within the last 40 years (Kristan and Boarman 2007; Knight et al. 1993).

Common Ravens nest throughout the study area. Boarman and Heinrich (1999) report that Common Ravens nesting in the eastern Mojave Desert of California foraged within 400 m of their nests. Nests are often on cliffs or in trees, between 5 and 20 m (i.e.,16 to 65 feet), but increasingly these occur on manufactured structures such as power poles, utility towers, and abandoned facilities (Boarman and Heinrich 1999; Baicich and Harrison 1997).

Kochert et al. (1984) suggest that Common Ravens prefer utility poles in areas of greater topographic relief. In the Mojave Desert, anthropogenic developments subsidize Common Ravens, and power poles provide important nesting platforms for the species (Kristan and Boarman 2007; Boarman et al. 2006).

Common Ravens do not typically migrate throughout their range, although in North America they are seasonal (fall or winter) visitors at the edges of range in North Dakota, South Dakota, northern Iowa, and central Wisconsin (Boarman and Heinrich 1999; Rea 1986). Seasonal variations in food availability can also affect local distributions (Boarman and Heinrich 1999; Stiehl 1978; Dorn 1972).

2.3.3. Turkey Vulture

The Turkey Vulture occurs from southern Canada south through the continental US, Central America, and as far south as Tierra del Fuego and the Falkland Islands in South America (Kirk and Mossman 1998; Bent 1961). In California, the Turkey Vulture is common throughout the state except for the highest elevations in the Sierra Nevada Mountains (Ahlborn 1988). Within the state, it winters from northern California along the coast and Central Valley south to Mexican border and the lower Colorado River Valley (Kirk and Mossman 1998). The Turkey Vulture migrates over the entire study area, with spring migration occurring from March through May and fall migration from September through November (Hawk Mountain Sanctuary 2014; Heintzelman 1986; Garrett and Dunn 1981; Grinnell and Miller 1944). It is a year-round resident in the Southern Sierra Nevada and Central Valley and Santa Barbara County (eBird 2014; Pardieck et al. 2014; Grinnell and Miller 1944).

Migrating Turkey Vultures can occupy many habitats, but require trees and cliffs, and occasionally manufactured structures, for resting during migration (Kirk and Mossman 1998; Ahlborn 1988, Grinnell and Miller 1944). Migration increases the number of Turkey Vultures at communal roosts, with higher numbers and greater persistence in fall (Kirk and Mossman 1998). Migration movements occur over large areas, but geographic features can concentrate large Turkey Vulture flocks (Moore and Moore 2014 [Southern Sierra Nevada, California]; Inzunza-Ruelas et al. 2010 [Isthmus of Tehuantepec, Mexico]; Smith 1985 [Isthmus of Panama]).

Nesting Turkey Vultures prefer open stages of habitats that provide cliffs or large trees for nesting and roosting (Kirk and Mossman 1998; Ahlborn 1988). Sheltered nest sites, often reused for years, may offer cooler conditions than surrounding areas and protection from predators (Kirk and Mossman 1998).

Chapter 3 Methods

This chapter covers field and quantitative methods used in this study. Included are analysis methods for collinearity, clustering, model testing and methods for checking the veracity of results.

3.1. Analysis Methods

This research employed ArcGIS to compile the electrocution data, to associate spatially overlapping datasets and to undertake initial analyses. The Hot Spot Analysis tool in ArcGIS Pro facilitates electrocution pattern determination for the three subject species within the study area. The tool uses the Moran's I statistic to determine if spatial autocorrelation exists and the Getis-Ord Gi* statistic to determine if data occurrences are clustered.

Spatial autocorrelation statistics, such as Moran's I, measure observation dependency in geographic space also known as spatial autocorrelation. It allows spatial autocorrelation assessment by employing the cross products of mean deviations (Equation 1).

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \tag{1}$$

where z_i is the deviation of an attribute for feature (i), w_i, j are elements of the weights matrix and S_0 is the sum of the aggregate weights (Equation 2) (Mitchell 2005; Moran 1950).

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \tag{2}$$

The Getis-Ord Gi* or local statistic measures the degree of association from a concentration of weighted features within a distance from the point of study and is as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}} \tag{3}$$

where x_j is the attribute for $_j$, $w_{i,j}$ is the spatial weights between features $_i$ and $_j$, and n is the total number of features (Mitchell 2005; Getis and Ord 1992).

Electrocution studies reviewed often employ linear regression analysis to establish relationships between input variables (Dwyer et al. 2014; Tinto et al. 2010; Janss and Ferrer 2001). Logistic regression although not a spatial model, is frequently used in analyzing spatial variables because it allows modeling of binary variables, the sum of binary variables, or variables with more than two categories (Addinsoft 2016). Logistic regression models link event occurrences or non-occurrences to explanatory variables (Addinsoft 2016). In this study, poles with electrocutions to poles absent of such occurrences against environmental, physical and design parameters. In conservation planning, models that perform well help to identify the factors that influence positive or negative outcomes for species, and this helps facilitate development of species protection and conservation measures (Mooney 2010).

3.2. Study Area and Physical Environment

The project study area and data are the same as that analyzed by Dwyer et al. (2014). It encompasses the SCE 129,500-km^2 service area, the includes all or portions of Fresno, Inyo, Kern, Kings, Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, Tulare, Tuolumne, and Ventura Counties in California.. The study area encompasses physical regions including the Mojave and Sonoran Deserts, the Sierra Nevada and Transverse Ranges, the Central Valley, and coastal plains and inland valleys of Southern California. Associated major vegetation types include conifer-forested portions of the Sierra Nevada Mountains in Tuolumne and Fresno Counties; vast expanses of the Mojave Desert in Inyo and San Bernardino Counties; and, agricultural, grass and shrublands in Kern and Kings Counties. In Tulare County, the study area overlaps foothill grasslands with sparse woodlands but is primarily in agricultural lands.

Large expanses of urbanization exist in Los Angeles and Orange Counties, and in the western portions of Riverside and San Bernardino Counties. Surrounding foothill areas and less-disturbed portions of inland and coastal valleys support shrublands and woodlands. Scrub vegetation also extends into less-disturbed parts of Ventura and Santa Barbara Counties.

3.3. Existing Dataset

SCE staff routinely assesses equipment to ensure that it is properly functioning. Workers sometimes detect bird carcasses during routine inspections and biological resource surveys required prior to equipment replacement and maintenance consistent with internal policy and to comply with various resource protection state and federal laws; most, however, were detected by repair crews during power outage responses. SCE maintains a record of avian carcasses found since 1981 during these events. Each datum contains carcass-specific information such as species, coordinates, environmental setting, location description, pole number, and cause of mortality (entanglement, fire, electrocution, etc.). The data used here represent the period from 1981 to 2012.

SCE's electrocution database documents 3,271 avian mortalities for the period from 1981 to 2012. Of these, 3,099 are electrocutions. Electrocution events selected for further review corresponded to the three species of concern to this study from the dataset; excluded from further analysis were all mortalities caused by mid-span collisions (collisions with wires between poles) and other known and unknown causes. Appendix A is a summary of the data fields in the electrocution database. The vetted data included only complete or verifiable electrocution records. This study analyzes thirty-three Golden Eagle, eighty-two Common Raven, and sixty-eight Turkey Vulture electrocutions (n=183) electrocution records (Appendix B).

In addition to electrocution data, five hundred random points were generated along mapped distribution lines in the study area to develop a control set for the analysis. Known electrocution sites were buffered by one kilometer and all points (utility poles) falling into these areas were eliminated from the control set. The remaining two hundred pole sites were verified using aerial imagery and field surveys (described further below). Of two hundred pole sites examined in the field and using aerial imagery, 176 served as controls for analyses.

The control poles selected for this study are those for which there are no recorded electrocutions of Common Raven, Golden Eagle or Turkey Vulture, but because utility personnel investigating outages find electrocuted birds, control poles may still be loci of undetected electrocutions that produce no outages or fires. Research by APLIC (2012) suggests that birds with larger wingspans such as eagles, hawks, vultures and ravens that capable of completing a circuit between energized wires or equipment on poles. The typical result of this interaction is a blown fuse and deenergized line that would merit a visit by the utility company; therefore, for the purposes of this study, it is unlikely that undetected electrocutions occurred on control poles during the data collection period.

Electrocution events for Golden Eagle, Common Raven and Turkey Vulture were each merged with control pole data and data sets.

3.4. Variables Examined

Prior to their analysis, Dwyer et al. (2014) eliminated four variables, effective height of adjacent poles, arm orientation, guy wire presence, and metal cross arm presence from their analysis using univariate analysis. In the same study, Dwyer et al. (2014) eliminated other variables such as canopy height, conductor termini, conductors on top of poles, unobstructed (commanding) views, public lands, and raptor use during regression analysis. Table 1 summarizes and provides sources for variables such as pole design, roads, vegetation, and topography, used in the analysis.

Table 1. Variables used in logistic regression analysis.

Variable	Description	Type
Grounding presence	Grounded appurtenances include metal brackets, guys, and neutral wires noted in the field for all electrocution pole data that did not already contain this information.	Categorical
Number of jumpers	APLIC (2006), Janss and Ferrer (2001) and others have noted that jumper wires, as well as transformers, surge arresters and other equipment increase the number of energized pole components that can cause electrocution. If SCE did not provide them as part of the electrocution data set, the number of jumpers on each pole was counted during field surveys.	Count
Number of primary conductors	Studies implicate the number of conductors in avian electrocution (APLIC 2006). If SCE staff did not collect these data, the energized primary conductors on each was counted during field surveys.	Count
Road density	Road density data from the National Oceanic and Atmospheric Administration (NOAA) and field surveyors calculated it using US Census Bureau data. Road density is the length in meters/per square kilometer for a one-kilometer area around each electrocution and control pole.	Continuous
Population Density	The population density layer obtained from Esri and is based on 2015 data from the U.S. Census Bureau. Population density is the number of persons per square mile; it is clipped to the study area shape.	Continuous
Proximity to Water	Dozens of electrocution events for the species examined appeared to cluster around bodies of water and larger streams. The layer "inland waters" is from the California Atlas. It depicts major hydrologic features digitized by the U.S. Bureau of Reclamation in 2005 and 2008 from 1:24,000-scale USGS topographic maps. A one-kilometer buffer surrounds these features and all electrocution and control poles that fell into the buffered area were assigned the value 1 and those that did not were assigned the value 0.	Categorical
Topographic variation	Topography is a salient feature of the nesting habitat for all three species evaluated in the study. A topographic ruggedness index (TRI) for the degree of elevation change between adjacent cells in a digital elevation model was created for this study following methods described by Riley, et al. (1999). Digital Elevation Model raster files from the US Geological Survey. Cell resolution was one-third (1/3) arc-second (or approximately 10 meters). Each processed cell is assigned to one of five TRI roughness categories (as described by Riley et al. 1999).	Categorical
Vegetation	Vegetation influences bird behavior including nest site selection, foraging habitat preferences, and migratory routes. The vegetation data are from the California Gap Analysis Project (Davis et al.1998) and corrected based on field data, aerial imagery, and site photographs.	Categorical

Layers and shapefiles downloaded from the sources described in Table 1 were manipulated to ensure consistency and accuracy during data analysis. Figure 6 illustrates the steps employed to manipulate raster and vector data obtained for this study.

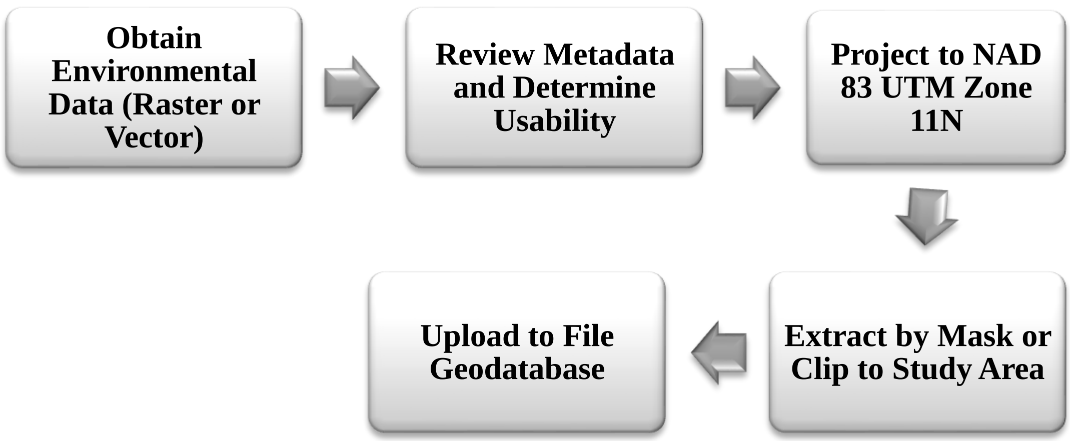

Figure 6. Typical workflow for preparing environmental analysis data sets for this study.’

3.4.1. Terrain

Topographic variation is noted as important for migration and nest site selection in Golden Eagles and Turkey Vultures (Kirk and Mossman 1998; Baicich and Harrison 1997; Ahlborn 1988 Grinnell and Miller 1944). Rugged terrain is also a feature of most Common Raven nest sites, although Common Ravens increasingly use utility poles in desert regions (Boarman and Heinrich 1999).

Topography was evaluated by creating a topographic ruggedness index (TRI) raster for the study area. The TRI expresses the degree of elevation change between adjacent cells in a digital elevation model. Developed by Riley et al. (1999), TRI determines the difference between the elevation of a raster cell and the eight cells immediately surrounding it. The differences are squared to make values positive, and the mean is calculated from squared differences.

The TRI was calculated from a digital elevation model (DEM) was downloaded from US Geological Survey’s “The National Map” (2014) and then clipped to the study area boundary. In 2014, it was the highest resolution seamless DEM dataset for the US with full coverage of the forty-eight conterminous states. The resolution is approximately ten meters north to south but varies more from east to west due to the convergence of meridians with latitude (US Geological Survey 2014). The DEM was processed using the methods described by Riley et al. (1999). The TRI raster data in ArcMap were assigned to the seven categories suggested by Riley et al. (1999) (Table 2), and TRI data were appended to each species data set using ArcMap (version 10.4).

Table 2. Terrain Ruggedness Index categories and values

Terrain Ruggedness Index	**Interval in Meters (m)**
Level	0 to 80
Nearly Level	81 to 116
Slightly Rugged	117 to 161
Intermediately Rugged	162 to 239
Moderately Rugged	240 to 497
Highly Rugged	498 to 958
Extremely Rugged	959 to 4367

3.4.2. Vegetation

Vegetation is an element of nesting, roosting, and foraging habitat. It is implicated as a factor in avian electrocution when considered with pole design. Janss and Ferrer (2001), for example, noted an increase in Spanish Imperial Eagle electrocution mortality with certain pole designs within specific vegetation types in Spain. The California Gap Analysis Project (Davis et al. 1998) supplied vegetation data. The data in that layer has a 0.25-acre (1,011 square meters) resolution. We clipped the vegetation layer to the study area shape and then classified the vegetation types into one of ten categories (Appendix C). Vegetation data were appended to each species data set using the spatial join feature in ArcMap (version 10.4).

3.4.3. Roads

In their study, Dwyer et al. (2014) deemed roads a factor in avian electrocution for multiple species. A road density raster obtained from the National Oceanic and Atmospheric Administration (NOAA) was used to calculate road density as length in meter per square kilometer using road layers from the US Census Bureau’s Tiger 98 files (NOAA 2011). The resolution is one square kilometer, and each pixel represents the sum of the lengths of streets and major roads (roads, streets, highways and interstate highways) in meters. This thesis used a one-kilometer road density area around each control and electrocution pole point.

3.5. Field Verification

Pole photographs obtained during environmental support for SCE's routine operations and maintenance operations from 2009 to 2014 helped verify electrocution pole data. These photos provided data relevant to the study including conductor numbers, jumpers, and surrounding habitats. Online sources, such as Google Maps and Google Earth provided context to limit the number of poles to examine in the field. A shapefile containing pole locations unverifiable using desktop methods created using ArcMap and was uploaded to a Trimble® Juno 3 Series handheld Global Positioning System (GPS) device. The GPS helped to locate poles by Id, which was easy for the electrocution poles because of pole identifier data in the data set, but more difficult for the randomly selected control poles. Buffers placed around poles helped to overcome this difficulty, 2.5-km buffers created around poles ensured that sufficient distance existed from electrocution poles. This also allowed for selection of alternate poles within 0.5-km of the approximate pole location for poles that were not readily located or deemed inaccessible due to physical or legal (e.g., private property) constraints. I visited 63 electrocution poles and 122 comparison (control) poles from 21 March to through 1 November 2014. The purpose of the site visits was to record the four determinant variables deemed important by Dwyer et al. (2014):

- Number of jumpers;
- Number of primary conductors;
- Presence of grounded equipment; and
- Presence of unforested, unpaved areas as the dominant nearby land cover.

The field verification effort also served to confirm the dominant vegetation type and to populate data fields to match the existing data set, including environmental setting, location description, pole number, and pole design elements (cross arms, jumpers, ground wires, etc.) (see Appendix A for a more complete description/illustration of pole parts).

3.6. Data Analysis Methods

The premise of the first law of geography is that nearby events and items are more similar, that is, autocorrelated than those that are farther apart (Tobler 1970; Fortin and Dale, 2005). Exploratory data analysis visualized avian electrocution patterns and identified potential data clusters. Clustering methods and associated autocorrelation statistics provide methods to statistically and quantitatively analyze patterns that can help identify predictor variables.

Autocorrelation and clustering methods, specifically Getis-Ord local G and Gi* statistics identify concentrated electrocution events, provide information about local high or low clusters (i.e., hot and cold spots) across the study area, and aid understanding of factors potentially contributing to avian electrocutions in the study area.

The Hot Spot Analysis tool in ArcGIS 10.4 was used to calculate the Getis-Ord Gi* statistic for Turkey Vulture, Golden Eagle and Common Raven electrocution events and associated control points. The resultant z-scores and p-values indicated where high or low values cluster spatially for each species. The method employs a local sum for a feature and its neighbors that is compared proportionally to the sum of all features. Statistically significant scores occur when the local sum differs from the expected local sum and that difference is unlikely to be the result of random chance (Mitchell 2005; Getis and Ord 1996).

Logistic regression modeled the relationship between the dependent variable (electrocution events) and the following explanatory variables: pole design factors, proximity to un-forested unpaved areas, vegetation type, and terrain roughness using both categorical and continuous explanatory variables (Table 1). Independent logistic regression analyses were accomplished for each species using the logistic regression analysis tool in XLstat (Addinsoft 2016). The Hosmer-Lemeshow goodness-of-fit test is a statistical test for logistic regression models used in risk analysis. This test assessed how well observed event rates match expected event rates in subgroups of the model population. The Receiver Operating Characteristics (ROC) curve was used to evaluate the performance of the model; models in the range of 0.9 to 1 are considered excellent (Hosmer et al. 2013).

Chapter 4 Results

This chapter documents the temporal and spatial distribution of Golden Eagle, Common Raven and Turkey Vulture electrocutions in the study area. It provides a description of clustering and model outcomes for each species; tests the validity of each model using goodness of fit statistics.

4.1. Electrocution Analysis

4.1.1. Golden Eagle

Within the study area, Golden Eagle electrocution events were highest from November to April with a peak in March (Figure 7). Golden Eagle electrocutions were concentrated in areas dominated by low-growing scrub, such as shadscale scrub and desert saltbush scrub (n=13 or 40%), and herbaceous vegetation such as non-native grasslands and agricultural lands (n=6 or 18%) with few paved roads present nearby (Figure 8).

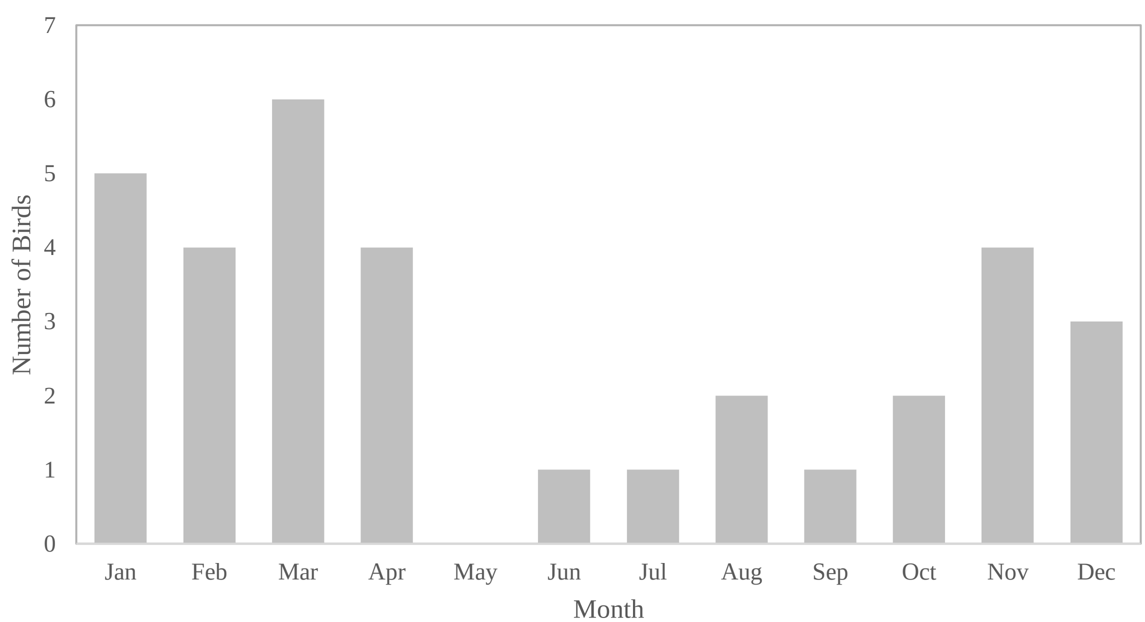

Figure 7. Golden Eagle electrocutions on overhead power lines in the study area from 1981 to 2012.

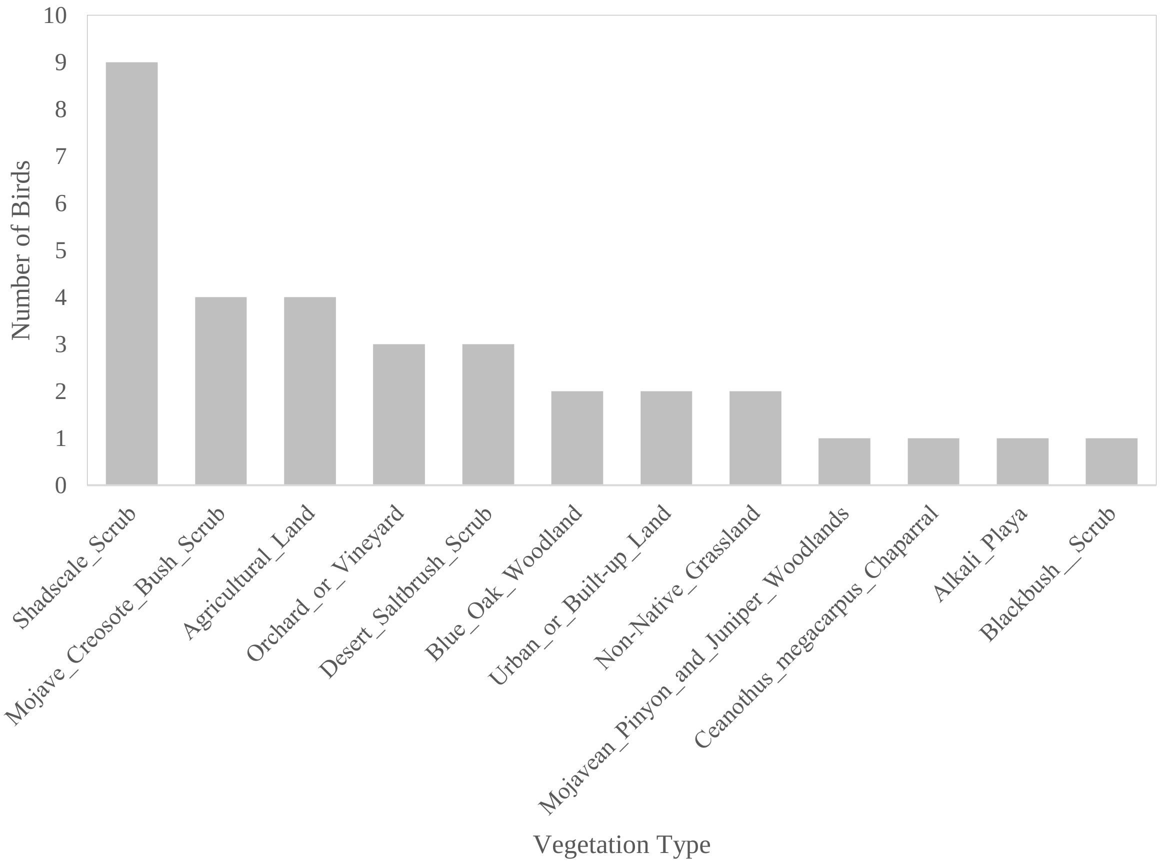

Figure 8. Golden Eagle electrocutions by vegetation type/habitat in the study area from 1981 to 2012.

The results of the clustering analysis for Golden Eagle electrocutions are shown in Figure 9. The high GiZ values for electrocutions in the western and northernmost portions of the study area coincide with the Southern and Eastern Sierra Nevada Mountains and indicate electrocution hot spots for this species in those areas.

Logistic regression analysis was accomplished for the six variables presented in Table 3 and these data were used to construct six models. The best performance was obtained using six variables: conductors, road density, jumpers, presence of a ground, vegetation and TRI.

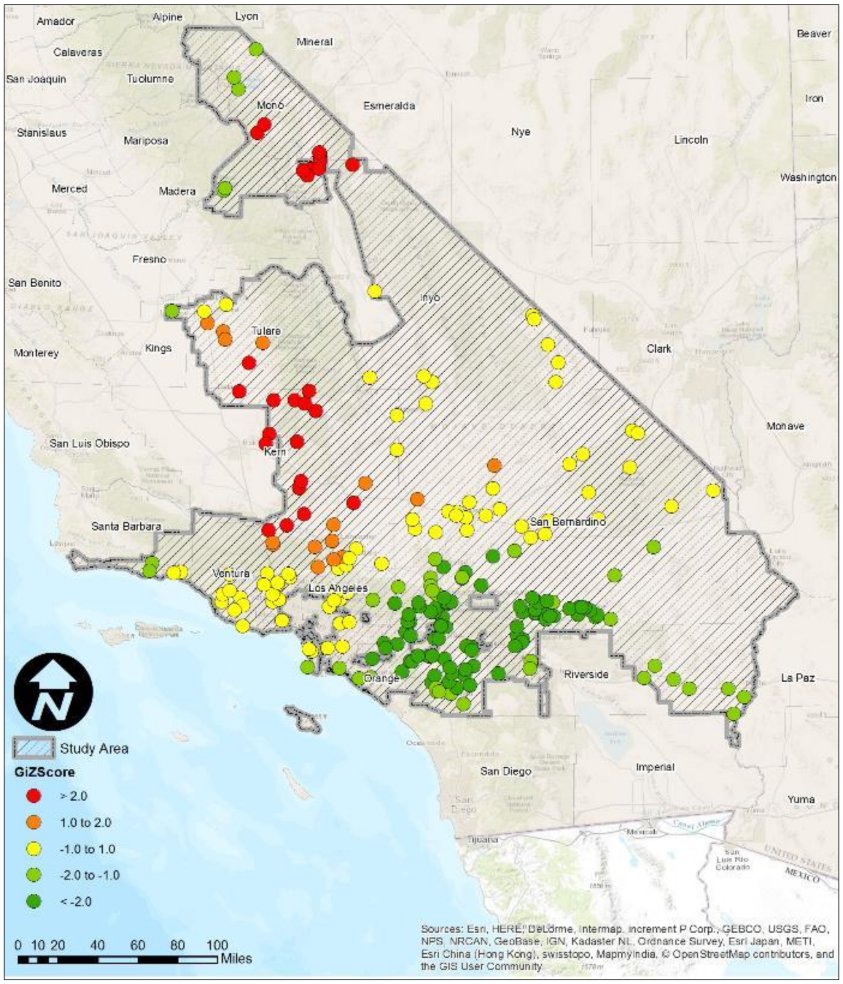

Figure 9. Results of the Hot Spot analysis for Golden Eagle within the study area; hot spots are concentrated on the valley-adjacent slopes on either side of the Sierra Nevada Mountains.

The models for all species are shown in Appendix D.

The goodness of fit statistics for the model are summarized in Table 3. The six-variable model results showed that the model did not fit well χ^2 (8, N = 207) = 8.564, p = 0.702 using the Hosmer-Lemeshow test; however, the model performs in the “Acceptable” range based on the AUC (0.783). according to Hosmer et al. (2013). Figure 10 shows the ROC curve for the model.

Table 3. Goodness of Fit Statistics for Golden Eagle Model.

Statistic	Independent	Full
Observations	207	207
Sum of weights	207.000	207.000
DF	206	189
-2 Log (Likelihood)	178.263	92.735
R^2 (McFadden)	0.000	0.480
R^2 (Cox and Snell)	0.000	0.338
R^2 (Nagelkerke)	0.000	0.586
AIC	180.263	128.735
SBC	183.596	188.724
Iterations	0	6

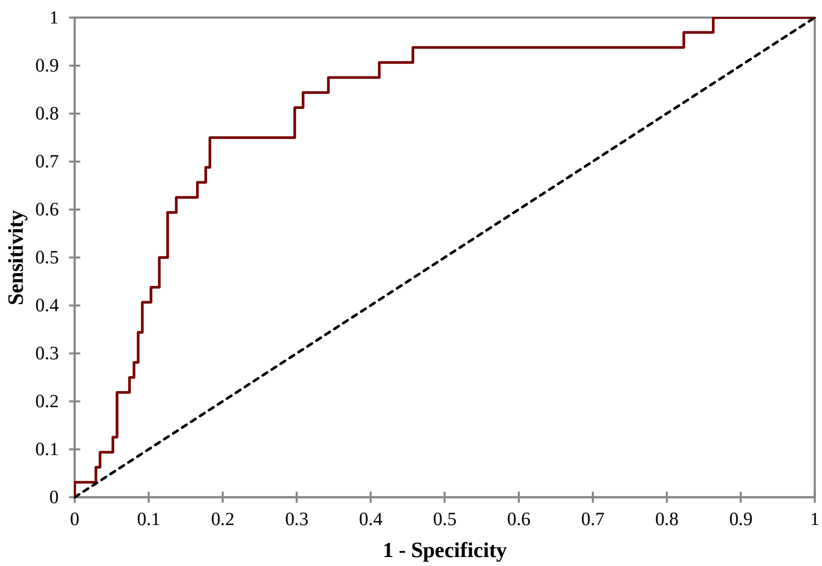

Figure 10. The figure above shows the ROC curve for the Golden Eagle model. The Area Under Curve is 0.783, which is considered above “Acceptable” (Hosmer et al. 2013).

4.1.2. Common Raven

Common Raven electrocution events within the Study Area were highest from May to August with a peak in May (Figure 11). Common Raven electrocutions were concentrated in desert scrub-dominated areas, such as desert saltbush scrub and Mojave creosote bush scrub (n=21 or 24%), and human-influenced areas such as agricultural lands and urban or built-up lands (n=48 or 56%) (Figure 12).

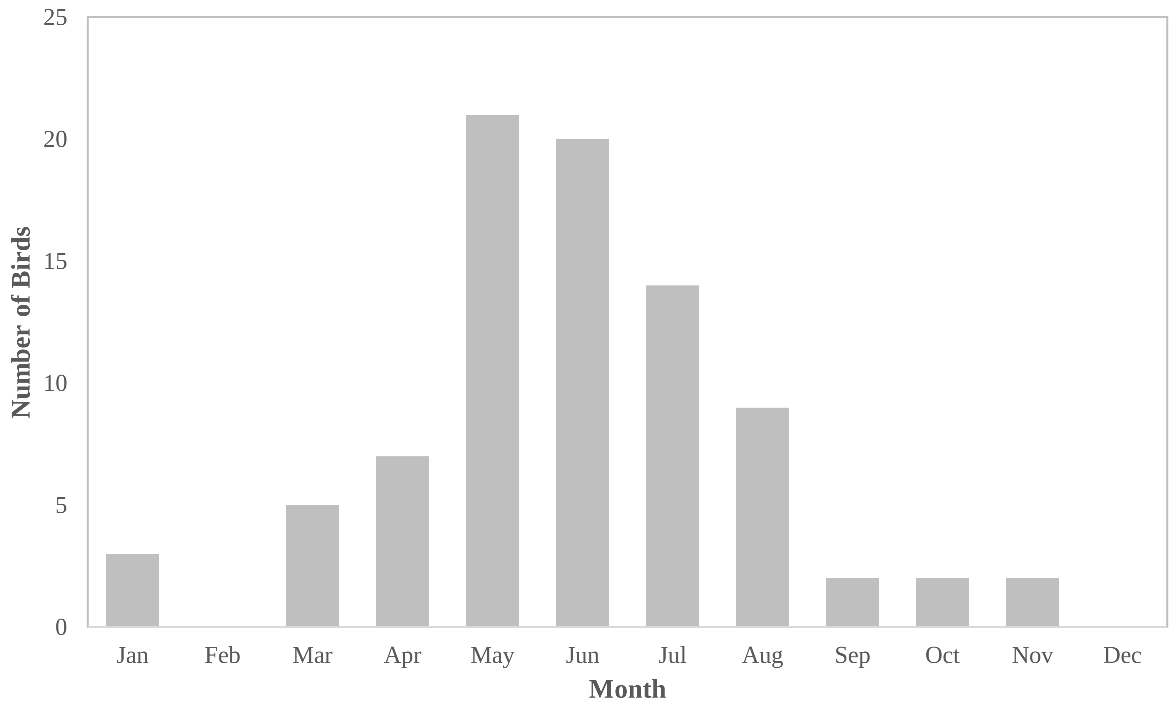

Figure 11. Common Raven electrocutions on overhead power lines in the study area from 1981 to 2012.

The results of clustering analysis for Common Raven electrocutions are shown in Figure 13. The high GiZ scores in the western portion of the study area coincide with the southern Central Valley and the western Mojave Desert and indicate electrocution hot spots for this species in those areas.

Logistic regression analysis was accomplished for the six of the seven variables presented in Table 1 and these data were used to construct ten models. The best-performance was obtained with just four variables: road density, human population, number of jumpers, and TRI (in order of importance) (Appendix D).

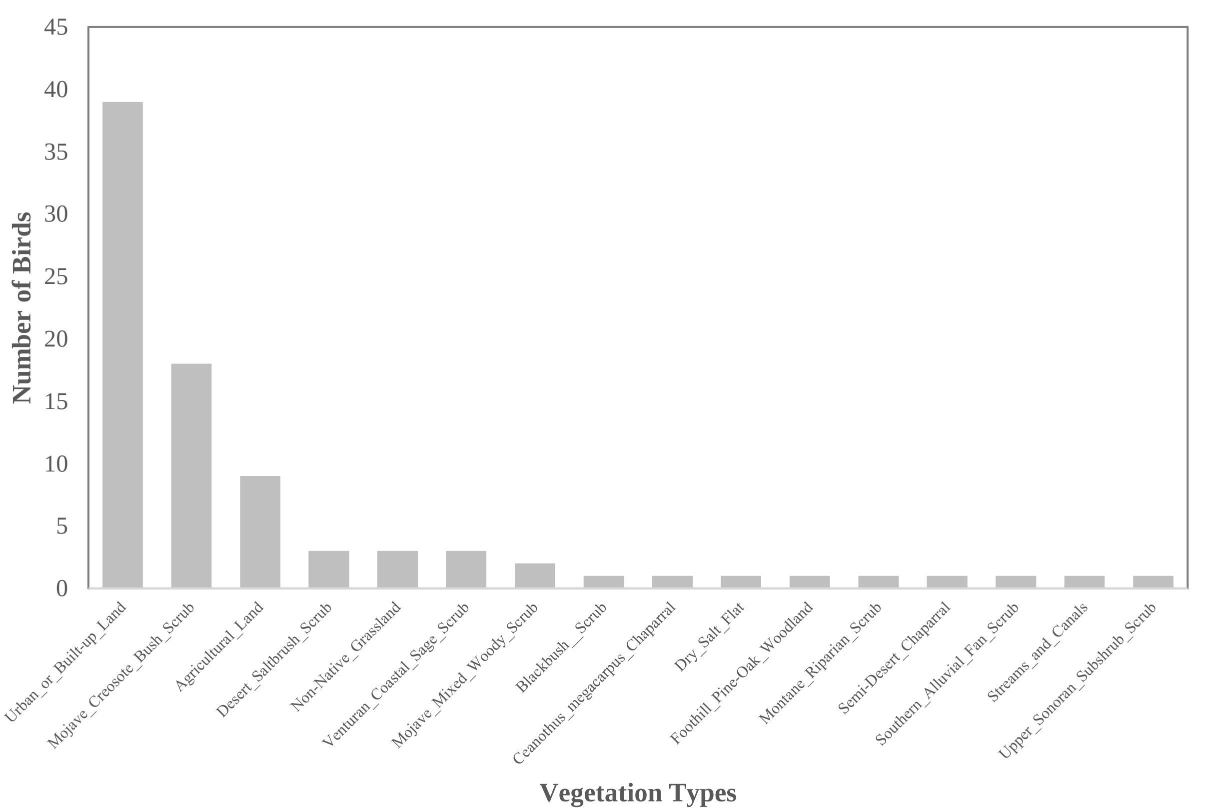

Figure 12. Common Raven electrocutions by vegetation type/habitat in the study area from 1981 to 2012.

The goodness of fit statistics for the model are summarized in Table 4. The Hosmer-Lemeshow goodness-of-fit test was not greater than significant (χ^2 (8, N = 247) = 7.652, p = 0.468) but the AUC displays performance of the Common Raven model; models in the range of 0.7 to 0.8 are considered above average to fair. Figure 14 shows the ROC curve for the model.

4.1.3. Turkey Vulture

Turkey Vultures are gregarious migrants often traveling in large flocks and roosting communally. Their electrocutions in the study area were highest from July to October with a peak in September (Figure 15). Turkey Vulture electrocutions were concentrated in Mojave Creosote Bush Scrub (n=15 or 22%) and human-influenced areas such as non-native grasslands, agricultural lands, orchards and vineyards and urban and built-up lands (n=38 or 57%).

Logistic regression analysis was accomplished for the variables presented in Table 1 and these data were used to construct twenty models. As with Golden Eagle data, separation was noted, so the model was rerun with Firth's penalized likelihood function for correction of biased estimates in logistic regression models. The best-performing model for Turkey Vulture electrocution was obtained with the following variables: Road Density, Population, Topographic Variation, Vegetation, and the presence of water within one kilometer of electrocution events.

Table 4. Goodness of Fit Statistics for the Turkey Vulture Model.

Statistic	Independent	Full
Observations	223	223
Sum of weights	223.000	223.000
DF	222	209
-2 Log (Likelihood)	229.674	69.703
R^2(McFadden)	0.000	0.697
R^2 (Cox and Snell)	0.000	0.512
R^2(Nagelkerke)	0.000	0.796
AIC	231.674	97.703
SBC	235.082	145.403
Iterations	0	6

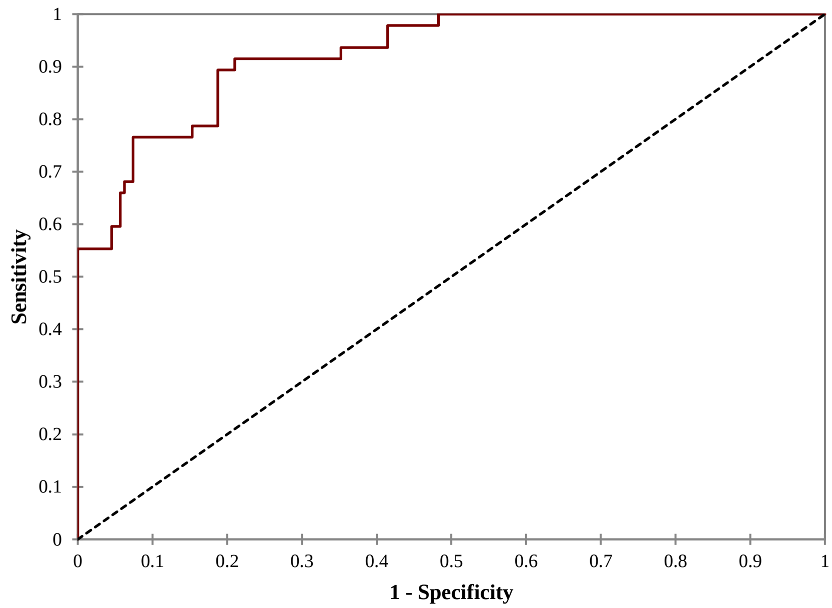

Figure 13. The figure above shows the ROC curve for the Turkey Vulture model. The Area Under Curve is 0.924; 0.90 is considered an excellent explanation/representation of electrocution events for this species.

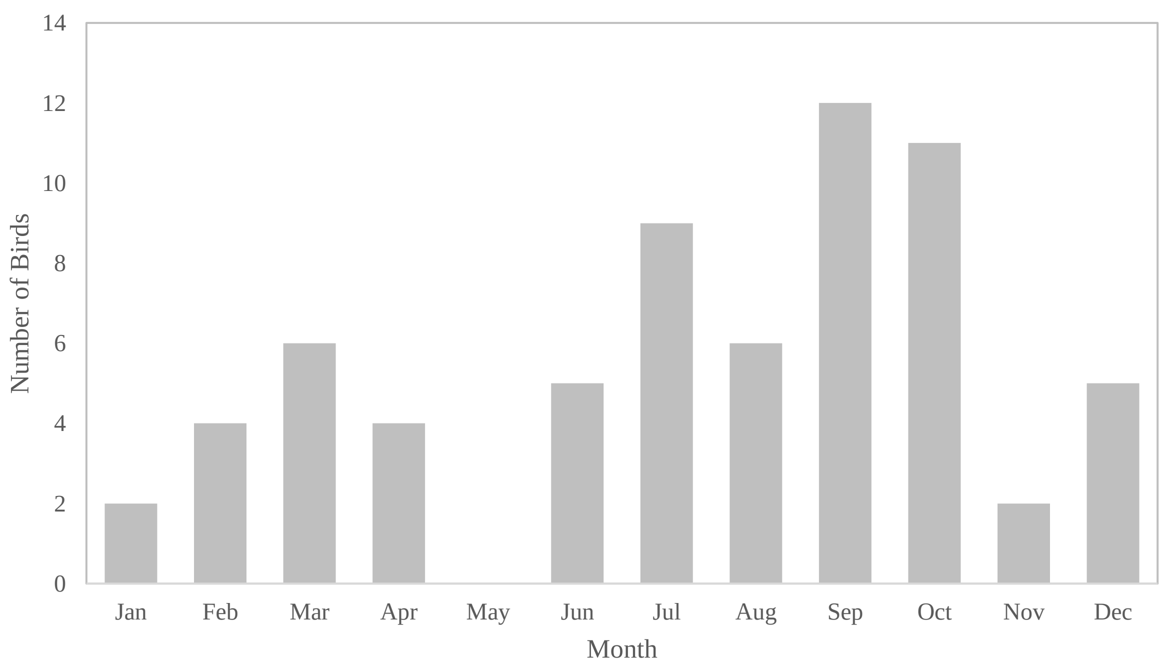

Figure 14. Turkey Vulture electrocutions on overhead power lines in the study area from 1981 to 2012.

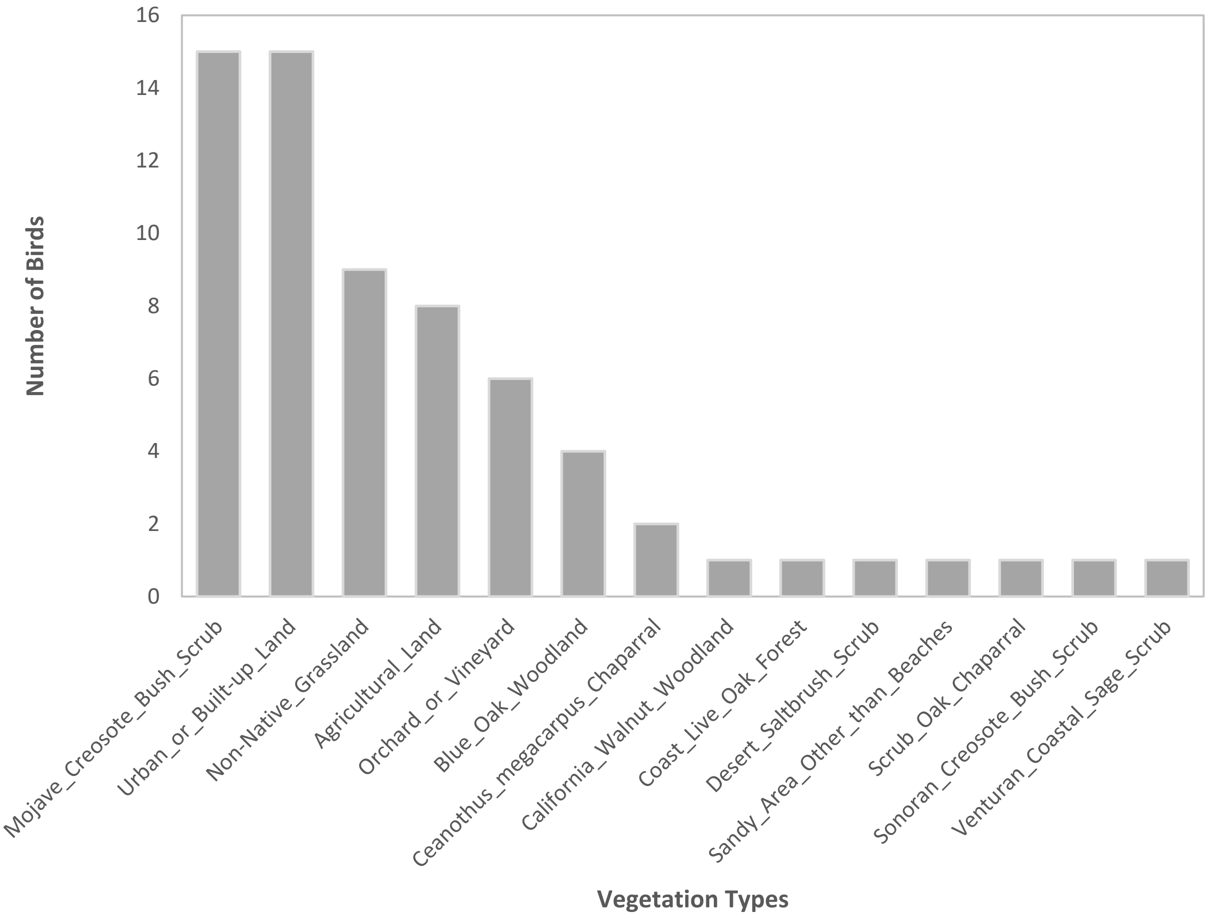

Figure 15. Turkey Vulture electrocutions by vegetation type/habitat in the study area from 1981 to 2012.

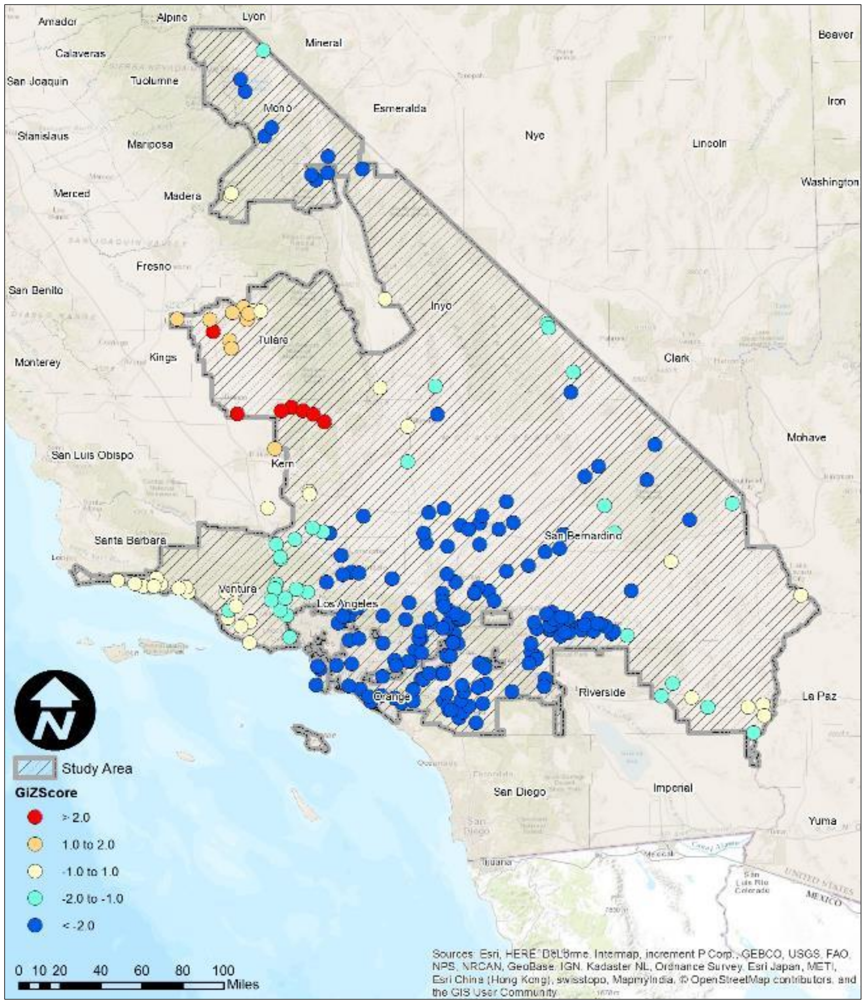

Figure 16. The figure above illustrates the results of the Hot Spot analysis for Turkey Vulture within the study area; clustering occurs in the west-central portion of the study area.

Chapter 5 Discussion and Conclusions

The results of the analysis suggest that environmental factors play a role in the location of electrocutions of the three species examined in the study area (see Table 5). Pole design influenced modeled electrocutions for Turkey Vulture and Common Raven, with conductors and jumpers contributing most to the models for those species. Pole design, including energized hardware, was less important than human influence (absence of roads and low populations) to the Golden Eagle model. Vegetation, topography and proximity to water had the slightest influence on the electrocutions of all three species, although the electrocution patterns for all three species had prevalent vegetation types. The results also suggest that the electrocutions are not random, but that they exhibit clustering in distinct geographic areas and are more prevalent during certain times of the year, offering further clues about their occurrence and possible suggestions for their management.

5.1. Timing, Habitat, and Spatial Characteristics of Electrocutions by Species

5.1.1. All Species

Although Golden Eagle, Common Raven, and Turkey Vulture occur throughout much of the study area, the species selected do not have uniform distributions within the area examined as shown in Section 2.3. Nevertheless, electrocution hotspot clusters did not necessarily coincide with areas where the three species are more abundant. Therefore, the electrocution hotspots of these three species are assumed to be independent of areas where the species are reported to be most abundant.

5.1.2. Golden Eagle

Clusters of Golden Eagle electrocutions in the study area occur where rugged terrain meets expansive valleys, such as where the western slopes of the Sierra Nevada Mountains border the southern Central Valley and where the eastern slopes of the Sierra Nevada Mountains meet Mono Basin and the northern Owens Valley. As the logistic regression model suggests, these areas (where Golden Eagle electrocutions are more frequent) are characterized by low-growing vegetation that occurs in topographically diverse areas with few paved roads. Foraging Golden Eagles likely exploit poles and trees in open habitats as vantage points for hunting lagomorphs (their preferred prey), especially where these are the tallest items in the landscape.

Golden Eagle electrocution clusters do not perfectly coincide with areas of intensive nest placement (see Figure 7). In the traditional North American nesting season, few Golden Eagle electrocutions occur and many more occur in late winter and early spring. This result is expected because Golden Eagle populations are regionally at their largest following the nesting season and in the winter; however, the data used in this study are ambiguous about the relative ages of electrocuted birds. Researchers have noted that juvenile raptors are killed more frequently than adults perhaps due to their underdeveloped flight and landing abilities (Stoychev et al. 2014).

5.1.3. Common Raven

Clusters of Common Raven electrocutions are concentrated in the southern Central Valley, west of Santa Barbara, and in the Antelope Valley at the western edge of the Mojave Desert (see Figure 11). The Breeding Bird Survey (reports that breeding densities for these species are not the highest in these areas, nevertheless, farming and human development in these regions subsidize expanding Common Raven populations and this adaptable species has learned to exploit human infrastructure as nesting platforms (Kristan and Boarman 2007; Boarman et al. 2006). Nesting in human-created electrical infrastructure may explain why within the study area Common Ravens were electrocuted most frequently during and immediately following the nesting season (from May to August with a peak in May) (see Figure 11). It may also explain why most of these electrocutions occurred in desert scrub, agricultural lands, and urban and built-up lands. A review of the electrocution record details shows that some events were related to nest placement on energized equipment in substations and poles resulting in multiple and simultaneous electrocutions of adults and young.

Consistent with cluster analyses in this study, logistic regression results suggest that electrocutions of Common Ravens are influenced most by moderate human population density and vegetation. During the field investigations for this study many, if not most, of the nests observed on poles in rural parts of the western Mojave Desert were occupied by Common Ravens.

5.1.4. Turkey Vulture

Migratory patterns of Turkey Vultures overlap substantial portions of California and, perhaps not surprisingly, electrocutions were documented throughout the study area. Spatial analyses showed an electrocution cluster in the central Sierra Nevada Mountains, west of Lake Isabella. Researchers have documented that large Turkey Vulture flocks congregate there during fall migration (Hunter et al. 1989). The conditions there closely match the results of the logistic regression analysis, which suggests that low road densities and human population, topographic variation, vegetation, and the presence of water within one kilometer of electrocution events contribute to Turkey Vulture electrocution in the study area.

Vegetation in these areas includes grasslands, agricultural lands, orchards, and vineyards, in which over half of the electrocuted Turkey Vultures in the dataset occur. The electrocution clusters are near heavily used nesting areas for the species, according to the Breeding Bird Survey (Pardieck et al. 2013), which is comprised of blue oak woodlands. Blue oak woodland was also the vegetation type that most heavily influenced the Turkey Vulture electrocution model. A recent study by Giusti et al. (2015) relates the importance of cavities in large oaks as nesting sites for Turkey Vultures in California.

Vegetation selection is important because as with Golden Eagles, nearby nesting areas likely augment Turkey Vulture populations in the months following the nesting season. Inexperienced and clumsy juveniles may be more prone to electrocution than adults. Moreover, Turkey Vultures have wide wingspans that can easily span phases or phases and grounds and behaviors that help Turkey Vultures identify ideal conditions for migrating, such as the outstretched wing “horaltic” pose may also increase the species’ chances of electrocution.

5.2. Comparison with Other Studies

The results documented in this study are generally consistent with Dwyer et al. (2014) in supporting the assertion that pole design and hardware are insufficient to explain electrocution in the three subject species. Instead, like Mañosa (2001) and Tinto et al. (2010), the results of the current study suggest that geographical location and habitat setting are as important as design in estimating the risk of electrocution. As suggested by Janss and Ferrer (2001), this study found that electrocution was higher in post-fledging juvenile Golden Eagles. Most of the Golden Eagles found (81%) died of electrocution during the winter months, but fewer than 6% were adult birds. Prey diversity, habitat, and topography were also contributing factors to Golden Eagle electrocution in that study. Sergio et al. (2004) found similar mortality patterns in raptors and other large birds. Electrocution-related deaths of these species spike after juveniles fledge. This was true for Turkey Vulture in this study. For all three species in this study, the findings resemble those of Tinto et al. (2010) and Janss and Ferrer (2001), who suggest that electrocutions of raptors and corvids occur on poles with exposed jumpers and wires in open habitats and with low vegetation cover.

5.3. Effective Electrocution Avoidance/Minimization

A systematic review of electrocution deterrent effectiveness by Lehman et al. (2007) concludes that there are few benefits to electrocution retrofits on poles. The team suggests that raptor mortality reduction on power lines requires careful siting, engineering, and monitoring to test the electrocution minimization method's effectiveness. For Golden Eagles, a federally protected species, Benson (1981) recommends routing lines around preferred prey habitat, locating power poles in topographically low areas, and insulating conductors on corner and transformer poles.

Retrofitting poles with devices that render the poles and hardware unattractive to nesting or perching birds and covers that preclude contact with energized components are methods that reduce the likelihood of electrocution for all three species; however, installing these devices on all poles in the vast service areas covered by utilities is impractical (Figures 19 and 20). Selective application of deterrents is well-served by understanding environmental factors that influence electrocution at poles and other facilities.

To minimize electrocutions cost-effectively, designs and devices that discourage Golden Eagles from perching on power poles should be prioritized in known electrocution clusters, such as the northern Owens Valley and the Mono Basin, the western Sierra Nevada Mountains near the southern Central Valley. Secondarily, anti-perching designs and devices should be installed in areas that meet the characteristics of the preferred Golden Eagle wintering habitat including shadscale scrub, desert saltbush scrub, and herbaceous vegetation such as non-native grasslands and agricultural lands with few paved roads present nearby.

Similar attention should be given to the southern Sierra Nevada Mountains and respective Blue oak woodlands, orchards, grasslands, and vineyards to discourage Turkey Vulture

Figure 17. Bird-safe power poles can be seen in the image, with perch deterrents at the top (marked with arrows). Photograph by Author.

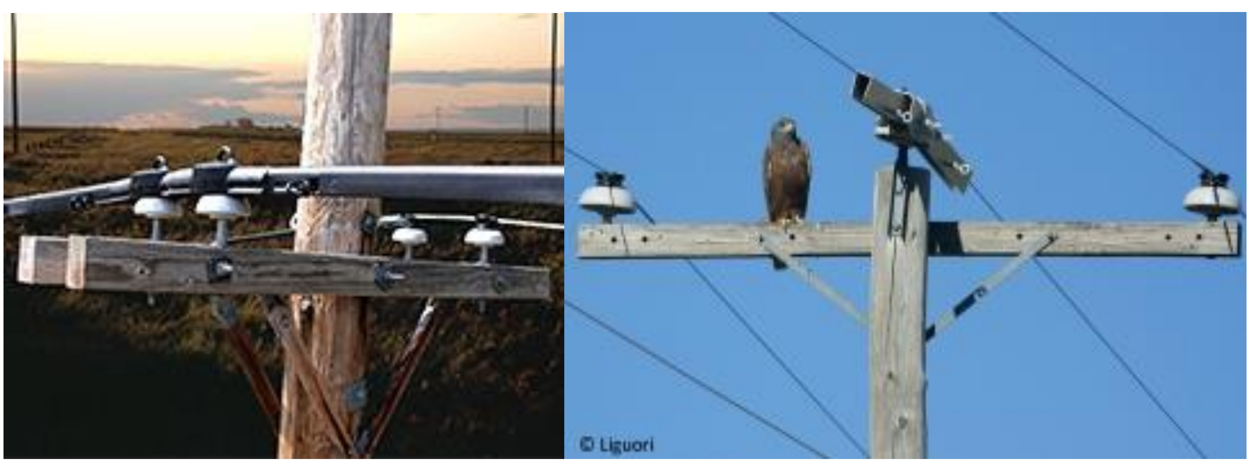

Figure 18. Installed anti-electrocution devices on powerlines. Photograph sources: Deloney LLC, Preformed Line Products, APLIC (2012).

electrocution, particularly those near water. Developing a better understanding of preferred nesting habitats will help inform the thoughtful allocation of resources to prevent or decrease the incidence of Turkey Vulture electrocutions following fledging and dispersal of young birds.

Common Raven populations have increased dramatically in the Mojave Desert over the last century due to human food, water, and nest site subsidies (Knight et al. 1993, Boarman and Berry 1995). Elsewhere, they have learned to use utility structures as nesting sites, which protect them from mammalian predators (Steenhof et al. 1993). Where this species overlaps the range of the federally listed Desert Tortoise (*Gopherus agassizii*), predation of hatchlings and juveniles by Common Ravens has resulted in the localized loss of young, which adversely affects Desert Tortoise population recruitment. Nest removal has sometimes been used to discourage Common Raven nesting on poles, and studies that have examined nest persistence and nest rebuilding rates indicate that these efforts are effective at discouraging nesting. Deterrents to perching and nesting, such as perch discouragers (large spike strips), have been effective at discouraging nesting by Chihuahuan Raven (*Corvus cryptoleucus*) on H-frame structures in southeastern Colorado (Dwyer et al. 2015). Installation of these devices is unlikely practical at a utility scale but may be useful in routinely problematic areas or where Common Ravens predate on special-status species, such as Desert Tortoises.

Increasing and expanding human development results in inevitable conflicts with the natural world. Avian mortality from collisions or electrocutions with electric transmission utility lines is but one example of these conflicts. Spatially explicit models help researchers simulate the conditions that contribute to these mortalities and where they are most prevalent and are, therefore, useful tools for analyzing phenomena that impact species populations. Researchers and resource specialists can use resulting models during facility siting to preclude or minimize impacts to birds, particularly protected species such as Golden Eagle. The models also provide a spatially explicit tool for the application of electrocution and collision deterrents, highlighting that conservation and project goals such as safe and reliable service need not be regarded as opposed or mutually exclusive goals.

5.4. Present Study Challenges and Future Studies

The large geographic area covered by this study posed several accuracy challenges. The Digital Elevation Model used to examine topographic roughness, for example, lacked sufficient detail to tease the subtle topographic details that appear to influence Golden Eagle perch selection at specific electrocution poles south of the Mono Basin. There, a slight rise created by gently rolling hills lifts a few poles above the others and the nearby tree canopy. The poles accommodate a sudden change in line direction with jumpers and extra conductors. Young wintering Golden Eagles perching here gain a commanding view of the surrounding landscape, rich with prey like Audubon cottontails (*Sylvilagus audubonii*) and black-tailed jackrabbits (*Lepus californicus*).

Vegetation data were also insufficient to convey the subtle changes in vegetation visible during the field visits. Datasets such as those that cover large geographic areas are generalized, based on larger/minimum mapping units, and are likely to have more omissions or errors than those focused on more specific areas. Vegetation fragmentation, habitat edges, and mosaics comprised of multiple habitats influence prey availability and associated bird densities. These slight environmental differences although observed during field visits are not conveyed in the dataset.

Future electrocution studies, focused on where electrocutions are prevalent, may better explain pole placement pattern problems in these species through the collection of finer-resolution data. Emerging technology, such as unmanned aerial vehicles equipped with LiDAR, would yield more precise elevations than those available in digital elevation models. LiDAR-equipped drones could collect a data point cloud that reveals subtle topographic details, information regarding perch elevations (cross arms and others), vegetation height and density, and even relative pole heights. Incorporation of these data in the model may validate detailed field observations such as those made at Golden Eagle electrocution locations.

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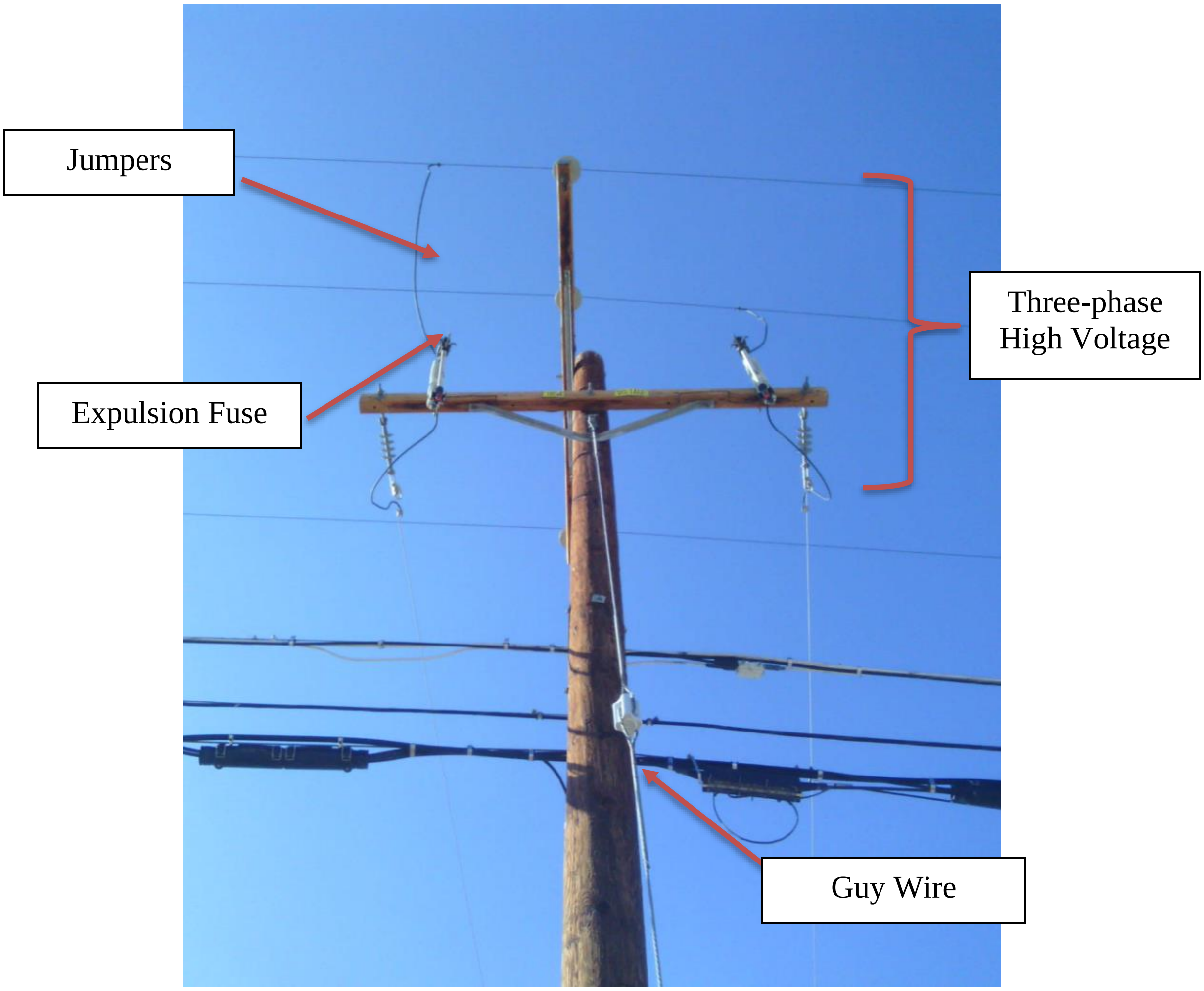
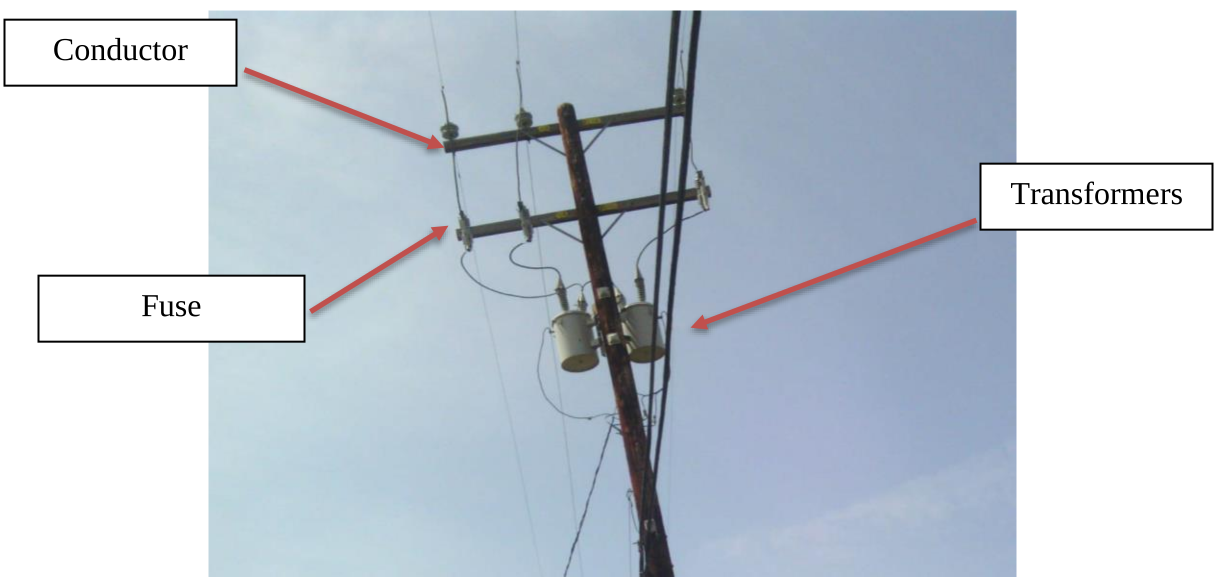
Appendix A: Power Pole Parts Reference Guide





Appendix B: Data Fields in Electrocution Data Set

Heading	Description
INC_ID	Unique Incident Identifier
STRUCTYPE	Type of structure, i.e., tower, pole, h-frame, etc.
INCDATE	Incident Date (reported normally as part of routine inspections or response to outages, fires, etc.) and “Month Date, Year” format
Month	Month of Incident (e.g., January, February, March, etc.)
Month	Month expressed as a numeric value corresponding to number of months in the year
Year	Year expressed as a four-digit value (e.g., 1981, 2006, etc.)
Number	Number of birds involved in incident
INCTIME	Incident time
OUTDUR	Duration of outage (as many incidents coincide with power outages)
SOURCE	How the data were obtained (e.g., other reports, email, etc.)
SRCNAME	Source Name - person generating report
CAUSEFATAL	Cause of fatality, or most apparent reason for avian mortality
VOLTAGE	Voltage associated with utility line or pole
POLENO	Pole number, a unique number identifier for each pole
POLELOC	Pole location refers to the way that the POLENO was obtained
ENVSETTING	Environmental setting is a general description of the area's natura habitat or man-made conditions
WEATHER	General weather conditions (e.g., cool, rainy, hot, windy, etc.)
QUADNAME	Quadrangle name refers to the US Geological Survey 7.5-minute quadrangle in which the incident took place
LABEL	A unique identification number for each bird found
CIRCNAME	Refers to the circuit name for the circuit line on which the incident occurred
DATAEDITOR	The data editor is the person or entity recording the event
SPECIES	Species attributed to the mortality
MORTCLAS	Mortality class distinguishes raptors with the letter “R” from non-raptors designated the letter “A”
X_COORD	x-coordinate for the electrocution in Universal Transverse Mercator (UTM) coordinate system (Longitude)
Y_COORD	y-coordinate for the electrocution in Universal Transverse Mercator (UTM) coordinate system (Latitude)
LATDMS	Latitude in degrees, minutes and seconds
LONGDMS	Longitude in degrees, minutes and seconds
LALOLABEL	Latitude and Longitude in decimal degrees

Heading	Description
NOTES	Notes provide a general description of the incident
EQUIPMENT	Equipment refers to the equipment implicated in the electrocution event
RCONAREA	RCONAREA refers to the geographic subarea in the SCE service area where the incident occurred (e.g., Oxnard Plain, Santa Barbara, Los Angeles Basin, Yucca Valley / 29 Palms, etc.)
AGENCY	Agency refers to land management agency where the incident occurred (e.g., US Forest Service, Bureau of Land Management, Bureau of Indian Affairs, etc.)
TOWERNUM	As applicable, the tower number where the incident occurred
RETROFITTE	Retrofitted is a yes or no field to indicate whether the pole was retrofitted following the event
PAX	Internal communication number
LOC_NOTES	Location notes provides more specific detail on the incident location
DISPOSAL	Disposal of bird involved in incident
LATITUDE	Latitude in decimal degrees
LONGITUDE	Longitude in decimal degrees
POTODESIGN	Pothead, tower or line design implicated in fatality
DISTRICT	SCE district responsibilty (e.g., Yucca Valley, Fullerton, Santa Ana, etc.)
SRCWORKLOC	Responsible entity for work accomplished in retrofit, as applicable
PHOTOS	A field to document if and how many photographs were taken
GPS	A field to document if GPS coordinates were taken
RECOMMEND	Recommendations following electrocution event
HISTORY	History refers to other electrocutions at the pole or in its vicinity
CUSTOMEREF	A customer reference number is provided, if applicable
TBM_PAGE	Thomas Brothers Map page number reference for incident location

Source: SCE Electrocution Dataset 1981 to 2012. These data are available by request from SCE.

Appendix C: Vegetation Classification Crosswalk

Original	Crosswalk
Agricultural_Land	Herbaceous
Alkali_Playa	Playa
Bigcone_Spruce-Canyon_Oak_Forest	Forest
Blackbush Scrub	Short Scrub
Blue_Oak_Woodland	Mosaic
Buck_Brush_Chaparral	Short Scrub
Ceanothus_megacarpus_Chaparral	Tall Scrub
Desert_Dry_Wash_Woodland	Woodland
Desert_Greasewood_Scrub	Short Scrub
Desert_Native_Grassland	Herbaceous
Desert_Saltbrush_Scrub	Short Scrub
Evergreen_Orchard	Orchard
Great_Basin_Mixed_Scrub	Short Scrub
Great_Basin_Woodlands	Woodland
Interior_Live_Oak_Chaparral	Tall Scrub
Jeffrey_Pine_Forest	Forest
Mojave_Creosote_Bush_Scrub	Tall Scrub
Mojave_Mixed_Woody_Scrub	Tall Scrub
Mojave_Riparian_Forest	Forest
Mojavean_Pinyon_and_Juniper_Woodlands	Woodland
Non-Native_Grassland	Herbaceous
Northern_Mixed_Chaparral	Tall Scrub
Open_Foothill_Pine_Woodland	Woodland
Orchard_or_Vineyard	Woodland
Permanently flooded_Lacustrine_Habitat	Wetland
Red_Shank_Chaparral	Tall Scrub
Riversidian_Sage_Scrub	Short Scrub
Semi-Desert_Chaparral	Tall Scrub
Shadscale_Scrub	Short Scrub
Sierran_Mixed_Coniferous_Forest	Forest
Sonoran_Desert_Mixed_Scrub	Short Scrub
Streams_and_Canals	Wetland
Tamarisk_Scrub	Woodland
Upper_Sonoran_Manzanita_Chaparral	Tall Scrub
Urban_or_Built-up_Land	Urban
Venturan_Coastal_Sage_Scrub	Short Scrub
Westside_Ponderosa_Pine_Forest	Forest
California_Walnut_Woodland	Woodland

Original	Crosswalk
Coast_Live_Oak_Forest	Woodland
Sandy_Area_Other_than_Beaches	Beach
Scrub_Oak_Chaparral	Tall Scrub
Sonoran_Creosote_Bush_Scrub	Tall Scrub

Appendix D: Species Electrocution Models

Golden Eagle = 1 / (1 + exp (-(-1.41206348007316+0.134759912506153*JUMPER_N_1-0.133732891131551*CONDUCT__1-1.497235241096E-04*roadedness-0.830754662707134*GROUNDIN_1-1+1.86431086201562*Vegetation-Herbaceous+2.26228991464614*Vegetation-Mosaic+1.52435552934388*Vegetation-Orchard+4.50995761517199*Vegetation-Playa+2.26534390881187*Vegetation-Short Scrub+0.136821240130487*Vegetation-Tall Scrub+1.10773558705471*Vegetation-Urban+1.11465418335934*Vegetation-Wetland+1.80618556843055*Vegetation-Woodland-0.3611698462226*Reclass_tp-2-0.608772621511291*Reclass_tp-3-0.221134591272924*Reclass_tp-4+0.493965875887805*Reclass_tp-5)))

Common Raven = 1 / (1 + exp (-(2.87181089531813-4.09748666114666E-04*usa_pop__1-5.85087525896981*Vegetation-Forest-4.94092120544916*Vegetation-Herbaceous-0.388033099263139*Vegetation-Low Scrub-3.9691939379879*Vegetation-Mosaic-3.96181846199784*Vegetation-Orchard-1.77319860665053*Vegetation-Playa-1.77074011465384*Vegetation-Riparian-7.8759493726591*Vegetation-Scrub+0.272667295501756*Vegetation-Tall Scrub-3.80885464143907*Vegetation-Urban-4.47042578290665*Vegetation-Wetland-4.68301287136058*Vegetation-Woodland)))

Turkey Vulture = 1 / (1 + exp (-(-1.77285542017879-4.72394033506478E-05*roadedness+1.20848077700155E-04*usa_pop_Cl-1.88913241744233*tpi1_Proje+1.75493985766466*Vegetation-Herbaceous+3.89726997235359*Vegetation-Mosaic+1.51310086671033*Vegetation-Orchard+0.122946968364092*Vegetation-Short Scrub+1.62901391614301*Vegetation-Tall Scrub+1.4157627149375*Vegetation-Urban+0.521481311689685*Vegetation-Wetland+2.36553473175266*Vegetation-Woodland+0.292364233680882*Water-1)))