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Evaluating the Effectiveness of Avian Interaction Mitigating Measures and Processes

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PREFACE

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Evaluating the Effectiveness of Avian Interaction Mitigating Measures and Processes is the final report for the project entitled Evaluating the Effectiveness of Avian Interaction Mitigation and Processes, project (contract number PIR-08-026) conducted by EDM International, Inc. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

Avian contact with overhead electric equipment can result in electrocution, equipment damage and power outages. Some California utilities are proactively developing avian protection plans and risk assessments to direct resources toward reducing avian contacts. In support of avian protection planning, Southern California Edison (Edison) partnered with EDM International, Inc. (EDM) and the California Energy Commission to perform four tasks to support their ongoing avian program. Specifically, EDM evaluated retrofitting along Edison's Magunden-Vestal 220kV line, identified patterns in historical data describing avian electrocution and collision (collectively "incidents"), tested an existing logistic regression model designed to predict the likelihood that evaluted structures would to be involved in avian electrocutions, and developed a revised logistic regression model to predict avian electrocutions. EDM concluded that retrofitting the Magunden-Vestal 220kV line appeared to have reduced incidents. In Edison's historical system wide outage data, EDM found incidents were most common May-June at distribution voltages on structures supporting energized equipment, and most commonly associated with red-tailed hawks and American crows. When bald eagles and golden eagles were evaluated separately, EDM found incidents were most common January-April on primary conductors at distribution voltages. The orginal logistic regression model tested did not distinguish Edison incident from comparison structures. To build a revised logistic regression model, EDM visited incident structures and comparison structures where no incidents were recorded. The resulting EDM model successfully predicted problem poles based on data from only 4 variables: 1) number of jumpers, 2) number of phases, 3) presence or absence of any pole-top grounding, and 4) presence or absence of unpaved open habitat as the dominant land cover within 200 m. The revised model correctly classified 90% structures used to validate the model. EDM's model can be used by Edison to strategically, consistently, and transparently prioritize structures for retrofitting.

Keywords: avian, avian protection plan, California, collision, electrocution, logistic regression, modeling, power line, raptor, retrofit

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EXECUTIVE SUMMARY

Introduction

Conflicts between birds and overhead electric transmission and distribution systems have been recognized in the United States since the early 1970s and are a conservation concern of global importance. Such interactions include collisions, electrocutions, electric shock injuries, and undesired perching or nesting by predators with potential impacts to prey species. Problem interactions can impact system reliability by causing outages or bird related equipment damage and fires. In summary, avian electrocutions can violate federal and state laws, reduce system reliability, and negatively impact public safety.

To reduce avian electrocutions, some California utilities are proactively developing avian protection plans. Avian protection plans enable utilities to focus limited resources on the highest risk structures and areas, thus enabling the greatest positive impact per expenditure. Avian protection plans often incorporate evaluating of existing retrofitting measures, evaluation of historical records, if available, and identification of high risk structures for retrofitting. Identification of high risk structures has typically relied on evaluations conducted by experts familiar with both avian biology and overhead electric systems. Quantitative modeling of electrocution risk has been undertaken in some areas and offers increased transparency in prioritizing structures for retrofitting, but has not yet been widely applied in the United States.

Purpose

Southern California Edison partnered with the California Energy Commission and EDM International, Inc. to:

- Evaluate retrofitting conducted under Southern California Edison's draft avian protection plan on the Magunden-Vestal 220kV line.
- Identify patterns in Southern California Edison's (Edison's) historical records describing avian electrocutions and collisions.
- Test an existing logistic regression electrocution risk calculator developed partially from data collected within Edison's electric service area.
- Develop an alternative logistic regression electrocution risk calculator from data collected entirely from within Edison's electric service area.

Approach

EDM evaluated retrofitting along Edison's Magunden-Vestal 220kV line, identified patterns in historical data describing avian electrocution and collision (collectively "incidents"), tested an existing logistic regression model, a statistical process for estimating the relationships among variables to predict the likelihood that evaluted structures would to be involved in avian electrocutions, and developed a robust logistic regression model to better predict avian electrocutions

Conclusions

Magunden-Vestal retrofitting:

- Retrofitting on the Magunden-Vestal 220kV line appeared to have reduced avian related outages on the line despite concurrent increases in at-risk species in the area.

Historical Records:

- In Edison's service area, there was an 1880% increase in documentation of avian electrocutions and collisions (collectively "incidents") in 2000-2009 as compared to 1981-1999, likely as a result of increased awareness rather than increased occurrence of incidents. There was only a 24% increase in the number of incidents involving bald eagles and golden eagles in 2000-2009 as compared to 1981-1999, also likely as a result of increased awareness rather than increased occurrence of incidents.
- Electrocutions were most common during the breeding seasons in May, June and July of most avian species.
- Electrocutions were most common for bald eagles and golden eagles in January, February, March and April during the breeding season for eagles.
- There were no monthly patterns in collision risk for either all species in general, or eagle species in particular.
- Many records of incidents did not identify a particular species, but when a species was identified, red-tailed hawks and American crows were most commonly identified.
- Most electrocutions and collisions occurred at distribution voltages (≤33kV) for all species in general, and for eagle species in particular.
- Most incidents were not associated with a particular piece of equipment, but when equipment was implicated, transformers, potheads (an insulated electrical terminal), and surge arresters were the equipment types most commonly associated with avian electrocutions.
- Contact with primary conductors was the most commonly identified cause of eagle electrocution.
- Incidents of all species occurred widely throughout the service area, but were most common in the San Joaquin Valley, Valencia, Montebello and South Bay districts.
- Incidents involving eagles were most common in the San Joaquin Valley, Antelope Valley and Bishop-Mammoth districts.

Logistic Regression Modeling:

- The existing logistic regression model did not distinguish between incident structures and comparison structures ($\chi^2_3 = 6.13$, $n = 461$, $P = 0.106$).
- The revised model included 10 independent candidate variables that addressed equipment characteristics, location and bird activity.
- AIC corrected for small sample size (AICc; Anderson 2008) was used to rank models.

- In contrast to the original model which required data collection for 22 variables, the revised model required only 4 variables. These variables were:
    - Number of jumpers
    - Number of phases
    - Presence of grounding
    - Presence of unpaved open habitat as the dominant land cover within 200 m
- The revised model successfully predicted where interactions would occur. Based on the revised model, the probability of electrocution:
    - Increased approximately 1.0-2.3% with each jumper.
    - Increased 2.0-3.5% with each primary conductor.
    - Increased approximately 4.0-13.0% with the presence of any pole-top grounding.
    - Increased 4.5-13.7% when open habitat was absent. The habitat variable appears to be driven primarily by the inclusion of a large number of urban incidents involving American crows.

The revised model was simpler to use, successfully identified structures where historical avian electrocutions occurred, and was effective in identifying structures where avian electrocutions were unlikely. Though the population to which inference can reasonably be drawn for the revised model was substantially more limited than that of the original model, the revised model demonstrated that a quantitative risk assessment strategy could facilitate placing mitigation where electrocutions were most likely.

Benefits for California

This research benefits California by demonstrating ongoing efforts by Edison to reduce avian impacts and to improve system reliability have been successful and should serve as an example for continued efforts. This research also demonstrates that an electrocution model can be used to predict avian risk, and benefits California by providing a model specifically built in and for one of California's largest electric utilities.

CHAPTER 1:
Evaluation of Retrofiting Measures to Prevent Streamer Outages on the Magunden Vestal 220kV Lines

In today's digital society, expectations for power quality and reliability are increasing. Because transmission line reliability is a key component in meeting those expectations, utilities continuously seek cost-effective ways to minimize the frequency and duration of forced outages. Some outages occur following direct contact between animals and energized parts (National Rural Electric Cooperative Association [NRECA] 1996), while other outages are caused by bird streamers (Burnham 1995; Van Rooyen et al. 2002; Zhou et al. 2009). A bird streamer is produced when a large bird releases a long stream of excrement either while perched on, or flying over a transmission tower. Streamer-related outages occur when a streamer bridges the gap between an energized wire and a grounded metal tower, or fills a sufficient part of that gap and facilitates arcing through air or tracking over conductors (Van Rooyen et al. 2003). Streamer pollution also can occur when avian excrement accumulates on overhead hardware. The number and species composition of birds around a line segment, and the voiding behavior of each species influences whether streamers are a concern. Fortunately, utilities can install or retrofit equipment to minimize the potential for such animal-caused outages.

Southern California Edison (Edison) has recorded bird streamers as a probable cause of forced outages since 1924 (Michener 1924). As technologies have improved, Edison has acted to minimize streamer-related outages. In 2005, Edison suspected bird streamers were causing repeated forced outages on two of its 220 kilovolt (kV) transmission lines: the Magunden-Vestal No. 1 and No. 2 transmission lines (MV1 and MV2, respectively). In response, Edison contracted EDM International, Inc. (EDM) to perform a study to identify whether streamers were likely to be a significant cause of forced outages on the Magunden-Vestal 220kV lines and, if so, to develop a mitigation program.

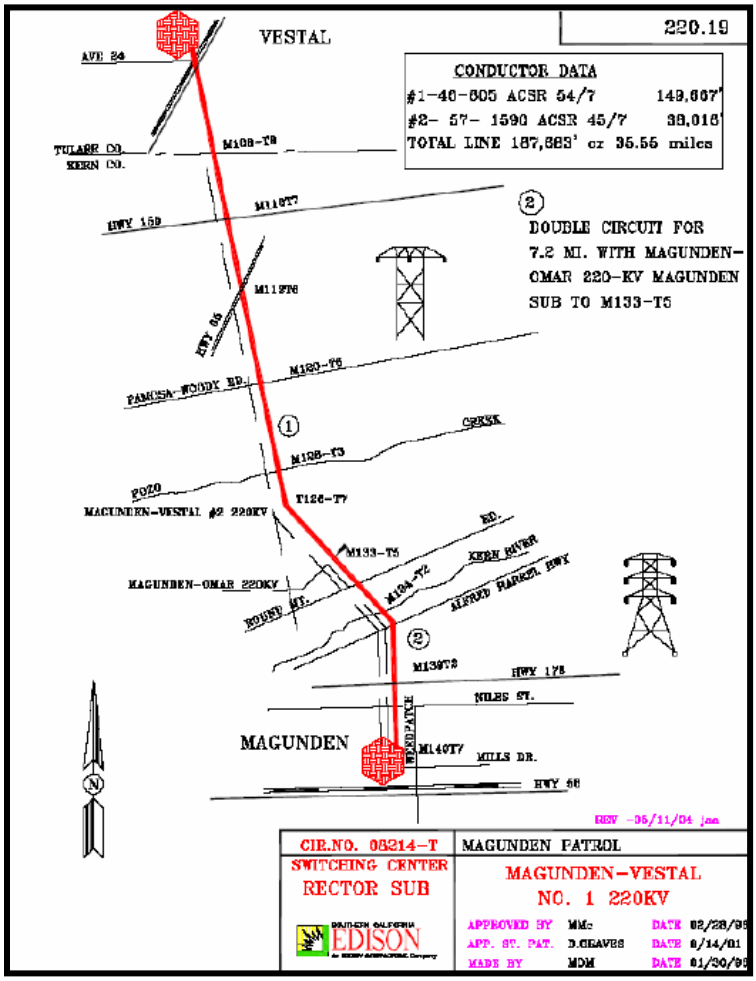
EDM collected and reviewed structure drawings and photos, GIS data, and outage records relating to the Magunden-Vestal 220kV lines, and conducted a field inspection of the line. Based on these activities, EDM concluded that bird streamers were reducing the reliability of the Magunden-Vestal 220kV lines, and that existing methods to prevent bird-caused outages could be improved. EDM recommended that the center conductor at all suspended and double deadend structures be insulated (EDM 2005). Although extensive information exists on a global scale regarding avian interactions with power lines, very little follow-up work has been conducted on the long-term effectiveness of retrofitting techniques and devices (Lehman et al. 2007). In the absence of published reports describing similar mitigation approaches, Edison and EDM partnered to evaluate the effectiveness of Edison's retrofitting measures applied to the Magunden-Vestal 220kV lines.

In this chapter, EDM reviews the extent of retrofitting applied by Edison, recent Edison forced-outage data from the Magunden-Vestal 220kV lines, and trends in raptor occurrence in the project area. The report concludes with an evaluation of retrofitting effectiveness and recommendations for future actions. Field observations and photographs were collected November 22, 2010 from 0900 to 1730 hours local time, and November 23, 2010 from 0730 to 1000 hours local time.

1.1 Survey Area

The Magunden-Vestal 220kV lines run generally north-south between Magunden and Vestal, California in Kern and Tulare counties (Figure 1). There are two parallel lines, designated MV1 (east line) and MV2 (west line). The structures supporting the lines are numbered with a prefix by mile and suffix within each mile. For example, Structure 116_1 is the first structure in Mile 116. The surveyed area extended from the Vestal Substation (Mile 105) to the Magunden Substation (Mile 140).

Figure 1: Route of Magunden-Vestal 220kV Lines



Source: Southern California Edison.

Immediately adjacent to the Vestal Substation, the MV1 and MV2 lines co-occur on double-circuit structures. Thereafter, the MV1 and MV2 lines are suspended on parallel single-circuit structures before being joined by a third line north of the Magunden Substation (Table 1). The northern quarter of the line transects primarily agricultural land producing grape, citrus, and other row crops (Figure 2). The remainder of the line is surrounded almost exclusively by rangelands used for cattle production (Figure 3) until the line passes through urban areas and desert rights-of-way (Figure 4) near the Magunden Substation (Table 1).

Table 1: Descriptions of Magunden-Vestal 220kV Structures and Landscape

Mile	Structure Description	Landscape
105	MV1 and MV2 together on DC	Agriculture (row crop, grape, citrus)
106-113	MV1 and MV2 on parallel SC	Agriculture (row crop, grape, citrus)
114-132	MV1 and MV2 on parallel SC	Rangeland (cattle)
133-138	MV1 and another line on DC, MV2 on parallel SC	Rangeland (cattle)
139-140	MV1 and another line on DC, MV2 on parallel SC	Desert or urban

DC: Double-circuit structure
SC: Single-circuit structure
MV1: Magunden-Vestal 220kV line No. 1 (the more eastern of the lines)
MV2: Magunden-Vestal 220kV line No. 2 (the more western of the lines)

Source: EDM International, Inc.

Raptors were attributed with most of the streamer-related forced outages on these lines (EDM 2005). Raptors often are attracted to structures based on local prey availability (Avian Power Line Interaction Committee [APLIC] 2006). Common prey animals around the Magunden-Vestal 220kV lines include the California ground squirrel, black-tailed jackrabbit, desert cottontail, striped skunk, and spotted skunk (EDM 2005).

Figure 2: Aerial View of Landscape Typical of Northern-most Portion of the Magunden-Vestal 220kV Line (white arrow)

Source: EDM International, Inc., Base image Google Earth.

Figure 3: Ground Level View of Landscape Typical of Most of the Magunden-Vestal 220kV Line (view north from Structure 116_4)

Source: EDM International, Inc.

Figure 4: Aerial View of Landscape Typical of Southern-most Portion of the Magunden-Vestal 220kV Line (white arrow)

Source: EDM International, Inc., Base image Google Earth.

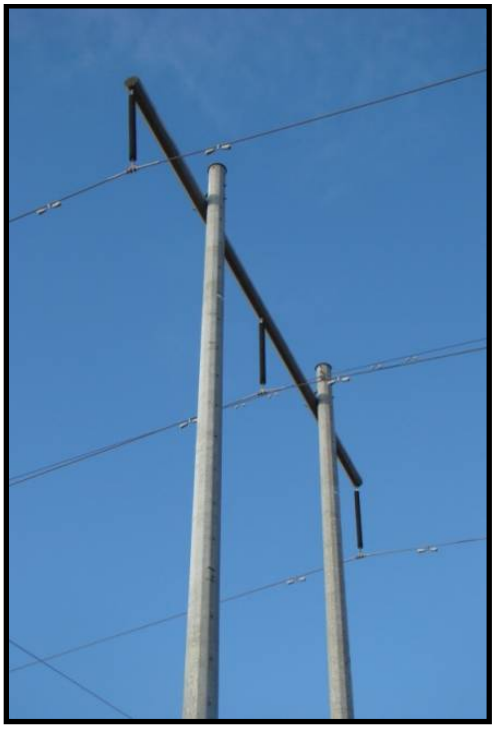
1.2 Structure Types

The Magunden-Vestal 220kV lines are supported by single-circuit suspended structures (Figure 5 and Figure 6), single-circuit double deadend structures (Figure 7), and double-circuit suspended structures (Figure 8).

Figure 5: Structure MV1 120_4; Single-circuit Suspended Structure

Source: EDM International, Inc.

Figure 6: Structure MV1 4410492; Non-lattice Single-circuit Suspended Structure



Source: EDM International, Inc.

Figure 7: Structure MV2 129_5; Single-circuit Double Deadend Structure

Source: EDM International, Inc.

Figure 8: Structure MV1 137_4; Double-circuit Suspended Structure

Source: EDM International, Inc.

1.3 Extent of Retrofitting

The location of bird nests, pellets, and excrement on and beneath transmission structures can help identify where birds perch and where streamers or other bird-related pollution are likely to occur (Electric Power Research Institute (EPRI) 2008). Using this strategy together with outage data, the center phase of the single-circuit structures were identified as at highest risk of involvement in a streamer-related forced outage (EDM 2005). Prior to 2005, many single-circuit structures on MV1 and MV2 had been modified with screens designed to prevent avian access

to the portion of the structure directly above the center phase. Some structures also were fitted with one or more of the following: metal pans designed to prevent avian pollution from reaching the center phase, horizontal wire perch deterrents designed to prevent perching on the top of structures, and bird spikes designed to prevent perching on other portions of structures. One structure had been retrofitted with a longer center phase insulator, one had a failed center phase cover, and one had an insulated center phase jumper (EDM 2005).

Following the EDM report (EDM 2005), Senior Patrolman for Edison's Northern Region Transmission System coordinated with Raychem (Tyco Electronics) to design a conductor cover for the center phase on suspended structures on the Magunden-Vestal 220kV lines (EDM 2010). During this study, Raychem covers deployed by Edison were seen on the center phase of all but eight of the suspended structures from Mile 105 through Mile 133 (Table 2). No suspended structures were retrofitted adjacent to urban areas from Mile 134 through Mile 140. From Mile 105 through Mile 133, 96% of the suspended structures were retrofitted with center phase covers.

Only two covers (structures MV2 116_1 and 116_2) showed evidence of impending failure. Each had slipped off the line at one end (Figure 9 and Figure 10). In general, the phase covers fit well at structures with and without weights, vibration dampers, or both weights and dampers. There was a broken insulator bell on Structure MV2 135_5. No other new retrofitting was observed.

Table 2: Descriptions of Magunden-Vestal 220kV Structures and Retrofitting

Mile	Structure Description	Description of Retrofitting
105	MV1 and MV2 together on DC	Raychem on center phase of all SC
106-107	MV1 and MV2 on parallel SC	Raychem on center phase of all SC
108	MV1 and MV2 on parallel SC	Missing covers on SC MV2 108_5 to 108_9; Raychem on all other SC
109-113	MV1 and MV2 on parallel SC	Raychem on center phase of all SC
114	MV1 and MV2 on parallel SC	Missing covers on SC MV1 and MV2 114_0; could not see MV1 or MV2 110_7 to 114_5
115	MV1 and MV2 on parallel SC	Raychem on center phase of all SC
116	MV1 and MV2 on parallel SC	Cover slipping off MV2 116_1 and 116_2; Raychem on all other SC
117-132	MV1 and MV2 on parallel SC	Raychem on center phase of all SC
133	MV1 and another line on DC, MV2 on parallel SC	Missing cover on MV2 133_6; Raychem covers on center phase of all SC
134-140	MV1 and another line on DC, MV2 on parallel SC	None

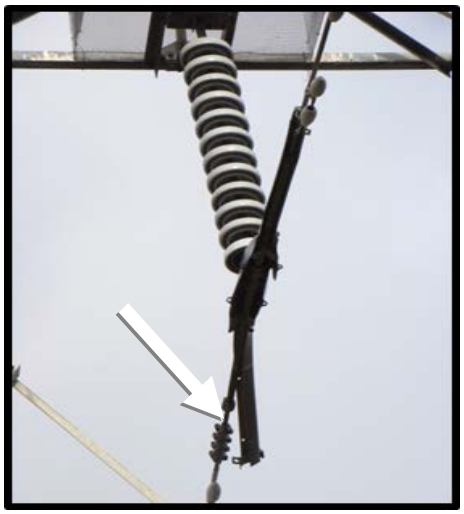
DC: Double-circuit structure
SC: Single-circuit structure
MV1: Magunden-Vestal 220kV line No. 1 (the more eastern of the lines)
MV2: Magunden-Vestal 220kV line No. 2 (the more western of the lines)
Raychem: (Tyco Electronics) conductor cover for the center phases on suspended structures

Source: EDM International, Inc.

Figure 9: MV2 116_2 with Center Phase Cover Slipping off of the Primary Line

Source: EDM International, Inc.

Figure 10: Structure MV2 116_1 with Center Phase Cover Slipping off of the Primary Line



Source: EDM International, Inc.

1.4 Avian Use of Structures

Twenty-nine common ravens, 18 red-tailed hawks, 3 golden eagles, 2 northern harriers, and 1 peregrine falcon were observed perching on or flying near structures supporting the Magunden-Vestal 220kV lines. Additionally, 64 complete or partial nests were observed on or at the base of MV1 and MV2 structures including two nests on one double-circuit suspended structure (Table 3). A dead common raven was suspended from nest materials on single-circuit double deadend Structure MV2 129_5 (Figure 11). Nests often contained conductive materials

such as bailing wire or fence wire (Figure 12). Avian pollution was observed on 15 additional structures that did not support nests, and on 8 Raychem covers.

Table 3: Locations of Nests on Magunden-Vestal 220kV Line Structures

Structure Number[1]	MV#[2]	No. of Circuits[3]	Structure Type[4]	Notes[5,6]
113_9	1	1	SUS	Nest not over phase wire
114_4	1	1	DDE	Complete
114_4	2	1	DDE	Complete
115_1	1	1	SUS	Incomplete nest
115_3	2	1	DDE	Complete
115_6	2	1	SUS	Nest has fallen
116_1	2	1	SUS	Complete
116_4	1	1	DDE	Complete
116_4	2	1	DDE	Complete
117_2	2	1	SUS	Incomplete nest
117_2	1	1	SUS	Incomplete nest
117_3	2	1	SUS	Incomplete nest
117_3	1	1	SUS	Incomplete nest
117_4	2	1	DDE	Complete
117_6	2	1	SUS	Complete
118_2	1	1	SUS	Incomplete nest
118_3	1	1	SUS	Incomplete nest
118_5	2	1	DDE	Incomplete nest
119_3	1	1	DDE	Incomplete nest
120_1	2	1	SUS	Incomplete nest
120_2	1	1	SUS	Incomplete nest
120_3	2	1	SUS	Incomplete nest
120_4	1	1	SUS	Complete
120_5	2	1	SUS	Complete
121_1	2	1	SUS	Complete
121_2	2	1	DDE	Incomplete nest
121_4	2	1	SUS	Complete
122_1	1	1	DDE	Complete
122_2	1	1	DDE	Complete
122_3	1	1	DDE	Incomplete nest
123_1	1	1	DDE	Nest has fallen
126_5	2	1	SUS	Complete
127_1	1	1	DDE	Complete
127_1	2	1	SUS	Complete
127_3	2	1	SUS	Complete

Structure Number[1]	MV#[2]	No. of Circuits[3]	Structure Type[4]	Notes[5,6]
127_4	2	1	DDE	GOEA nest (?) center phase covered
128_6	1	1	SUS	Complete
129_1	2	1	SUS	Complete
129_3	1	1	DDE	Complete
129_3	2	1	SUS	Complete
129_5	2	1	DDE	Dead CORA hanging from nest
129_6	2	1	DDE	Complete
130_2	2	1	SUS	Complete
130_4	2	1	SUS	Complete
130_5	1	1	SUS	Complete
130_6	1	1	SUS	Complete
130_6	2	1	SUS	Complete
130_8	2	1	SUS	Incomplete nest
131_1	1	1	DDE	Complete
131_2	2	1	SUS	Complete
131_3	1	1	SUS	Complete
131_3	2	1	SUS	Complete
131_5	1	1	DDE	Complete
132_3	1	1	DDE	Complete
132_4	1	1	SUS	Complete
132_5	1	1	DDE	Complete
132_5	2	1	DDE	Complete
136_1	1	2	SUS	Nest not over phase wire
136_2	1	2	SUS	Nest not over phase wire
136_3	1	2	SUS	Nest not over phase wire
137_4	1	2	SUS	Nest not over phase wire
138_3	1	2	SUS	Two nests. Neither over phase wire
139_4	1	2	SUS	Nest not over phase wire
140_4	2	1	SUS	Complete

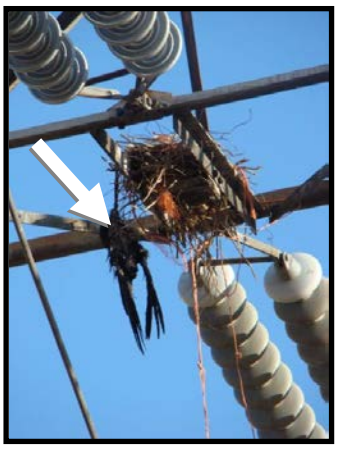
[1] Structures supporting the lines are numbered with a prefix by mile and suffix within each mile
[2] The lines are composed of two parallel 220kV lines, designated MV1 (east line) and MV2 (west line)
[3] The number of three-phase transmission circuits supported by each structure
[4] DDE = double deadend; SUS = suspended
[5] Complete = nest was completely constructed and intact on the structure at the time of the observation.
[6] GOEA = Golden eagle, CORA = Common raven.

Source: EDM International, Inc.

The species most likely to have built the nests were identified based on species present during breeding seasons, nest size, nest materials, surrounding habitat, and EDM's 2005 report. Smaller nests were attributed to common ravens. Common ravens are one of the most ecologically widespread avian species in the world and occupy all of the land cover types surrounding the Magunden-Vestal 220kV lines (Boarman and Heinrich 1999). Ravens have adapted to a variety

of human-dominated landscapes and are known to nest on power line poles and other man-made structures (Knight 1984; Kochert et al. 1984; Steenhof et al. 1993; Avery et al. 1991). Common raven nests are as small as 15 inches across and can contain wire or other metal materials (Boarman and Heinrich 1999).

Figure 11: Dead Common Raven Suspended from Nest Materials on Structure MV2 129_5



Source: EDM International, Inc.

Figure 12: Nest Materials Found Beneath Structure MV2 115_06 (note the wire)

Source: EDM International, Inc.

Most large nests were attributed to hawks in the Buteo family. Both Swainson's hawks and red-tailed hawks occupy open habitats typical of area around most of the Magunden-Vestal 220kV line, construct nests in the range of 20 to 30 inches in diameter, and have been documented

nesting on power poles (Bechard et al. 1990; Preston and Beane 2009; Bechard et al. 2010). Swainson's hawks also may incorporate wire in their nests (Bechard et al. 2010). Edison's biologist guided EDM's visit to the Magunden-Vestal 220kV line, and indicated that one nest at Structure MV2 127_4 was suspected to be a golden eagle nest.

1.5 Recent Forced-Outage Data

Edison recorded 92 avian pollution-caused flashovers from 2000 through the "first part of 2005" (EDM 2005). Assuming the "first part of 2005" consisted of the first 3 months, EDM identified an average of 17.5 flashovers per year during pre-retrofitting. From 2006 to 2009, most fault data were corrupted when the patrol logging system used to record faults (relays) was moved (EDM 2010). Thus, information on faults during this period was limited (Table 4). In 2006, retrofitting began and there were less than nine reported faults, but no information was available on causes. In 2010, six faults were recorded as of March and no faults were known to have occurred since then. With the exception of one event in 2008, all recent faults occurred on un-retrofitted double deadend structures. This suggests that retrofitting has been effective where installed. However, declines in bird numbers could cause similar results. If fewer birds were present, there would likely be fewer bird-related outages. Thus, additional information on trends in raptor populations around the Magunden-Vestal lines is necessary to evaluate the reason for decreases in bird-related outages.

Table 4: Review of Bird-Related Fault Records and Mitigation Actions Reported in EDM (2010)

Year	Number of Faults Recorded on Both Lines	Mitigation Action
2004	33	No data
2005	23	EDM evaluation
2006	< 9	Prototype conductor covers installed
2007	No data	Production conductor covers installed on some structures
2008	≥ 1	Production conductor covers installed on some structures
2009	No data	Production conductor covers installed on some structures
2010	6	EDM evaluation

Source: Magunden-Vestal 220kV Lines Outage Evaluation and Recommendations (EDM 2010)

1.6 Trends in Raptor Occurrence

1.6.1 Methods

Data from Christmas Bird Counts (National Audubon Society 2002) are routinely used to evaluate patterns in raptor numbers over time (Warkentin and James 1988; Viverette et al. 1996; Pandolfino and Suedkamp Wells 2009). Patterns in the number of raptors detected during Christmas Bird Counts from the winters of 1989 through 2009 were used to form hypotheses to explain changes in outage rates on the Magunden-Vestal 220kV line.

EDM evaluated trends in the four species likely responsible for most of Edison's avian-related outages: golden eagle, red-tailed hawk, American crow, and common raven (4). EDM also evaluated trends for the seven species observed during field surveys at the Magunden-Vestal line that are known to cause outages elsewhere. Furthermore, because ospreys are commonly involved in avian-power line interactions and occur in Kern and Tulane counties (although not reported near the Magunden-Vestal line), EDM assessed trends in osprey numbers.

EDM used Christmas Bird Count data (National Audubon Society 2002) from 15 count circles occurring at least partially in Kern and Tulare counties during the winters of 1989 through 2009 to evaluate population trends. These sites included an average of 15.2 years of counts per site (range = 2-21; SE = 1.73). EDM used linear regression to estimate changes in counts per party hour by year and tested the null hypothesis that no change occurred by using t-tests to compare the slope of each fitted regression line to zero. For each species, EDM summed the count per party hour from all count sites and divided this by the sum of the number party hours in the count to generate a count per party hour throughout Kern and Tulare counties for each year.

1.6.2 Results

Counts for three of the four species believed responsible for most streamer-related outages prior to retrofitting increased per party hour from 1989 to 2009 (Table 5). The fourth species, the golden eagle, remained stable. Counts per unit effort of one species known to cause outages elsewhere and observed near the line (turkey vulture), and one species known to cause outages elsewhere and observed within the county (osprey), also increased. Five species remained stable, and one decreased (rough-legged hawk). EDM could not evaluate one species, Swainson's hawk, because it is migratory and was not present during Christmas Bird Counts.

Table 5: Results of Trend Analyses from Christmas Bird Count (1989 – 2009) at 15 Count Circles in Kern and Tulare Counties, California

Species	Regression Equation	R^2	D.F.	T-Test	P (2-tailed)	Trend
Species believed to cause streamer outages on the Magunden-Vestal line 220kV (EDM 2005)						
Red-tailed hawk	y = 0.0082x - 15.561	0.196	19	2.149	0.045	increasing
American crow	y = 0.0607x - 120.91	0.408	19	3.616	0.002	increasing
Common raven	y = 0.0823x - 158.74	0.181	19	2.049	0.055	increasing
Golden eagle	y = 0.0001x - 0.2001	0.002	19	0.206	0.839	stable
Species known to cause outages elsewhere, and observed near the Magunden-Vestal 220kV line (EDM 2005)						
Bald eagle	y = -0.0003x + 0.5551	0.039	19	-0.879	0.390	stable
Ferruginous hawk	y = 0.0006x - 1.1867	0.047	19	0.966	0.346	stable
Rough-legged hawk	y = -0.0005x + 0.9764	0.196	19	-2.151	0.045	decreasing
Swainson's hawk	N/A (migratory)	N/A	N/A	N/A	N/A	N/A
Turkey vulture	y = 0.0045x - 8.8804	0.228	19	2.368	0.029	increasing
Great blue heron	y = -0.0029x + 5.9754	0.083	19	-1.307	0.207	stable
Great egret	y = 0.0056x - 11.005	0.060	19	1.101	0.285	stable
Species known to cause outages elsewhere, and been observed in Kern or Tulare counties						
Osprey	y = 0.0007x - 1.3554	0.453	19	3.966	0.001	increasing

Source: National Audubon Society 2002

1.6.3 Discussion

These findings were compared to published evaluations of raptor populations in and around California. In north-central Oregon, red-tailed hawk, Swainson's hawk, and golden eagle populations were stable (Janes 2003). In the central valley of California, there was concern that habitat loss to urbanization and vineyards might negatively impact Swainson's hawk populations (England et al. 1995; Swolgaard et al. 2008). However, region-wide analyses of Swainson's hawk counts at migration sites indicated that Swainson's hawk numbers had increased significantly at some sites since the early 1980s, and appeared stable otherwise (Smith et al. 2008). Other raptor populations evaluated remained stable at some migration sites but increased or decreased at others (Smith et al. 2008). The results of EDM's analysis above represent the best possible evaluation of raptor populations encountering the Magunden-Vestal 220kV line at this time.

1.7 Evaluation of Effectiveness

In the absence of clear outage numbers before and after retrofitting, a detailed statistical evaluation of the effectiveness of retrofitting is precluded. However, available information suggests that, despite increases in the number of potentially at-risk species around the Magunden-Vestal 220kV lines, bird-related forced outages have decreased by as much as 74-82% following retrofitting (comparing 2004 and 2005 to 2010). EDM's analysis suggests that the apparent pattern of reduced outages is a result of effective retrofitting rather than decreases in the number of birds encountering the Magunden-Vestal 220kV line. The high number of deployed center phase covers and the high retention of these covers support this assertion.

1.8 Suggestions for Future Action

Forced outages on the Magunden-Vestal 220kV line now occur almost exclusively at the center phase of single-circuit double deadend structures (EDM 2010). Consequently, the single action likely to yield the greatest reduction in future outages would be to retrofit all double deadend structures with an insulated or covered jumper as currently employed at Structure MV2 127_4 (Figure 13). A device designed for this type of application is available from Tyco Electronics, and may be viewed at http://energy.tycoelectronics.com/index.asp?act=page&pag_id=2&prl_id=5&pls_id=29&prf_id=133&prr_parent=940. Additional retrofitting measures should focus on correcting the center phase covers on structures MV2 116_1 and 116_2, identifying the reason those covers are slipping from the intended position, and on deploying covers on single-circuit suspended structures where covers do not currently exist.

Because double-circuit suspended structures do not appear to pose forced outage problems, no retrofitting measures of those structures appear warranted at this time. To maintain positive public relations, many utilities clear animal carcasses from distribution structures as quickly as possible regardless of whether the animal was electrocuted. In keeping with this strategy, Edison should consider removing the raven carcass from Structure MV2 129_5.

The retrofitting measures described in the preceding paragraph should prevent most forced outages. However, the risk of a forced outage will persist as long as loose equipment (disintegrating metal screens and pans previously installed to prevent nesting) or nests occur

above energized equipment. This risk includes not only forced outages, but also potential fire and subsequent legal risks if falling nest materials contact exposed energized equipment on un-retrofitted structures or dislodges phase covers on retrofitted structures, and thus exposes energized equipment that is currently protected.

Figure 13: Insulated Center Phase Jumper under Nest on Structure MV2 127_4 (note relative thickness compared to outer jumpers)

Source: EDM International, Inc.

Screens mounted on many structures supporting the Magunden-Vestal 220kV lines were intended to prevent birds from nesting directly over the center phase. The screens are now degraded and collapsing and, contrary to intention, this loose equipment appears to provide support for many of the nests on these structures. Nesting may decrease (and service reliability increase) if these screens were routinely removed when crews accessed the top of structures for any other reason.

Active nests of migratory birds are federally protected by the Migratory Bird Treaty Act, which is enforced by the U.S. Fish and Wildlife Service (USFWS). Consequently, occupied nest(s) must be left as-is during summer breeding seasons as long as the nest(s) do not pose an immediate health or safety hazard to humans. Golden eagle nests are protected by the Bald and Golden Eagle Protection Act and neither active nor inactive nests may be disturbed without a permit. Because nests on the Magunden-Vestal 220kV line sometimes contain conductive materials such as wire (which can pose reliability, fire, and liability risks), Edison should consider consulting with the USFWS to remove problem nests outside of breeding seasons. However, nest removal alone typically does not solve the problem because many species will rebuild at the same location. Typically, a removal program combined with other strategies (e.g., stick deflectors, artificial nest platforms) more effectively mitigates nesting problems on power line structures (Dwyer and Leiker 2012). Edison should consider such a strategy to maintain the long-term reliability of the Magunden-Vestal 220kV line.

CHAPTER 2:
A Review of Southern California Edison Avian Interaction Records

2.1 Introduction

Edison proactively collects information on avian power line interactions within the Edison service territory (Figure 14) through internal Wildlife Mortality and Bird Nesting Reports and through daily outage Morning Reports. These data are compiled into Edison's Avian Incident Management System (AIMS). Prior to adopting AIMS, Edison recorded data in a variety of spreadsheets and hard copy forms.

Figure 14: Southern California Edison Service Territory

Source: Southern California Edison Territory polygon provided by Southern California Edison. Basemap developed by National Geographic and Esri.

As part of Edison's draft Avian Protection Plan (APP) designed to minimize negative avian power line interactions, historical data are used to investigate patterns of avian electrocution and wire collision. Such investigations allow Edison to target retrofitting investments to areas and structures where resources will have the greatest effect in reducing avian electrocutions, collisions and associated outages. To enable Edison to use historical data to make the most informed retrofitting decisions, EDM evaluated historical data to identify patterns in the timing, species, voltages, construction configurations, and locations involved in avian electrocutions and collisions (collectively hereafter "incidents").

Since the effectiveness of some mitigation strategies have not been evaluated in California, EDM also partnered with Edison to review historic eagle electrocution sites. The goal was to evaluate a sample of structures retrofitted after they electrocuted either a bald eagle (see Appendix B for Latin names of all species referenced herein) or golden eagle. The sites were visited to search for additional avian carcasses and to ascertain if retrofitting measures adhered to Suggested Practices for Avian Protection on Power Lines – The State of the Art in 2006 (APLIC 2006).

2.2 Methods

EDM first consolidated all historical Edison data from September 1981 through December 2009. Data sources included spreadsheets provided by Edison containing 1) AIMS data, 2) Transmission and Distribution Business Unit (TBDU) mortality data, 3) other raptor mortality data, and 4) other avian mortality data. Hard copies of reports collected prior to the initiation of digital recordkeeping also were collected and incorporated.

EDM then used dates and comments included with each record to identify and remove duplicate records. Because the California Energy Commission (Energy Commission) and Edison were specifically interested in avian mortality incidents, EDM also removed all records lacking attribute data specifically identifying bird(s) and either electrocution or collision. These procedures facilitated consolidating 5223 candidate records into 2169 unique records evaluated herein. All subsequent analyses were conducted using the chisq.test command in program R (The R Foundation for Statistical Computing, Vienna, Austria).

To evaluate retrofitting measures, EDM visited a sample of structures where an eagle incident had been recorded. During visits, EDM quantified the characteristics of each visited structure and surrounding landscape as described in the *Chapter 3 Evaluation of Avian Electrocution Risk Calculator*. EDM also qualitatively assessed whether each structure was fully retrofitted, partially retrofitted, or not retrofitted to APLIC (2006) recommendations. With respect to partially retrofitted and non-retrofitted structures, EDM acknowledges some of the retrofitting strategies available in the 1980s and 1990s were not as durable or persistent as intended, and retrofitting may have been completed with products that have since fallen off.

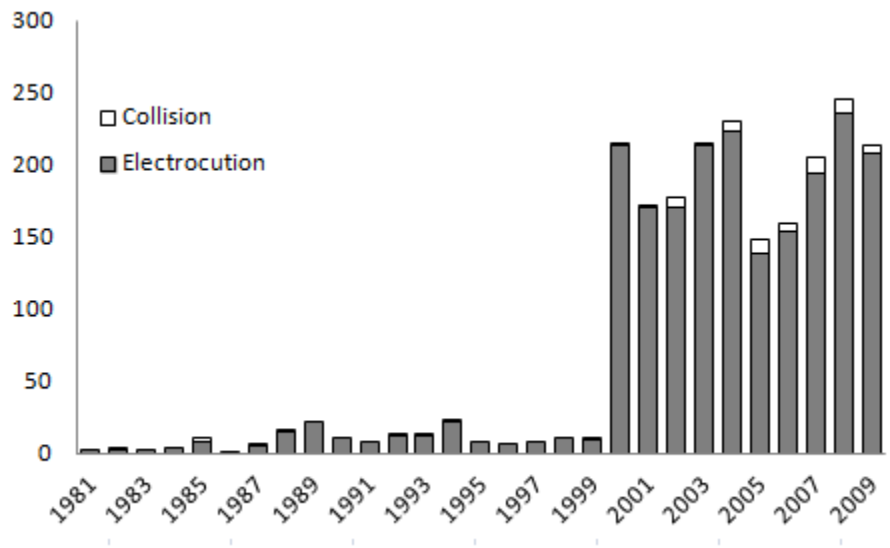
Electrocution can occur where horizontal separation is less than the wrist-to-wrist (flesh-to-flesh) distance of a bird's wingspan, or where vertical separation is less than a bird's length from head to foot. According to APLIC 2006, 60 inches (in) (152 centimeters [cm]) of horizontal separation and 40 in (100 cm) of vertical separation are recommended to protect eagles. EDM's qualitative assessment evaluated whether differently energized exposed conductors or

grounded contacts occurred less than 60 (in) (152 cm) from one another in the horizontal plane or less than 40 in (102 cm) in the vertical plane. The structures EDM evaluated were in service and energized during assessments, so all distances were estimated from the ground based on known crossarm lengths (typically 8 feet [ft]; 2.4 meters [m]). EDM personnel circled each structure at distances of 10-25 ft (3.0-7.6 m) to examine all potential points of contact, and search for evidence of additional incidents (whole or partial carcasses) within a radius of 25 ft (7.6 m) of each pole (Harness et al. 2001, Dwyer and Mannan 2007). All retrofitting assessments were undertaken in clear weather during daylight, and structures were free of snow or other visual obstructions.

2.3 Results

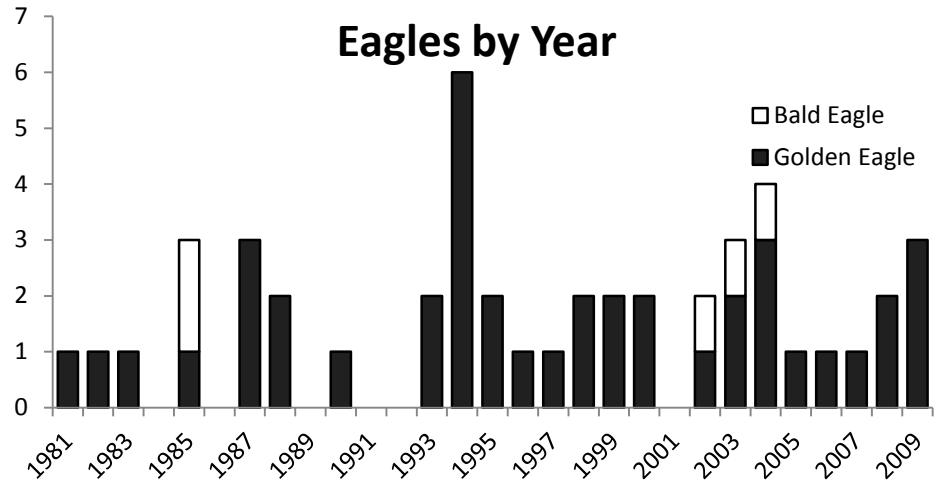
EDM identified 2169 incidents involving avian mortalities, including 2098 electrocution incidents and 71 collision incidents. Comparison between years indicated most incidents (94.3%) were recorded from 2000 through 2009 (Figure 15). There was an 1880% increase in the average number of incidents documented annually prior to 2000 ($\bar{x}$ = 10, SD = 6.037) compared to 2000 through 2009 ($\bar{x}$ = 197.9, SD = 31.841). Incidents involving bald eagles were relatively rare across years, and incidents involving golden eagles were identified relatively consistently (Figure 16).

Figure 15: All Species Incidents by Year



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

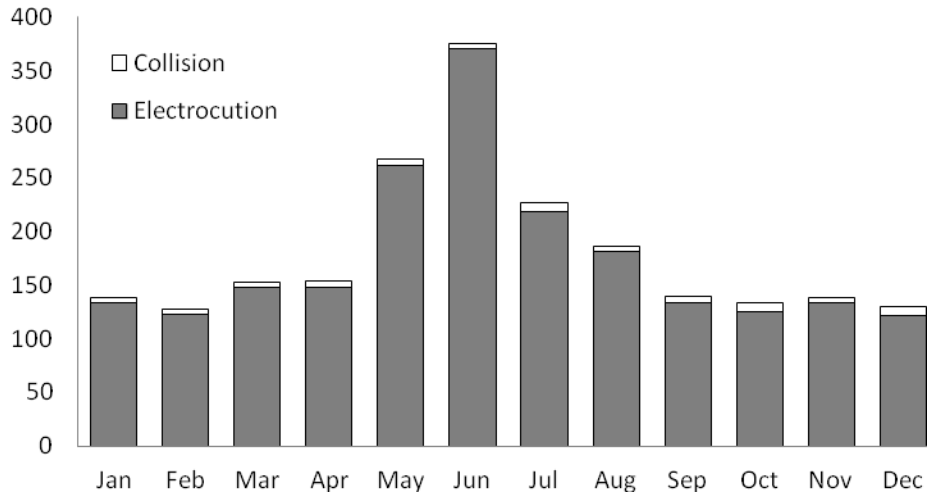
Figure 16: Eagle Incidents by Year



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

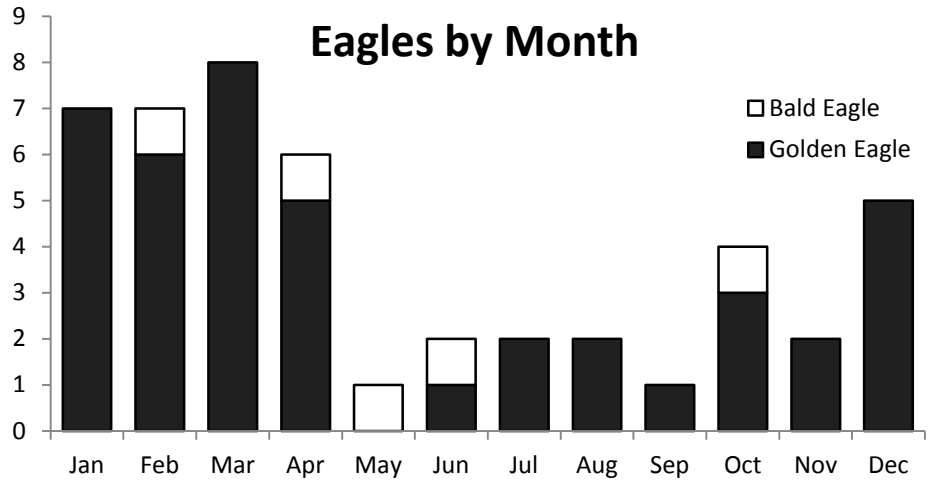
Comparison between months indicated electrocutions were more likely during May through August (positive residuals) than during September through April (negative residuals; Figure 17; χ^2=356.715, df = 11, $P < 0.001$), but collisions were not more or less likely to occur in any particular month (χ^2=5.901, df = 11, $P = 0.880$). Electrocution data specific to eagles was insufficient for statistical analyses, but qualitative evaluation suggests a peak of electrocution January through April (Figure 18).

Figure 17: All Species Incidents by Month



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

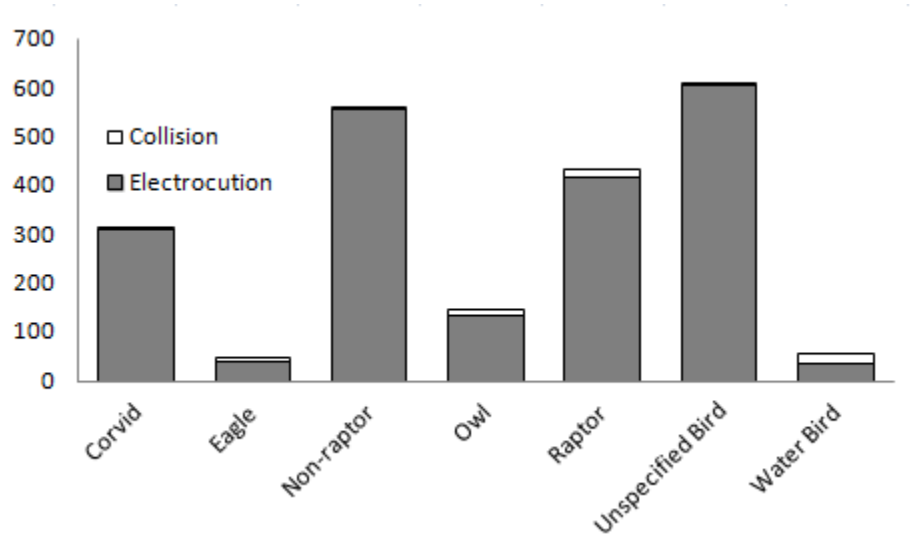
Figure 18: Eagle Incidents by Month



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Table 6 lists incidents by bird species or taxon. Among records where a species was identified, red-tailed hawks (n = 265) and American crows (n = 258) were the most commonly identified species. Many of the records EDM evaluated described the electrocuted animal simply as "bird." Birds with no species or taxonomic attribute (n = 612) were reported more commonly than any described species or taxon (Figure 19). The second largest group reported was "bird-non raptor" (n = 433) with no additional information. These two categories together accounted for 48.2% of records.

Figure 19: All Species Incidents by Bird Group



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Table 6: Incidents by Bird Species or Taxon

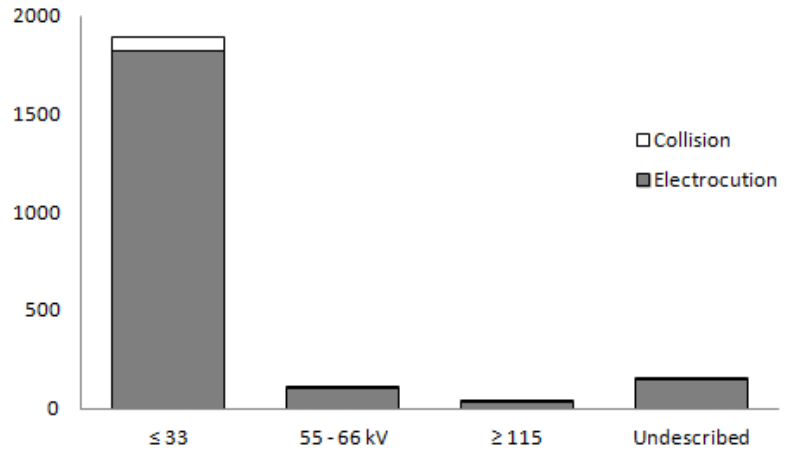
Species or Taxon[a]	Count	Species or Taxon[a]	Count
Red-tailed hawk	265	Parrot species	3
American crow	258	Pelican species	3
Rock pigeon	87	American white pelican	2
Hawk species	78	Brown pelican	2
Owl species	63	Canada goose	2
Turkey vulture	58	Egret species	2
Great horned owl	56	Falcon species	2
Common raven	51	Greater roadrunner	2
Golden eagle	42	Northern flicker	2
Barn owl	28	Peregrine falcon	2
Great blue heron	19	Sandhill crane[b]	2
Raptor species	12	Sparrow species	2
Gull species	11	Western scrub jay	2
Blackbird species	10	Wild turkey	2
Red-shouldered hawk	8	Woodpecker species	2
European starling	7	Acorn woodpecker	1
Duck species	6	California condor[c,d]	1
Goose species	6	Corvid species	1
Bald eagle	5	Mute swan	1
Common peafowl	5	Osprey	1
Dove species	4	Prairie falcon	1
American kestrel	3	Swainson's hawk[b]	1
Cooper's hawk	3		

[a] See Appendix B List of Scientific Names for Latin names
[b] State of California Threatened species (State of California 2011)
[c] State of California Endangered species (State of California 2011)
[d] Federally endangered species (State of California 2011)

Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

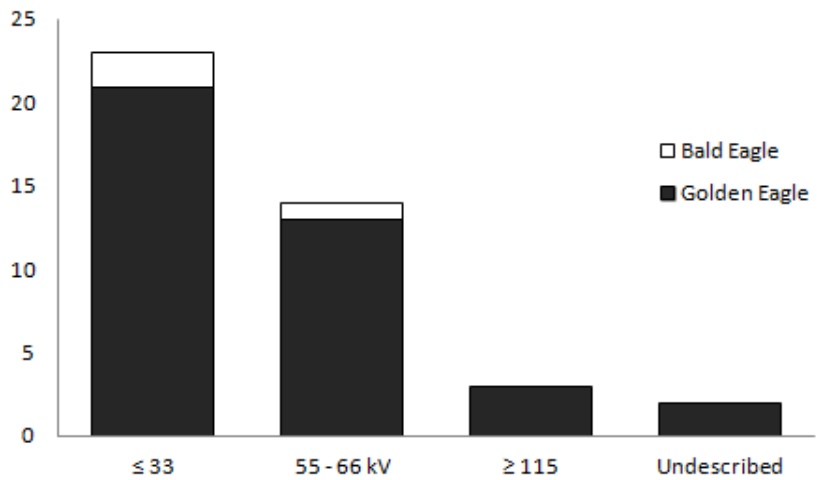
The majority of incidents occurred at distribution voltages (≤ 33kV; Figure 20), and distribution voltages were more likely to be involved in an incident than either sub-transmission (55kV - 66kV) or transmission (≥ 115 kV) voltages (χ^2=3269.93, df = 2, $P < 0.001$). Specific to eagle electrocutions, distribution and sub-transmission voltages were more likely to be involved in an incident than transmission voltages (Figure 21; χ^2=15.05, df = 2, $P = 0.001$).

Figure 20: All Species Incidents by Voltage



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

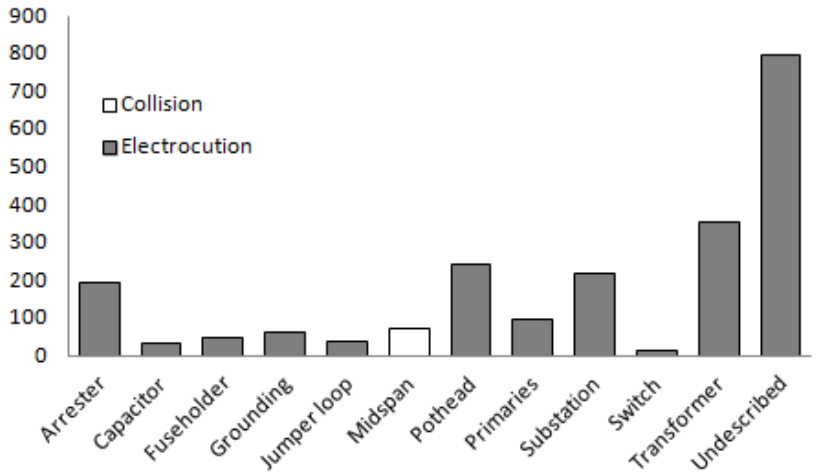
Figure 21: Eagle Incidents by Equipment Voltage



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Although incident records sometimes included detailed information on the specific energized equipment contacted by a bird, the majority of incidents were not described in association with a particular component (Figure 22). However, of the 1081 incidents that were associated with specific equipment (Table 7), transformers, riser potheads and arresters were most commonly implicated, and were more likely to be involved in incidents than expected (positive residuals) given the proportions of equipment types reported (χ^2=2909.282, df = 8, $P < 0.001$). An additional 219 incidents occurred within substations, and were most commonly associated with bus bars. Specific to eagles, data were insufficient for statistical analyses, but qualitative assessment suggests incidents were most common on primary conductors (Figure 23).

Figure 22: All Species Incidents by Equipment Type



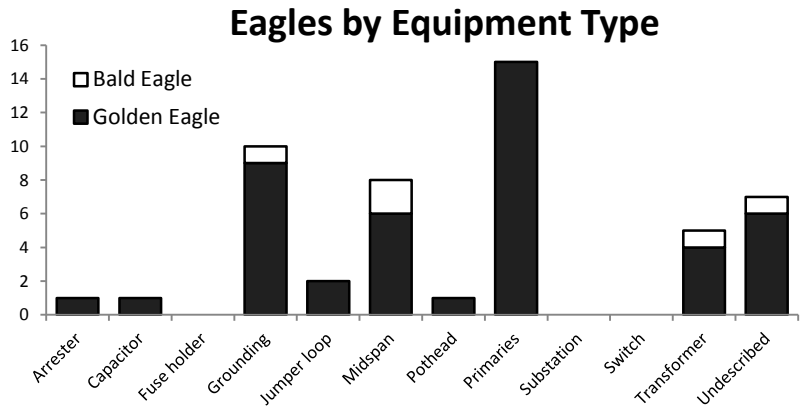
Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Table 7: All Species Incidents by Equipment Type

Equipment Type	Count	Equipment Type	Count
Arrester	193	Pothead	243
Capacitor	33	Primaries	97
Fuseholder	48	Switch	16
Grounding	61	Transformer	353
Jumper loop	37		

Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

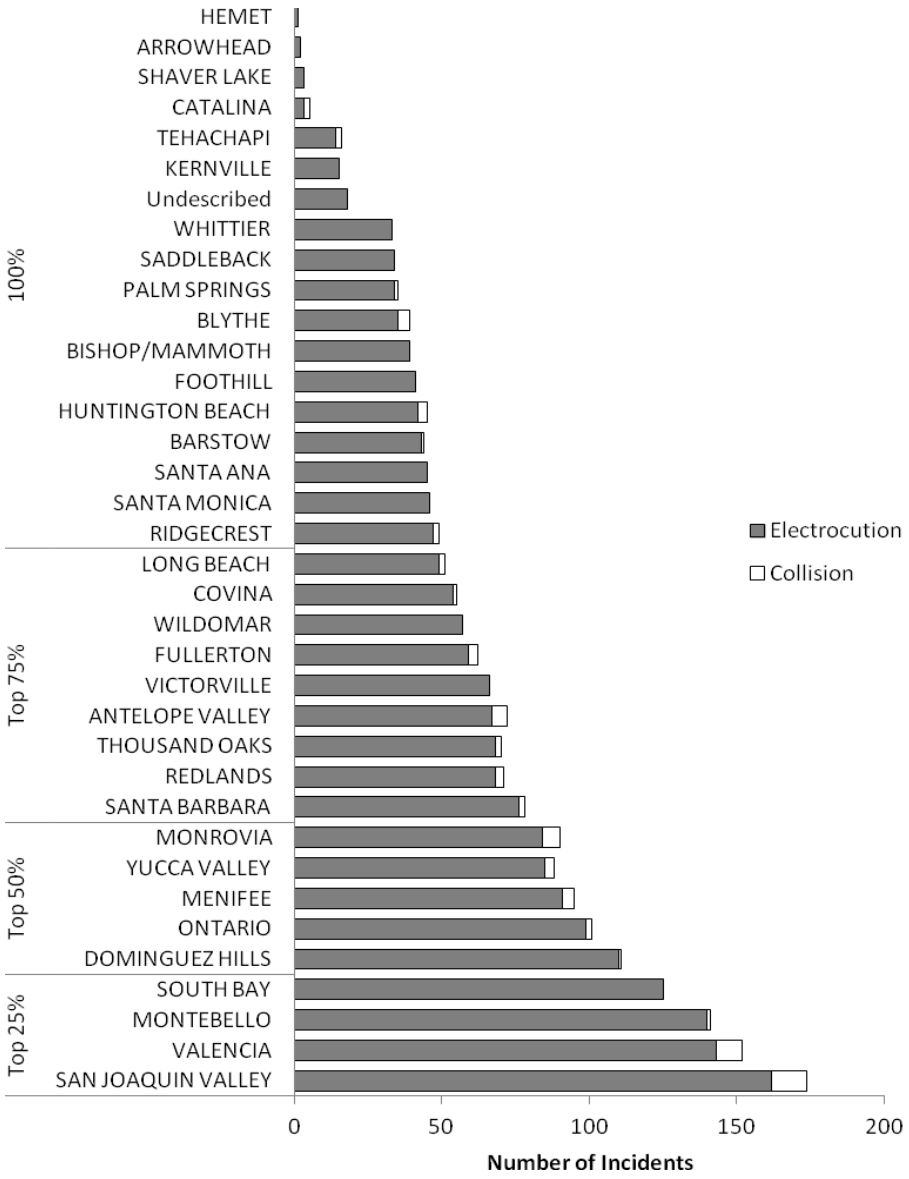
Figure 23: Eagle Incidents by Equipment Type



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

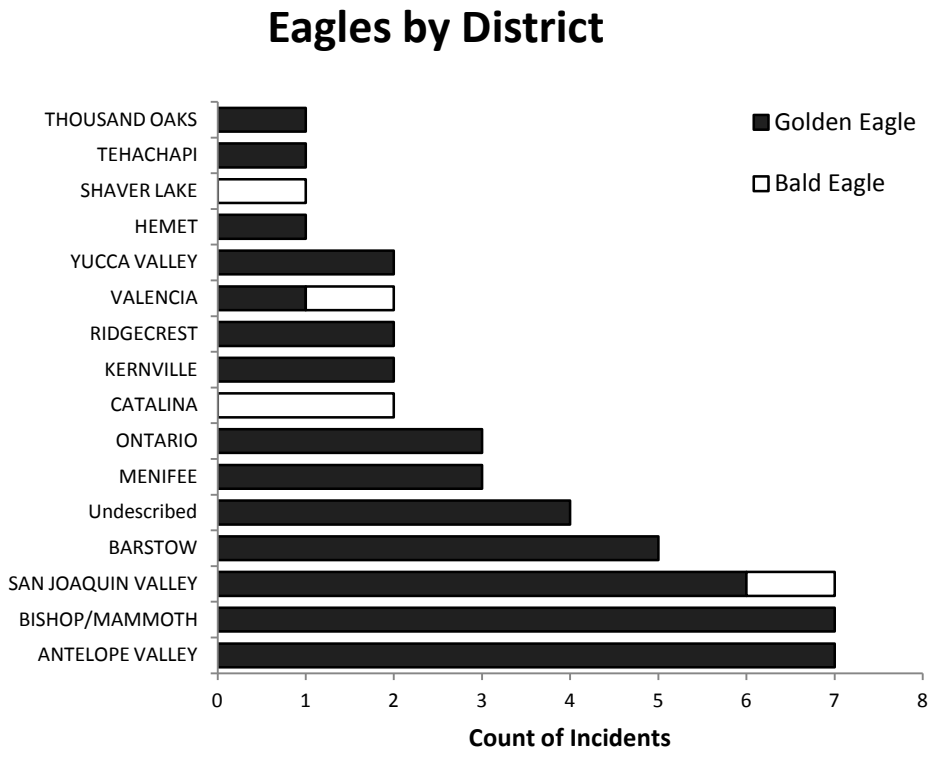
EDM identified incidents from 35 Edison districts (Figure 24, Figure 25, and Figure 26). Incidents were most commonly reported from the San Joaquin Valley district, but also were widely reported from districts throughout the Edison service area. Incidents tended to be clustered near urban areas, particularly around the greater Los Angeles metropolitan area (Figure 27). With respect to particular species, incidents involving bald eagles and golden eagles tended to occur in undeveloped areas. Incidents involving American crows tended to occur in developed areas, particularly the Los Angeles area. Incidents involving red-tailed hawks occurred in both undeveloped and developed areas (Figure 28).

Figure 24: All Species Incidents by District



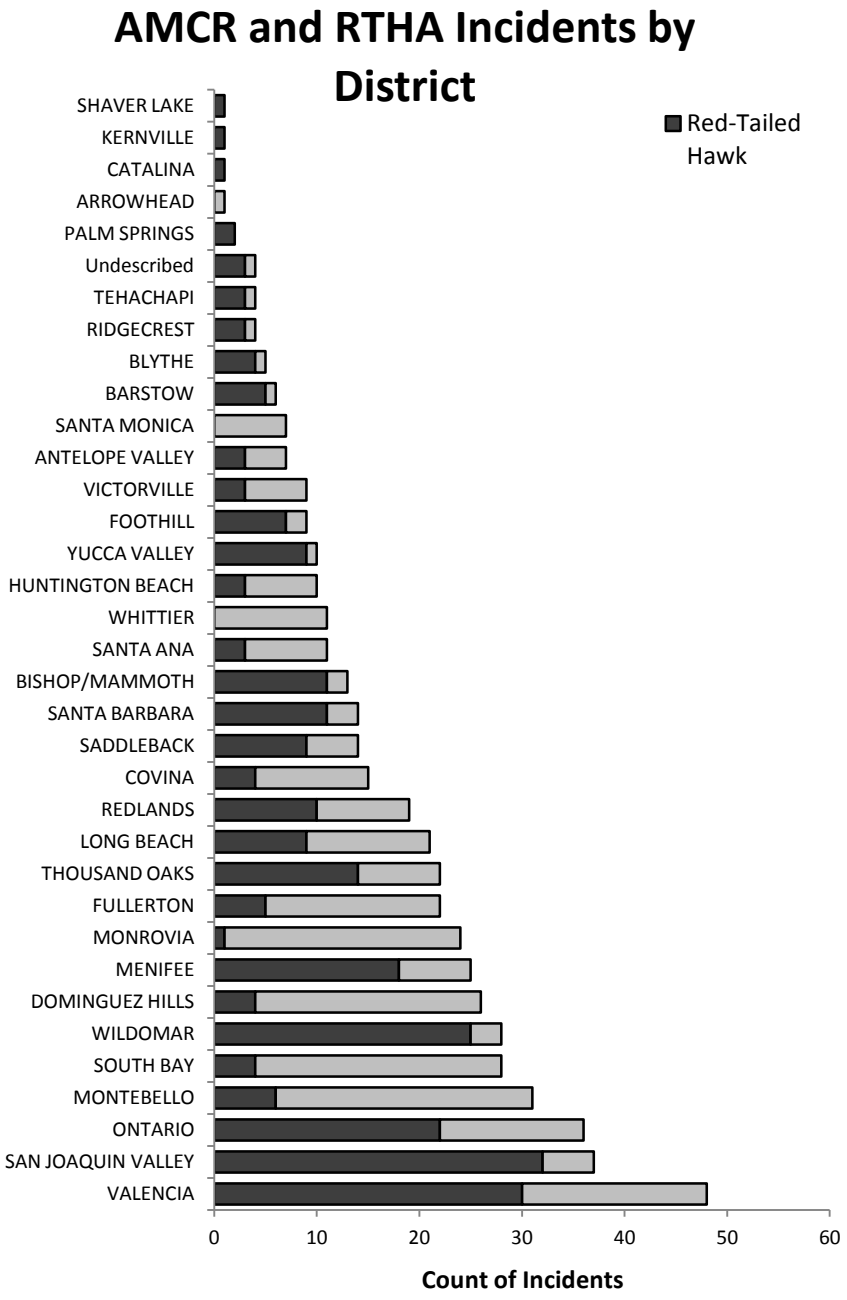
Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Figure 25: Eagle Incidents by District



Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Figure 26: American Crow and Red-tailed Hawk Incidents by District

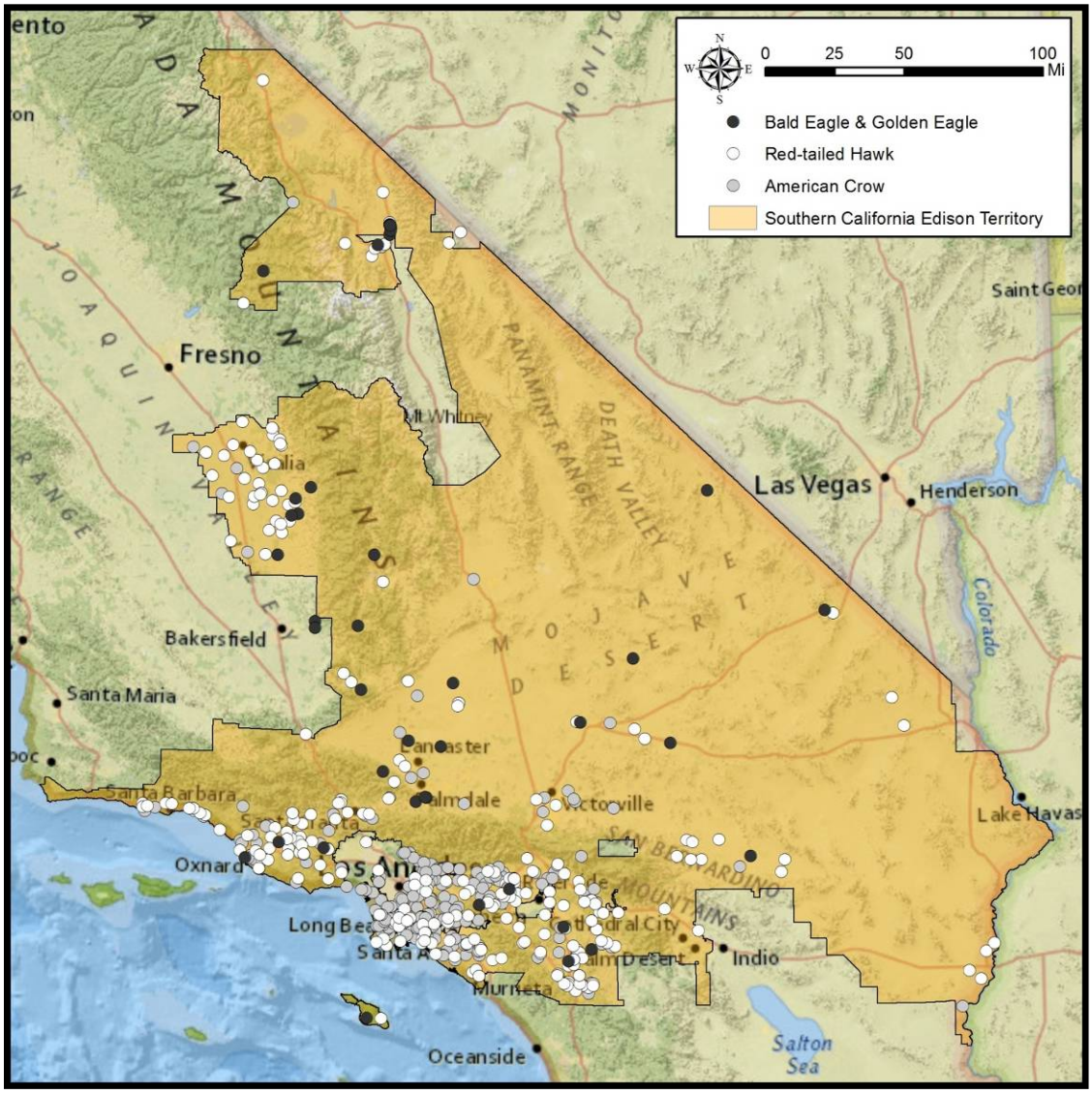


Source: Data provided by Southern California Edison and analyzed by EDM International, Inc.

Figure 27: Map of Incident Locations for All Species

Source: Southern California Edison Territory polygon provided by Southern California Edison. Incident location data developed by Southern California Edison and EDM, International, Inc. Basemap developed by National Geographic and Esri.

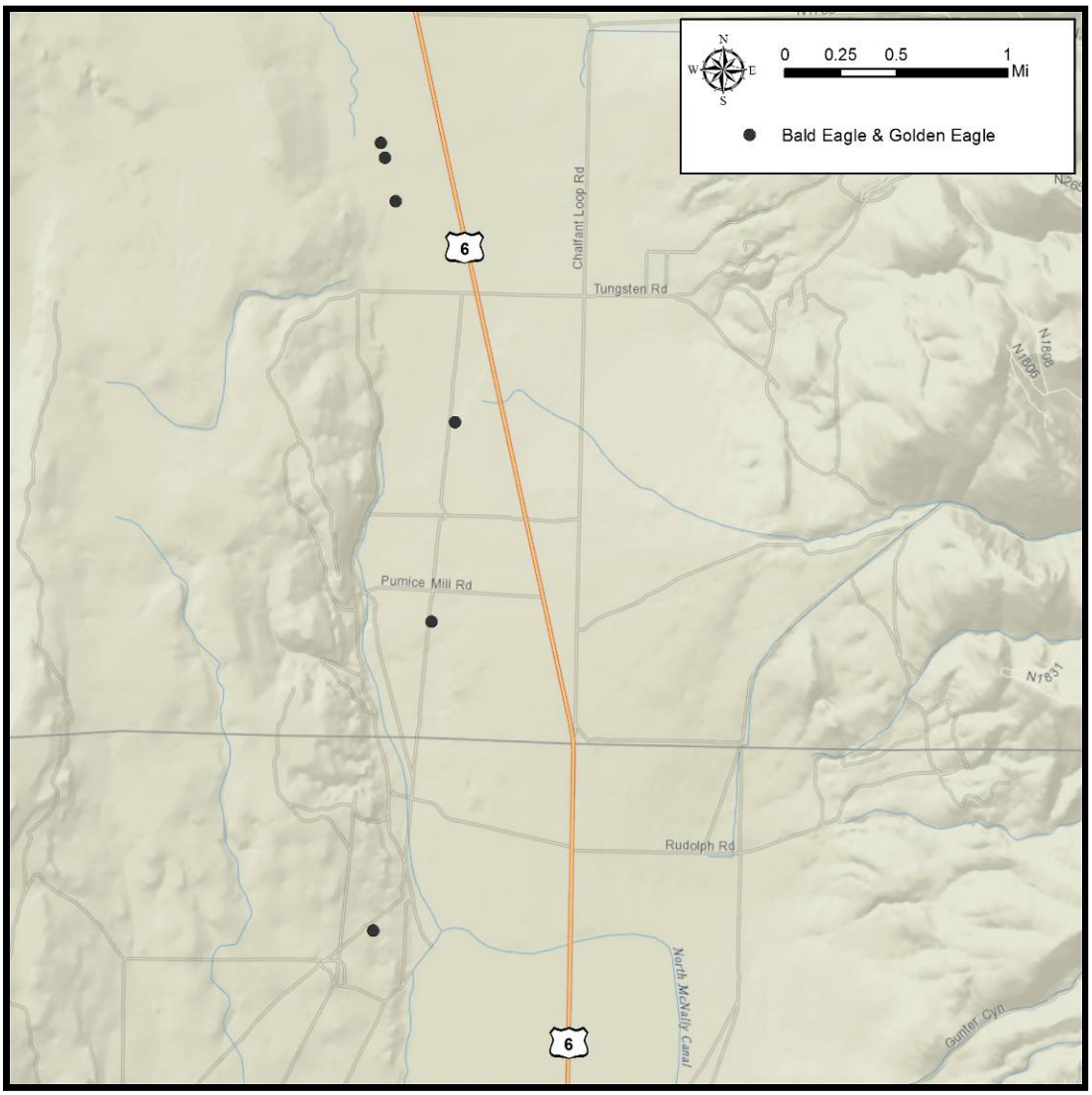
Figure 28: Map of Incident Locations for Bald Eagles, Golden Eagles, Red-tailed Hawks, and American Crows



Source: Southern California Edison Territory polygon provided by Southern California Edison. Incident location data developed by Southern California Edison and EDM, International, Inc. Basemap developed by National Geographic and Esri.

EDM visited 21 structures where eagle incidents had previously occurred. Most structures were widely distributed throughout the Edison service area. However, structures 45520S, 45534S, 45553S, 45556S, and 45557S all occurred on the same line within 2.2 miles (mi) (3.5 kilometers [km]) of one another. Structure 454196S occurred on an adjacent line, 1.4 mi (2.2 km) to the south. Thus, a total of 6 known eagle electrocutions occurred within 3.6 mi (5.8 km) (Figure 29).

Figure 29: Cluster of Structures Involved in Eagle Incidents



Source: Incident location data developed by Southern California Edison and EDM, International, Inc. Basemap developed by National Geographic and Esri.

EDM found no evidence additional eagles had been electrocuted on any of the structures visited. Of the 21 structures visited, 4 were retrofitted to fully meet or exceed the separation standards identified by APLIC (2006) as necessary to minimize electrocution risk for eagles, and 4 were retrofitted to meet the standards recommended at the time of the incident (APLIC 1996), though they do not meet current standards (APLIC 2006). Each of the structures retrofitted to meet the standards of the day was equipped with perch discouragers or supplemental perches. These mitigation approaches are no longer recommended except on high-risk configurations that are difficult to retrofit through isolation or insulation of energized hardware (i.e., over-arm switches; APLIC 2006). An additional 5 structures were partially retrofitted with some high-risk

points corrected either through isolation or insulation, and 1 structure was partially retrofitted with perch discouragers. The remaining structures were not retrofitted.

2.4 Discussion

When strategies are implemented to protect birds from negative interactions with overhead power lines, new awareness training and reporting mechanisms are typically employed (APLIC and the USFWS 2005). These mechanisms can lead to increases in the number of reported incidents even as the number of total incidents declines (Dwyer and Mannan 2007). The substantial increase in detection of incidents in 2000 and later as compared to 1999 and prior, likely represents this type of increased awareness.

The higher number of incidents for most species during May through August and for eagles during January through April described here correlates with breeding seasons, fledging seasons, and data describing eagle electrocutions in Colorado (Harness 1997). Birds tend to have low survival at fledging because individuals must learn to survive a complex suite of risks not previously encountered (Kershner et al. 2004). Among this suite of risks is electrocution, and some studies have shown electrocution rates to be higher during breeding seasons for both breeding birds and their young (Dwyer and Mannan 2007).

Distribution voltage structures with pole-mounted equipment such as transformers were most commonly implicated in electrocutions. These types of structures also have tended to be the most commonly implicated in other studies (Harness and Wilson 2001, APLIC 2006, Dwyer and Mannan 2007, Lehman et al. 2010). Chapter 3 of this report describes how a logistic model predicting electrocution risk can facilitate using this knowledge to prioritize high risk structures for retrofitting. These data also showed a high correlation between eagle events and poles with exposed primary conductors. Harness and Wilson (2001) also recorded elevated eagle incidents for distribution configurations without equipment in a review of raptor electrocution records gathered from 58 electric utilities located in the western United States. Accordingly, retrofitting for eagles should include focusing on addressing exposed primary conductors, particularly in the area where we identified a cluster of eagle incidents.

Consistently across years, red-tailed hawks and American crows were the most commonly identified electrocuted species. Many incidents reported herein were associated with urban areas. This is not surprising for American crows, but urban areas are not typically correlated with high raptor electrocution rates (Schomburg 2003, APLIC 2006, Mojica et al. 2009). In this study, EDM used pre-existing outage data to identify mortalities. Avian electrocutions do not necessarily result in outages (Harness and Wilson 2001, APLIC 2006, Dwyer and Mannan 2007), but when they do, the cause of an outage may be more easily identified in developed areas where access to structures is facilitated by adjacent infrastructure. EDM cautions that undetected raptor electrocutions may also be occurring in exurban and undeveloped areas.

Two state or federally threatened or endangered species were identified in collision incidents (sandhill crane and California condor). These incidents were isolated and should not necessarily trigger major investments in line marking in areas unlikely to be used by other members of the species involved in the incidents. However, Edison should remain alert to the possibility of

additional incidents, and deploy line marking in high use areas if ongoing risk is identified through additional incidents.

EDM found no evidence of additional eagle electrocutions at any eagle incident locations. However, EDM did find substantial evidence of ongoing avian use of these structures, persistent high electrocution risk, and one (non-eagle) raptor carcass. Thus, outage and reliability risks persisted. The equipment and strategies available to mitigate avian electrocution risk have changed substantially since the occurrence of, and response to, many of the avian electrocutions contributing to this dataset. To maximize system reliability, new equipment and strategies should be applied to at-risk structures as those techniques become available.

CHAPTER 3:
Avian Electrocution Risk Calculator Evaluation

Negative interactions between birds and overhead electric transmission and distribution systems have been recognized in the United States since the early 1970s (Miller et al. 1975) and are a conservation concern of global importance (Lehman et al. 2007, Barrientos et al. 2011). Specific problem interactions include collisions (Pandey et al. 2007, Heck 2007), electrocutions (Harness and Wilson 2001, Hunting 2002, Dwyer and Mannan 2007), electric shock injuries (Morrow and Morrow 2003, Dwyer 2006, Mojica et al. 2009) and undesired perching or nesting by predators with potential impacts to prey species (Lammers and Collopy 2007, Prather and Messmer 2010, Dwyer and Leiker 2012). Problem interactions can impact system reliability by causing outages directly attributable to electrocution (Harness and Wilson 2001, Dwyer 2004, APLIC 2006), to bird related equipment damage (APLIC 2006) and fires (Lehman and Barrett 2002, Tintó et al. 2001), or to avian pollution and avian streamers (Van Rooyen et al. 2003).

To minimize negative interactions between birds and overhead power systems, electric utilities have historically developed service-area specific strategies to retrofit dangerous structures (e.g., Harness and Wilson 2001, Schomburg 2003, Dwyer and Mannan 2007). These strategies often are documented in an APP and risk assessment (APLIC and the USFWS 2005) that includes strategies for proactive retrofitting of high risk structures (Harness and Nielsen 2005, Harness and Nielsen 2006, APLIC 2006). Focusing on high risk structures allows utilities to use limited resources to greatest effect (Harness and Nielsen 2005, Harness and Nielsen 2006, APLIC 2006). Typically, structures most in need of retrofitting support energized equipment (e.g., transformers, reclosers, surge arresters, cutouts) in addition to primary wires, located in favorable habitat (Harness and Wilson 2001, Dwyer and Mannan 2007, Lehman et al. 2007). Identification of high risk structures has typically relied on gestalt-based evaluations conducted by experts familiar with both avian biology and overhead electric systems. Quantitative modeling of electrocution risk (Schomburg 2003, Tintó et al. 2010, Guil et al. 2011) and collision risk (Rollan et al. 2010, Shaw et al. 2010) has been undertaken in some areas and offers increased consistency and transparency in prioritizing structures for retrofitting.

In California, numerous studies document negative interactions between birds and energy infrastructure (e.g. Hunting 2002, Smallwood 2008, Smallwood and Karas 2009). Recognizing the potential advantages of a quantitative model, the Energy Commission contracted the development of a quantitative model of electrocution risk on distribution structures in central and southern California (BioResource Consultants 2008). Twenty-three candidate *a priori* models were subsequently compared in an information theoretic framework and a preferred model (Eq. 1) was published in the Public Interest Energy Research (PIER) 2008 final report "Identifying electric distribution poles for priority retrofitting to reduce bird mortality (BioResource Consultants 2008).

Equation 1 describes the original model for predicting electrocution risk. See BioResource Consultants (2008) for explanations of variable names.

$$X = -4.13 + .41(\text{slighter}) + 0.05(\text{pellets}) + 0.27(\text{prey_1}) + 0.09(\text{hard1sum}) + 0.81(\text{Veg_gr_wet}) - 0.1(\text{perchopt}) - 5.34(\text{Guy_uninsul}) + 0.7(\text{Aspect_corner}) + 0.09(\text{sfusecut}) - 0.68(\text{effheigh}) - 1.78(\text{use_public}) - 0.27(\text{vegstruc}) - 0.34(\text{sswitch}) + 0.56(\text{Aspect_dead}) + 0.56(\text{Guy_insul}) - 0.19(\text{stranso}) - 0.004(\text{armorien}) - 0.06(\text{arms}) + 0.27(\text{Metal_arm}) + 0.23(\text{Phase_tangent}) - 0.03(\text{sjumper}) + 0.14(\text{Metal_armbrace}) \quad \text{[Eq. 1]}$$

Using a historical Edison data set, EDM evaluated the ability of the logistic regression model to predict electrocution as a likely outcome on a sample of structures where avian electrocutions were known to have occurred (incident structures), and on a sample of structures where avian electrocutions were not known to have occurred (comparison structures). EDM predicted the logistic regression model would identify the majority of incident structures as high or extreme risk (as defined by BioResource Consultants 2008), and the majority of comparison structures as low or medium risk. Some incident structures were expected to be identified as low or medium risk because even low risk structures can pose some risk (Harness and Wilson 2001, APLIC 2006, Dwyer and Mannan 2007). Similarly, some comparison structures were expected to be identified as high or extreme risk because they had the distinguishing characteristics of such structures.

Because a 22-variable model (hereafter the original model) had the potential to be difficult for some users, EDM also developed and tested an alternative logistic regression model (hereafter the revised model). Herein, EDM describes using a sample of Edison historical outage data to test the original model and to develop and test revised model

3.1 Methods

3.1.1 Study Area

Incident and comparison structures were visited throughout Edison's 50,000 mi^2 (129,500 km^2) service area which included all or parts of Fresno, Inyo, Kern, Kings, Los Angeles, Orange, Riverside, San Bernadino, Santa Barbara, Tulare, Tuolumne, and Ventura Counties in central, coastal, and southern California (Figure 30).

Surveyed areas of Fresno and Tuolumne counties occurred in mountainous, conifer-forested portions of the Sierra bioregion (FRAP 2006). Surveyed areas of Inyo and San Bernadino counties were composed primarily of desert in the Mojave Desert of the Mojave bioregion (FRAP 2006). Characteristic plants included white bursage (*Ambrosia dumosa*), creosote bush (*Larrea tridentate*), Joshua tree (*Yucca brevifolia*), and indigo bush (*Psorothamnus fremontii*) (Bowers and Wignall 1993). Surveyed areas of Kern and Kings Counties were composed primarily of a mix of agriculture, grassland, and desert shrublands. Much of Kern County had plant communities typical of Mediterranean ecosystems with native species characterized largely by tolerance to drought, heat and fire (Fox 1995). Surveyed areas of Los Angeles and Orange counties were dominated by urban areas and ringed by mountainous shrubs in the South Coast bioregion. Shrubby areas extended into the southwestern corner of San Bernadino

County and the western half of Riverside County. Despite extensive urbanization (FRAP 2010), the south coast counties of California are important wintering areas for avian species. Surveyed areas of Riverside County were composed primarily of desert in the Sonoran desert of the Colorado bioregion (FRAP 2006). Characteristic plants included blue paloverde (*Cercidium floridum*), triangle-leaf bursage (*Ambrosia deltoidea*), ironwood (*Olneya tesota*), and jumping cholla (*Opuntia fulgida*) (Bowers and Wignall 1993). Surveyed areas of Santa Barbara and Ventura counties were largely shrubby with mixed terrain of rolling hills and extensive suburban areas where native lands were interspersed with developed areas (FRAP 2006). Surveyed areas of Tulare County included agricultural areas, herbaceous areas, and hardwood and coniferous forests.

Figure 30: Edison Service Territory

Source: Southern California Edison Territory polygon provided by Southern California Edison. Basemap developed by National Geographic and Esri.

3.1.2 Sampling Design

The original model was constructed with electrocution data from all avian species found during fieldwork, regardless of whether the incident caused an outage. Data collection for the original model included some structures within the Edison service area. The original model was tested by EDM by sampling structures where the electrocution of a raptor or corvid caused an outage (as recorded by Edison) and only within the Edison service area. Thus, EDM tested a non-random sample of the total scope of inference intended for the original model. Ideally, data used to test the original model would have been collected through regular or randomized searches throughout the model's intended scope of inference (e.g., Harness and Wilson 2001, Dwyer and Mannan 2007, Lehman et al. 2010) but such action was precluded by budget. The implications of testing only part of the originals model's intended scope of inference are addressed in the *Original Model* Discussion section of this chapter.

To test the model, Edison provided records of wildlife-caused outages on the Edison system collected from 1981 through 2009. Record keeping strategies changed within Edison during that period, so Edison provided all available data in all available forms (written records, individual electronic records, and electronic databases). EDM combined all records into a single database then cross-referenced all records by date and location to identify and remove duplicate records. Records were contributed by personnel with varied amounts of knowledge of avian ecology and electric utility operations. Questionable electrocution incident records were removed if the data were ambiguous. To identify ambiguous data, all records that did not explicitly describe the mechanism of the electrocution (e.g., "the bird went phase-to-phase"), were discarded. Records which did not explicitly describe either a raptor or a corvid also were discarded. Since some records described structures which had since been removed or replaced and therefore not available for study, these records also were discarded.

A total of 5,223 wildlife related outage records were identified in Edison's archives, including 2,098 avian electrocutions (compare to 2169 total incidents including collisions reported in *Chapter 2 A Review of Southern California Edison Avian Interaction Records*). After discarding duplicate records, records of collision mortalities, and incomplete records that could not be attributed to a specific structure or species of interest, approximately 700 records remained. Of these, 440 structures were still in service, and of these 215 were randomly sampled. To identify comparison structures, 440 random locations were generated within the Edison service area, and of these 248 were randomly sampled. To sample random locations, the closest utility structure to each random location was visited.

Edison has a draft APP calling for retrofitting structures where avian electrocutions occur. Thus, many of the incident structures EDM visited were retrofitted following electrocution incidents. Some records included details on subsequent retrofitting, but many did not. EDM assumed retrofitting equipment would not have been in place at the time of the incidents, and evaluated all structures accordingly. It is also possible some pole configurations were modified since the incident occurred.

3.1.3 Testing the Original Model

To evaluate the predictive characteristics of the original model, all 22 variables needed for the original model were collected at each structure (BioReseource Consultants 2008). β estimates from the original model and the inverse logit link transformation were then used to calculate the predicted probability of electrocution. Significance was defined at $\alpha = 0.05$, and a Pearson chi-square was used to test for differences in the proportion of outputs for incident and comparison structures occurring in the four categories (extreme, high, medium, and low) defined in BioResource Consultants (2008).

3.1.4 Revised Model

The original model required compiling information on 22 variables. EDM was interested in identifying whether a simpler model could be used to predict electrocution. A simpler model was created by focusing only on variables that were independent of one another, and focusing on variables of potential importance based on EDM's experience developing risk assessments and APPs (Harness and Nielsen 2005, Harness and Nielsen 2006, Dwyer and Mannan 2009). All variables from the original model were incorporated in these categories or were included as they occurred in the original model. Fourteen independent variables were considered (Table 8 and Table 9).

Table 8: Candidate Variables for Inclusion in the EDM Model

Candidate Variable	ID used in Table 9	Type
Count of Jumpers	A	Num.
Count of Phases	B	Num.
Canopy Heights	C	Num.
Presence of Deadends	D	Cat.
Phases on Top of Pole	E	Cat.
Any Grounded Equip. on Structure	F	Cat.
Commanding View	G	Cat.
Open Habitat	H	Cat.
Public Land	I	Cat.
Any Prey Occurrence or Raptor Use	J	Cat.
Effective Height Sum	K	Num.
Arm Orientation	L	Num.
Guy Wire Absent	M	Cat.
Metal Crossarms Present	N	Cat.

Source: EDM International, Inc.

Table 9: Descriptions of Candidate Variables for the EDM Model

Variable A: Count of jumpers. Possible values: 0 through *n*. This variable was a count of the true number of energized jumpers on each structure. The variable allowed all energized equipment (e.g., transformers, regulators, capacitors, reclosers, sure arresters, cutouts) to be incorporated into a single variable because equipment depends on jumpers to operate. The variable avoided lack of independence concerns associated with recording each type of energized equipment separately.
Variable B: Count of phases. Possible values: 1 through *n*. This variable described the number of energized phases on a structure. Values typically were 1-3, but some structures supported multiple sets of unconnected primary conductors (e.g. underbuild configurations).
Variable C. Count of canopy heights. Possible values: 1 through 8. This variable describds the total number of canopy heights estimated within 200 m of the structure. This variable was included in the EDM model because it existed in the original model and was independent of other variables.
Variable D. Presence of deadends. Possible values: 0 = no, 1 = yes. This variable identified whether any primary conductor terminated at the structure. Configurations included terminal structures, corner structures, double deadend tangents and taps.
Variable E. Presence of phases on top of pole. Possible values: 0 = no, 1 = yes. This variable identified whether any energized conductor occurred on top of the pole top or upper-most crossarm.
Variable F: Presence of grounded equipment. Possible values: 0 = no, 1 = yes. This variable consolidated grounded metal brackets, grounded guy wires, pole-top grounds, and overhead neutral wires. It excluded grounding associated with energized equipment as the risks associated with the equipment were reflected in the count of jumpers.
Variable G: Presence of commanding view. Possible values: 0 = no and 1 = yes. This variable identified whether a structure occurred on flat ground or at the base of a topographic rise (a 0 value) or occurred on the side or top of a topographic rise (a 1 value).
Variable H: Presence of open unpaved habitat. Possible values: 0 = no, 1 = yes. This variable described the general land cover within 200 m of each structure. If ≥ 50% of the land cover within 200 m of the structure was covered by vegetation ≤ approximately 1 m tall, the land cover was considered open and unpaved. If vegetation grew > approximately 1 m tall or the land cover was paved, a 0 value was recorded.
Variable I. Presence of public land. Possible values: 0 = no, 1 = yes. Public land was identified as yes when an observer could reach or view the base of a structure without crossing a fence defining private property or violating a no trespassing sign.
Variable J: Presence of prey occurrence or raptor use. Possible values: 0 = no, 1 = yes. This variable consolidated observations of raptors or corvids observed on structures, avian whitewash, prey remains, raptor or corvid remains, or nests observed on or at the base of structures, and prey or prey sign observed within 200 m of structures.
Variable K. Effective height sum. Possible values –*n* through *n*. This variable was an estimate of the height of the structure being evaluated compared to the height of the structure one span to either side of the structure being evaluated. All height estimates were made from the base of the incident or comparison structure of interest.
Variable L. Arm orientation. Possible values 0 through 90. This variable described the orientation of the crossarm relative to the prevailing wind. The prevailing wind was always assumed to be from the west. A zero value indicated the short axis of the crossarm was perpendicular to the west wind. A 90 value indicated the long axis of the crossarm was perpendicular to the west wind. If multiple crossarms were present, the uppermost crossarm was used to inform this variable. This variable was included in the EDM model because it existed in the BRC model and was independent of other variables.
Variable M. Presence of ungrounded guy wire. Possible values: 0 = no, 1 = yes. This variable described the presence of an ungrounded guy wire on the structure. This variable was included in the EDM model because it existed in the original model and was independent of other variables.
Variable N. Presence of metal crossarms. Possible values: 0 = no, 1 = yes. This variable described the presence of a metal crossarm.

3.1.5 Data Analyses for a Revised Model

EDM used multivariate logistic regression to evaluate the simultaneous combined effects of several variables on the probability that a structure would be involved in an outage caused by the electrocution of a raptor or corvid. The simplest model possible was sought so personnel with little knowledge of avian ecology or overhead electric systems could use the model to evaluate electrocution risk. Because no prior information on the relative importance of variables existed, EDM decided *a priori* to model all possible combinations of the variables tested.

When modeling all possible combinations, the number of candidate models increases exponentially with the number of variables. To reduce the number of candidate models, EDM began by using univariate logistic regression and χ^2 analyses to identify variables most likely to be useful in predicting the probability of an incident (Hosmer and Lemshow 1989). To minimize the risk of excluding potentially influential factors, EDM used $P \leq 0.50$ from univariate analyses as a cutoff for including candidate variables in multivariate modeling (Hosmer and Lemshow 1989). Data from 80% of sampled structures was to create the EDM model and data from 20% of sampled structures was used validate the revised model (out of sample cross validation; as in Tintó et al. 2010). Data were randomly assigned to be used in model building or validation. Based on prior experience developing APPs and risk assessments, probability of electrocution values were identified *a priori* as $P \geq 0.80$ extreme risk, $0.79 \geq P \geq 0.60$ high risk, $0.59 \geq P \geq 0.40$ medium risk, and $P \leq 0.39$ low risk.

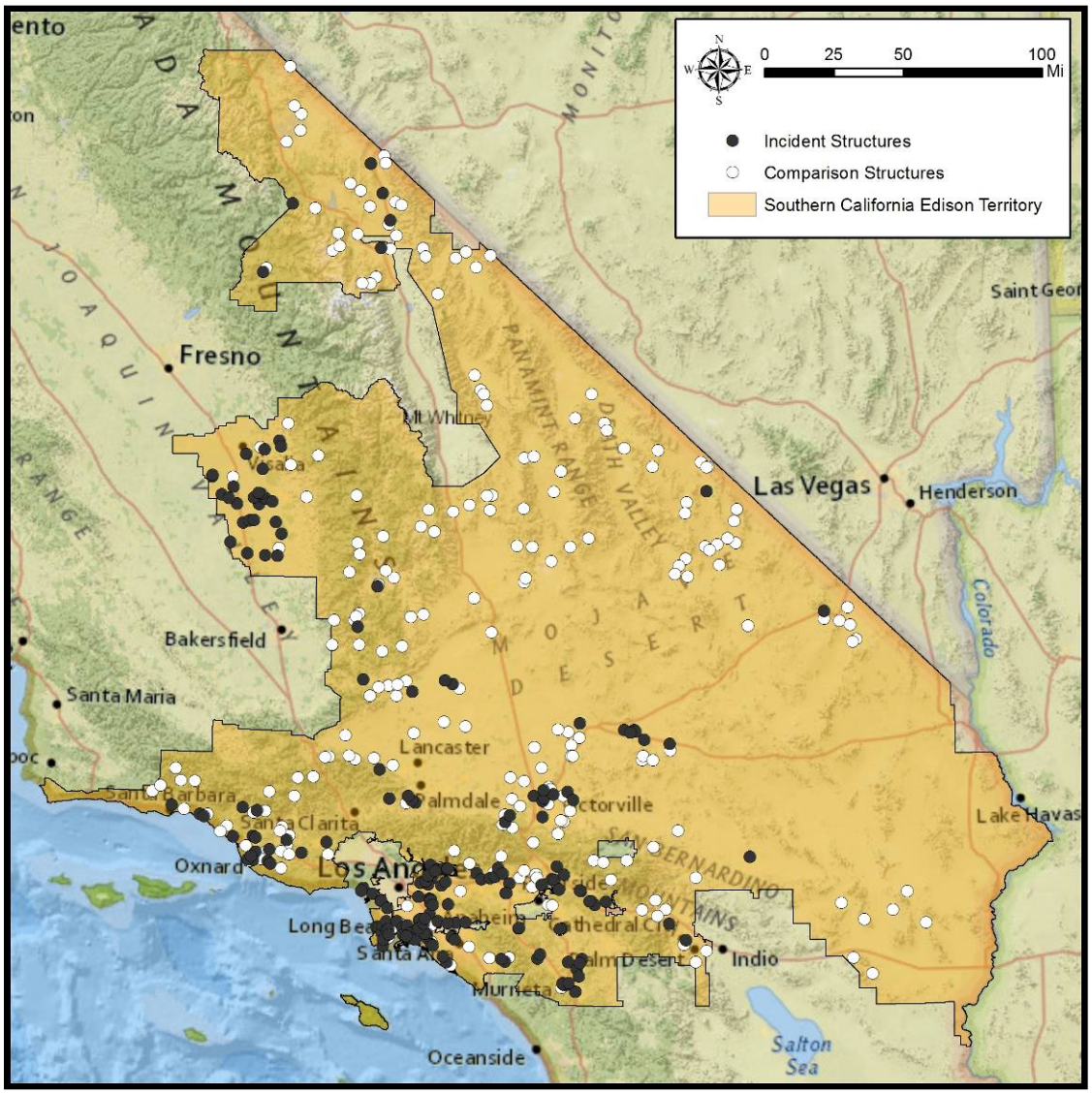
The logit link and the gmulti package (Calcagno and Mazancourt 2010) in program R (The R Foundation for Statistical Computing, Vienna, Austria), was used to model all possible subsets of variables, to rank models using Akaike information criterion with a correction for finite samples (AICc), and to calculate an averaged model, averaged model parameter estimates ($\hat{\beta}$'s), and estimates of error for $\hat{\beta}$'s. The binary logistic regression option in Minitab 16 (Minitab, State College, PA) was used to conduct a Hosmer-Lemeshow goodness of fit test not available in the gmulti package. AICc scores were used to rank and weight models (Burnham and Anderson 2002, Burnham and Anderson 2004, Burnham et al. 2011). All models within approximately $\Delta 7$ AICc of the best model describe plausible hypotheses (Burnham et al. 2011). In the interest of space, only models within $\Delta 4$ AIC values of the best model are reported here. Because weighted model averaging incorporating all models provides the optimal method of constructing a final model after accommodating uncertainty in model selection (Burnham and Anderson 2002, Burnham and Anderson 2004), $\hat{\beta}$ estimates and standard error estimates are reported only for a weighted average model.

3.2 Results

3.2.1 Overall Results

From May 10-22, 2011 and November 1-6, 2001, 213 incident structures and 248 comparison structures were visited by field biologist experienced in documenting avian electrocutions (Figure 31).

Figure 31: Locations of Sampled Structures

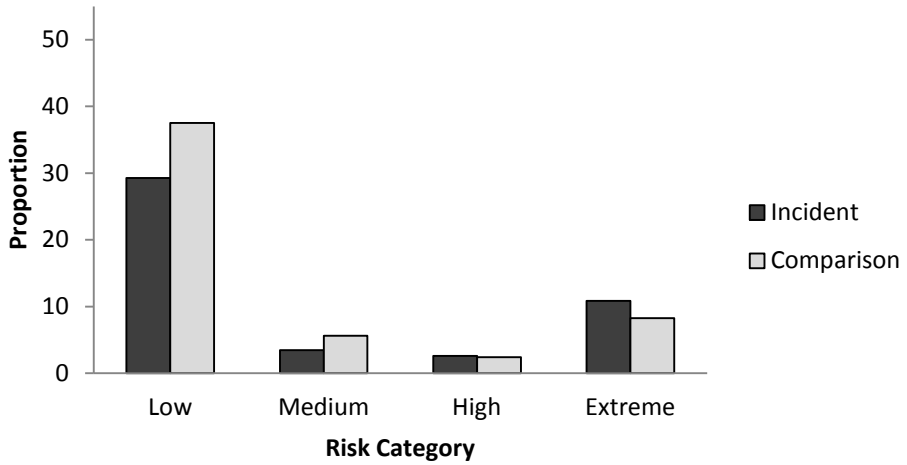


Source: Southern California Edison Territory polygon provided by Southern California Edison. Incident location data developed by Southern California Edison and EDM, International, Inc. Basemap developed by National Geographic and Esri.

3.2.2 Original Model

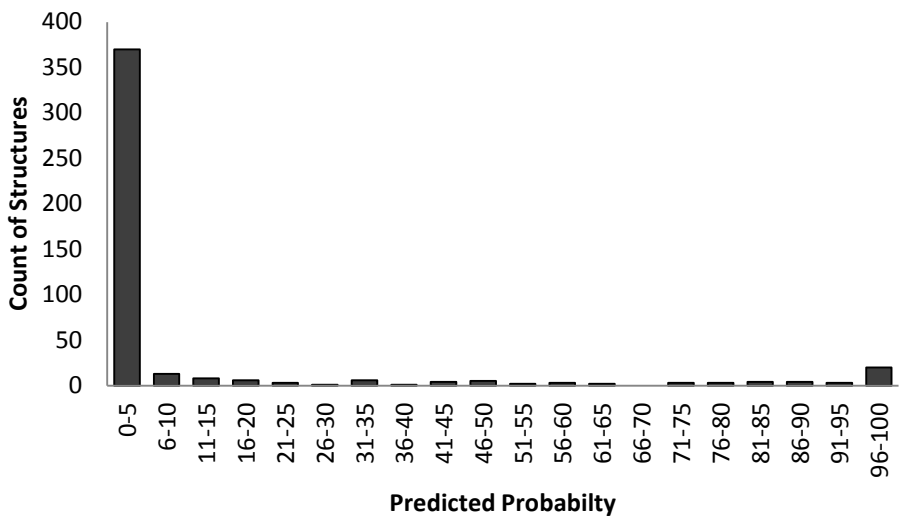
The original model identified 29.1% of incident structures as high or extreme risk, and 70.9% as low or medium risk (Figure 32). The original model identified 19.7% of comparison structures as high or extreme risk, and 80.3% as low or medium risk. There was no difference in the proportions of incident structures and comparison structures identified by the original model as extreme, high, medium, or low risk ($\chi^2_3 = 6.13$, $n = 461$, $P = 0.106$). Overall, this model tended to predict that structures had ≤ 5.0% probability of electrocution or ≥ 96% probability of electrocution with few structures in each intermediate class (Figure 33).

Figure 32: Proportion of Structures in BioResource Consultants (2008) Risk Categories



Source: EDM International, Inc.

Figure 33: Count of Structures in Predicted Probability Categories



Source: EDM International, Inc.

3.2.3 Revised Model

Univariate analyses indicated 10 of the 14 candidate independent variables had $P < 0.50$, thus meeting the criteria for inclusion in multivariate modeling (Table 10). The Hosmer-Lemeshow goodness of fit test for the full 10-variable model indicated QAIC was unnecessary ($\chi^2_8 = 2.603$, $n = 461$, $P = 0.957$), so EDM used AIC corrected for small sample size (AICc; Anderson 2008) to rank models.

Table 10: Candidate Variables used in Multiple Logistic Regression Modeling

Candidate Variable	ID[a]	X^2	*P*	Selected for Multivariate Modeling
Any Prey Occurrence or Raptor Use	A	91.930	< 0.000	Yes
Count of Jumpers	B	61.080	< 0.000	Yes
Topography	C	33.340	< 0.000	Yes
Any Grounded Equip. on Structure	D	29.820	< 0.000	Yes
Dominant Habitat	E	25.839	< 0.000	Yes
Count of Phases	F	20.644	< 0.000	Yes
Canopy Heights	G	12.850	< 0.000	Yes
Phases on Top of Pole	H	12.231	0.001	Yes
Public Land	I	7.318	0.007	Yes
Presence of Deadends	J	6.244	0.013	Yes
Effective Height Sum	K	0.390	0.532	No
Arm Orientation	L	0.380	0.536	No
Guy Wire Absent	M	0.335	0.563	No
Metal Crossarms Present	N	0.157	0.692	No

[a] Variables are identified by Variable ID in Table 9.
Source: EDM International, Inc.

EDM constructed 1024 candidate models. More complex models tended to have lower AICc scores and 36 models were with Δ 4 AICc of the best model (Table 11) indicating all candidate variables contributed to electrocution risk. However, standard errors for many of the variables in the models overlapped zero, indicating that many of the variables contributed minimally to the effectiveness of the model as a predictor. Averaging over all models indicated only four variables were necessary to model and predict electrocution risk (Table 12; Figure 34; Eq. 2). The variables required were 1) number of jumpers, 2) number of phases, 3) presence vs. absence of grounding, and 4) presence vs. absence of unpaved open habitat as the dominant land cover within 200 m.

$$Y = -0.93167 + 0.09048(\text{number of jumpers}) + 0.14506(\text{number of phases}) + 0.53203(\text{grounding present}) - 0.55151(\text{open habitat present}) \quad \text{[Eq. 2]}$$

Where 1 = grounding present, 0 = grounding absent, 1 = open habitat present, and 0 = open habitat absent (See Table 9). The inverse logit link function transforms outputs from Eq. 2 into a probability of electrocution (Eq. 3).

$$P = 1/(1+(e^{-Y})) \quad \text{[Eq. 3]}$$

The revised model can be used to investigate the effects of model parameters on the probability that an outage resulting from the electrocution of a raptor or corvid will be detected. Specifically, the probability of an incident increased approximately 1.0-2.3% with each additional jumper and 2.0-3.5% with each additional primary phase conductor (Figure 35). The probability of an incident increased approximately 4.0-13.0% with the addition of any pole-top grounding, and increased 4.5-13.7% when open habitat was absent (Figure 36). Overall, structures in closed or developed habitats with high numbers of jumpers, phases, and the presence of grounding had relatively high probabilities of being involved in an avian

electrocution, and structures in open undeveloped habitats with low numbers of jumpers, phases, and no grounding had low probabilities of being involved in an avian electrocution.

Table 11: Models within 4 AICc of the "Best" Model for Model Predicting the Probability of Electrocution of a Corvid or Raptor

Models	K	ΔAICc	Weight
v1 + v2 + v4 + v5 + v6 + v7 + v8 + v10	9	0.000	0.067
v1 + v2 + v6 + v7 + v8 + v10	7	0.459	0.054
v1 + v2 + v3 + v4 + v5 + v6 + v7 + v8 + v10	10	0.511	0.052
v1 + v2 + v3 + v6 + v7 + v8 + v10	8	0.597	0.050
v1 + v2 + v5 + v6 + v7 + v8 + v10	8	0.799	0.045
v1 + v2 + v3 + v5 + v6 + v7 + v8 + v10	9	1.051	0.040
v1 + v2 + v4 + v5 + v6 + v7 + v8	8	1.601	0.030
v1 + v2 + v4 + v5 + v6 + v8 + v10	8	1.899	0.026
v1 + v2 + v4 + v6 + v7 + v8 + v10	8	1.910	0.026
v1 + v2 + v6 + v7 + v8	6	1.991	0.025
v1 + v2 + v4 + v5 + v6 + v7 + v8 + v9 + v10	10	2.041	0.024
v1 + v2 + v3 + v4 + v6 + v7 + v8 + v10	9	2.129	0.023
v1 + v2 + v5 + v6 + v7 + v8	7	2.155	0.023
v1 + v2 + v6 + v8 + v10	6	2.324	0.021
v1 + v2 + v6 + v7 + v8 + v9 + v10	8	2.397	0.020
v1 + v2 + v3 + v6 + v7 + v8 + v9 + v10	9	2.406	0.020
v1 + v2 + v3 + v4 + v5 + v6 + v7 + v8 + v9 + v10	11	2.476	0.020
v1 + v2 + v5 + v6 + v8 + v10	7	2.565	0.019
v1 + v2 + v3 + v4 + v5 + v6 + v7 + v8	9	2.566	0.019
v2 + v3 + v6 + v7 + v8 + v1	7	2.647	0.018
v1 + v2 + v3 + v4 + v5 + v6 + v8 + v10	9	2.721	0.017
v1 + v2 + v3 + v6 + v8 + v10	7	2.808	0.017
v1 + v2 + v5 + v6 + v7 + v8 + v9 + v10	9	2.849	0.016
v1 + v2 + v3 + v5 + v6 + v7 + v8	8	2.900	0.016
v1 + v2 + v3 + v5 + v6 + v7 + v8 + v9 + v10	10	3.023	0.015
v1 + v2 + v3 + v5 + v6 + v8 + v10	8	3.132	0.014
v1 + v2 + v4 + v5 + v6 + v8	7	3.194	0.014
v1 + v2 + v4 + v5 + v6 + v7 + v8 + v9	9	3.486	0.012
v1 + v2 + v6 + v8	5	3.566	0.011
v1 + v2 + v4 + v6 + v7 + v8	7	3.576	0.011
v1 + v2 + v5 + v6 + v8	6	3.644	0.011
v1 + v2 + v6 + v7 + v8 + v9	7	3.712	0.011
v1 + v2 + v4 + v6 + v7 + v8 + v9 + v10	9	3.804	0.010
v1 + v2 + v4 + v6 + v8 + v10	7	3.849	0.010
v1 + v2 + v3 + v4 + v6 + v7 + v8 + v9 + v10	10	3.883	0.010
v1 + v2 + v4 + v5 + v6 + v8 + v9 + v10	9	3.984	0.009

v1 = count of jumpers, v2 = count of phases, v3 = count of canopy heights, v4 = presence of deadends, v5 = presence of phases on top of pole, v6 presence of grounded equipment, v7 = presence of commanding view, v8 = presence of open habitat, v9 = presence of public land, v10 = presence of prey occurrence or raptor use.

Source: EDM International, Inc.

The role of closed or developed habitats in the revised model was largely a function of the species documented in Edison's historical data. Incidents involving corvids occurred at 44.6% of the incident structures visited, and most of those electrocutions (77.9%) were in closed or paved habitats ($\chi^2 = 29.568$, df = 1, $P < 0.001$). Incidents involving buteos were not disproportionately associated with either open unpaved habitats or closed or paved habitats ($\chi^2 = 0.710$, df = 1, $P < 0.399$), nor were incidents involving owls ($\chi^2 = 2.286$, df = 1, $P < 0.399$). Incidents involving eagles tended to occur in open unpaved habitats ($\chi^2 = 17.191$, df = 1, $P < 0.001$; Table 13).

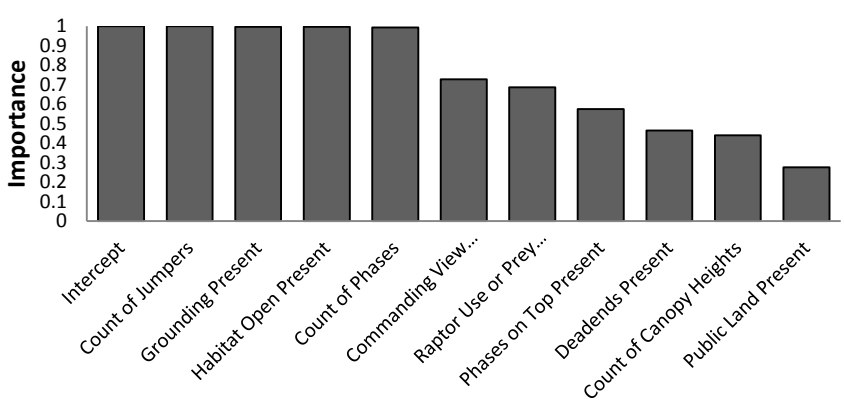
Table 12: Model Averaged Parameter Estimates ($\hat{\beta}$) and Standard Errors (SE) from Revised Model

Variable	$\hat{\beta}$	SE	Importance (Sum of Weights)
Intercept	-0.93167	0.35358	1.0000
Count of Jumpers	0.09048	0.02006	1.0000
Grounding Present	0.53203	0.15302	0.9969
Habitat Open Present	-0.55151	0.16374	0.9957
Count of Phases	0.14506	0.04703	0.9929
Commanding View Present	-0.22891	0.19231	0.7276
Raptor Use or Prey Present	0.23423	0.21706	0.6869
Phases on Top Present	-0.17202	0.20210	0.5739
Deadends Present	-0.12057	0.17714	0.4646
Count of Canopy Heights	0.03257	0.04950	0.4399
Public Land Present	-0.02429	0.08004	0.2759

Source: EDM International, Inc.

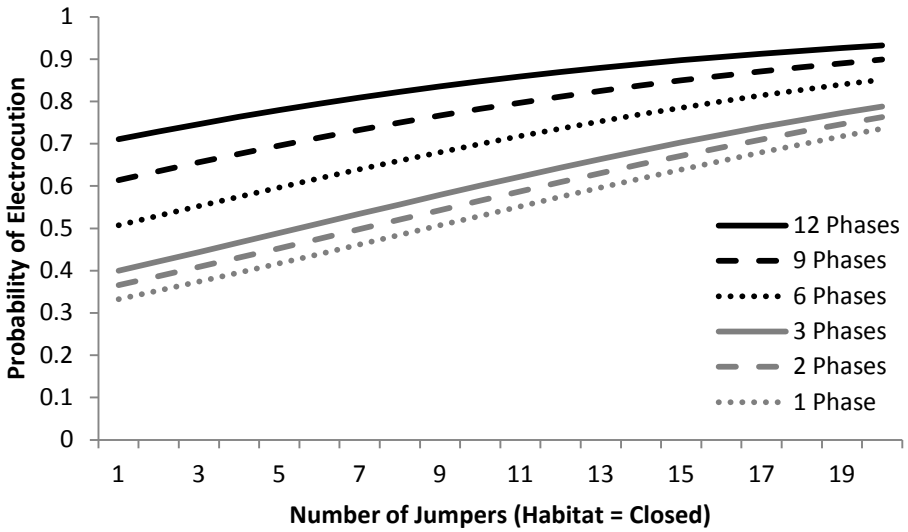
Users of these estimates must perform an inverse logit link transformation on the Y (output) value to transform values to a 0 to 1 probability scale (See Eq. 3).

Figure 34: Relative Importance of Candidate Variables in Final Averaged Model



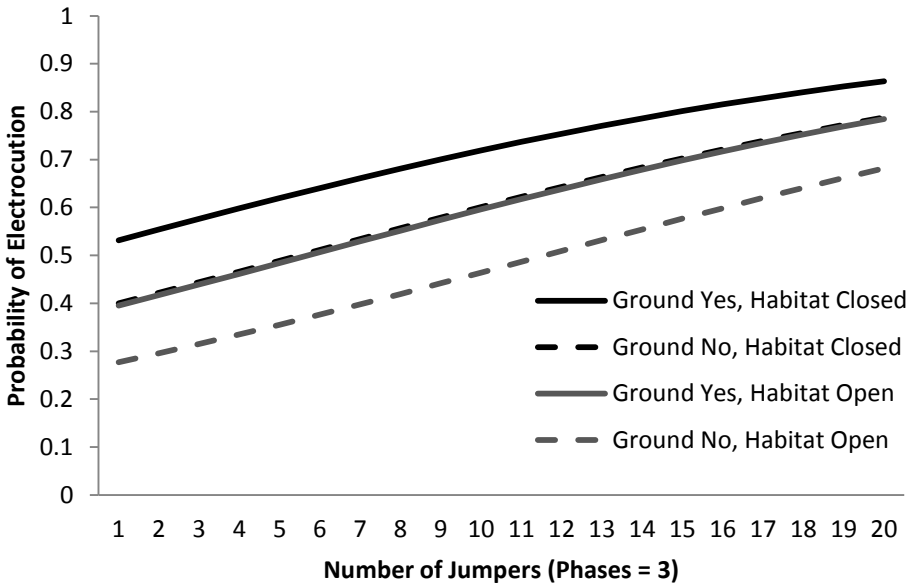
Source: EDM International, Inc.

Figure 35: Probability that a Structure will Electrocute a Raptor or Corvid and Cause an Outage as a Function of the Number of Jumpers and Number of Phases on a Structure



Source: EDM International, Inc.

Figure 36: Probability that a Structure will Electrocute a Raptor or Corvid and Cause an Outage as a Function of the Number of Jumpers, Presence of Grounding, and Presence of Open Habitat,



Source: EDM International, Inc.

Table 13: Count of Avian Taxa by Habitat Type

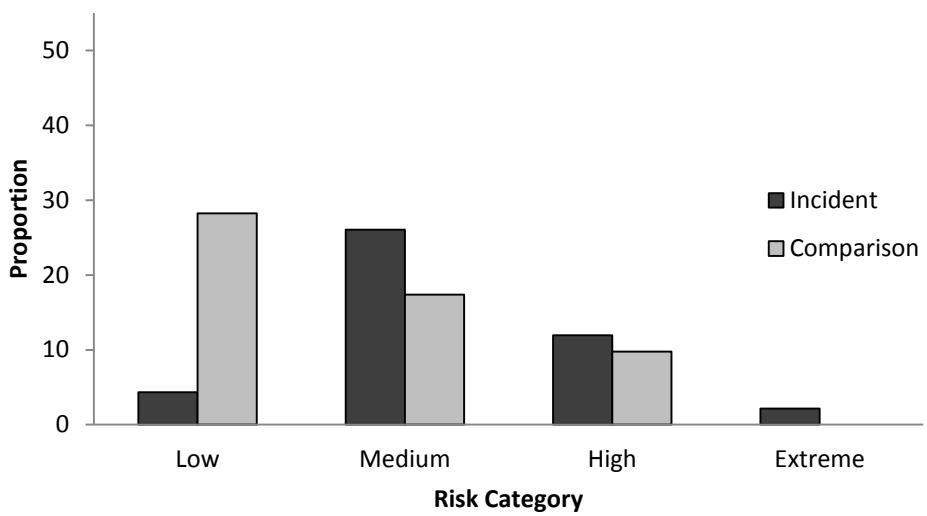
	Count Data Habitat		
	Open	**Closed**	**Sum**
corvid species	21	74	95
owl species	10	18	28
buteo species	31	38	69
eagle species	20	1	21
Sum	82	131	213

Source: EDM International, Inc.

3.2.4 Revised Model Performance

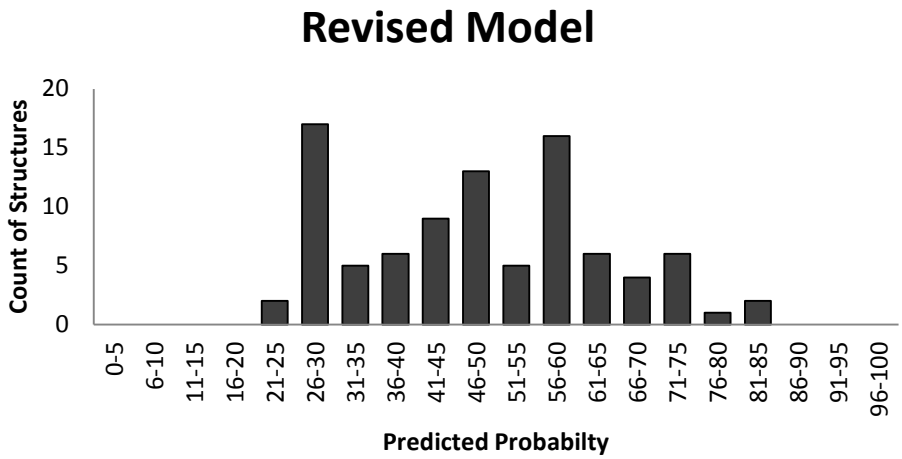
The revised model successfully distinguished incident from comparison structures. Specifically, the average risk probability was higher for incident structures than for comparison structures ($F_{1,90} = 20.65$, $P < 0.001$; $\bar{x}$ incident = 0.556, SD = 0.132; $\bar{x}$ comparison = 0.418, SD = 0.155). Based on the *a priori* risk categories, of P ≥ 0.80 extreme risk, 0.79 ≥ P ≥ 0.60 high risk, 0.59 ≥ P ≥ 0.40 medium risk, and P ≤ 0.39 low risk, the revised model correctly classified 90% of incident structures used to validate the model (Figure 37). The revised model also distributed structures relatively normally across risk values (Figure 38).

Figure 37: Proportions Structures Occurring in Risk Categories Identified in the Revised Model



Source: EDM International, Inc.

Figure 38: Count of Structures in Predicted Probability Categories from the Revised Model



Source: EDM International, Inc.

3.3 Discussion

3.3.1 Original Model

The original model did not distinguish incident structures from comparison structures. A variety of competing hypotheses may explain this result. First, only a portion of the total scope of inference of the original model was tested. The original model may have performed better if the entire scope of inference could have been evaluated. Second, the original data used to test the original model were not collected randomly, but rather were collected opportunistically during investigations of outages. The original model may have performed better if it could have been tested with data not associated with outages. Third, the original model may have incorporated strategies which violated modeling assumptions.

Because the original model did not predict electrocution risk as expected, it was reviewed for independence among regressor variables, selection procedures for the preferred model, and the sampling strategy used to collect data to build the model. The model may not have performed well due to a lack of independence among variables. The original model included 22 variables (BioReseource Consultants 2008). To meet the assumptions of the modeling strategy used, each variable needed to be independent of all other variables (Montgomery et al. 2006). Assigning such variables can be difficult as some variables are likely to be nested, or subtly dependent. For example, assigning a separate variable for switches and another for jumpers is not independent as each switch requires two jumpers to operate. Additionally, given the application of the principal of parsimony in AIC modeling (Burnham and Anderson 2002, 2004, Burnham et al. 2011), it was atypical that so many variables would be included in the final model, particularly when many had very little effect (Bioresource Consultants 2008).

3.3.2 Revised Model

All structures in an overhead electric system are not equally likely to electrocute a bird (Harness and Wilson 2001, APLIC 2006, Lehman 2001, Dwyer 2004). Thus, to minimize avian electrocution it is important to identify high-risk structures so electric utilities can use limited budgets to greatest effect (Dwyer and Mannan 2007). The revised model achieves this objective for electrocution of raptors and corvids causing outages in the Edison service area. This model identified four factors as important to predicting electrocution risk within the model's scope of inference: 1) number of jumpers, 2) number of phases, 3) presence of grounding, and 4) presence of unpaved open habitat as the dominant land cover within 200 m.

Representative structures illustrating important pole-top variables are presented in the *Representative Structures* section at the end of this chapter. As an example, if a structure supported 9 jumpers, 3 phases, a pole top ground, and occurred in closed habitat (i.e. a typical 3-phase transformer tangent structure in an urban area), the probability of electrocution would be computed as (Eq. 4 and Eq. 5), and would be classified as high risk.

$$Y = -0.93167 + 0.09048(9) + 0.14506(3) + 0.53203(1) - 0.55151(0) = 0.8498 \qquad \text{[Eq. 4]}$$

$$P = 1/(1+e^{(-0.8498)} = 0.700. \qquad \text{[Eq. 5]}$$

Jumpers link energized structure-mounted devices to one another and to the primary conductor. Structure-mounted equipment including transformers (Harness and Wilson 2001, Dwyer 2004), lightning arresters (Harness et al. 2008), capacitors, reclosers, regulators, switches, and cutouts (APLIC 1996, APLIC 2006) are regularly associated with avian electrocution. Because many structure-mounted devices operate in combination, modeling the number of jumpers avoids lack of independence concerns associated with modeling various pole-mounted equipment types simultaneously. In this study, all jumpers were modeled as exposed and energized because many of the electrocution incidents contributing to the dataset occurred prior to the widespread application of insulated jumpers. However, when using the revised model to predict current electrocution risk, covered jumpers should not be counted toward the total number of jumpers unless any portion of a jumper is exposed.

The number of phases on a structure has previously been identified as contributing to electrocution risk (APLIC 2006). For example, three-phase transformer structures contribute disproportionately to electrocutions in part because of the occurrence of multiple differently energized devices on the structures increases phase-to-phase electrocution risk (Harness and Wilson 2001). However, the number of phases does not appear to have been explicitly included in previous models designed to predict electrocution risk (Sergio et al. 2004, BioResource Consultants 2008, Tintó et al. 2010, Guil et al. 2011). Users of this model should count all primary conductors supported by each structure of interest including transmission conductors, distribution conductors, and underbuild conductors. Primary conductors linked via with jumper, such as occurs at corner poles and double deadend structures, should be counted as only one phase. Low voltage insulated conductors linking transformers to individual buildings should not be counted.

The presence of grounding on a structure is known to influence electrocution probability (Mañosa 1997, Harness et al. 2008, Gerdzhikov and Demerdzhiev 2009), but grounding has typically been modeled only as a function of structure type where metal or concrete poles supporting a structure provide a path to ground for electric current. To our knowledge, this concept has not previously been expanded to model structure-top ground wires, uninsulated grounded guy wires, and overhead neutral wires as a group, though each of these configurations is regularly considered in APPs and risk assessments (Harness and Nielsen 2005, APLIC and the USFWS 2005, APLIC 2006). This model offers evidence that neglecting to consider all possible paths to ground may reduce the effective predictive ability of other avian electrocution models.

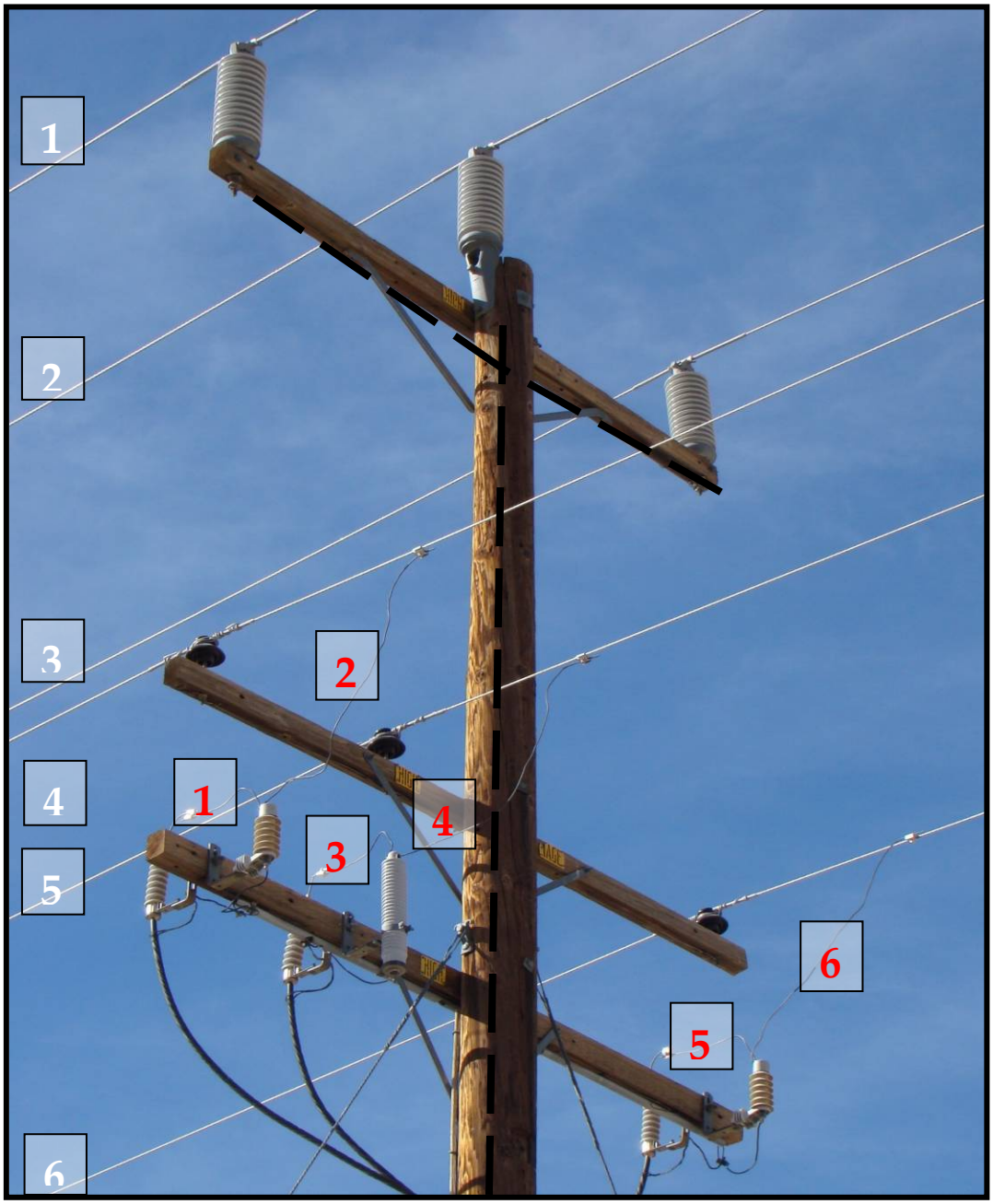
The revised model indicated electrocution risk was lower in open land covers than in developed or forested land covers. Previous studies have typically identified open habitat as a risk factor for electrocution in the U.S. (Schomburg 2003, APLIC 2006, Mojica et al. 2009) and in Europe (Sergio et al. 2004, Gerdzhikov and Demerdzhiev 2009, Tintó et al. 2010; but see Guil et al. 2011 for results similar to those reported here). Those studies differed from this study by surveying randomly selected structures or line segments to identify mortalities. In this study, pre-existing outage data was used to identify mortalities independent of outage data. Avian electrocutions do not necessarily result in outages (Harness and Wilson 2001, APLIC 2006, Dwyer and Mannan 2007), but when they do, the cause of an outage may be more easily detected in developed areas where access to structures is facilitated by adjacent infrastructure. Furthermore, because the incident structures contributing to this study were biased to developed areas, and comparison poles were randomly distributed throughout the service area, the habitat variable used in this model may not transfer well to incidents beyond the scope of the sampling regime used here. This is particularly true given that eagles tend to be electrocuted in open habitats, and buteos and owls were electrocuted in both open and closed habitats, but each of these species was overshadowed in this model by the large number of corvids electrocuted in closed habitats. As a correction factor, we suggest using the closed habitat value in all locations where electrocution of raptors may be of concern.

Two important weakness of the revised model are 1) it was constructed exclusively based on incident data associated with outages, and 2) it includes no information on nesting. To expand the strict scope of inference, future research should seek to create a model using a broader data set collected though random sampling. Future research also should expand the modeling concept to utilities with more comprehensive historical incident data. A model incorporating information on raptor nesting would be particularly informative since the proximity of nests to overhead electric structures is known to influence electrocution risk (Dwyer and Mannan 2007) but is rarely investigated. Comparison between models constructed from different types of data also would provide an important wider perspective on differences in important predictors between service areas. In the absence of a broader model, the revised model described herein offers a tool for predicting avian electrocution risk in southern and central California. Consequently, for convenience, each of the equations necessary to use the model are included in Appendix A as a spreadsheet intended to be copied into Microsoft Excel®. An functioning electronic version of Appendix A also is available directly from the authors of this report.

3.5 Representative Structures

Four example structures are illustrated to demonstrate the use of the revised model (Figure 39 through Figure 42).

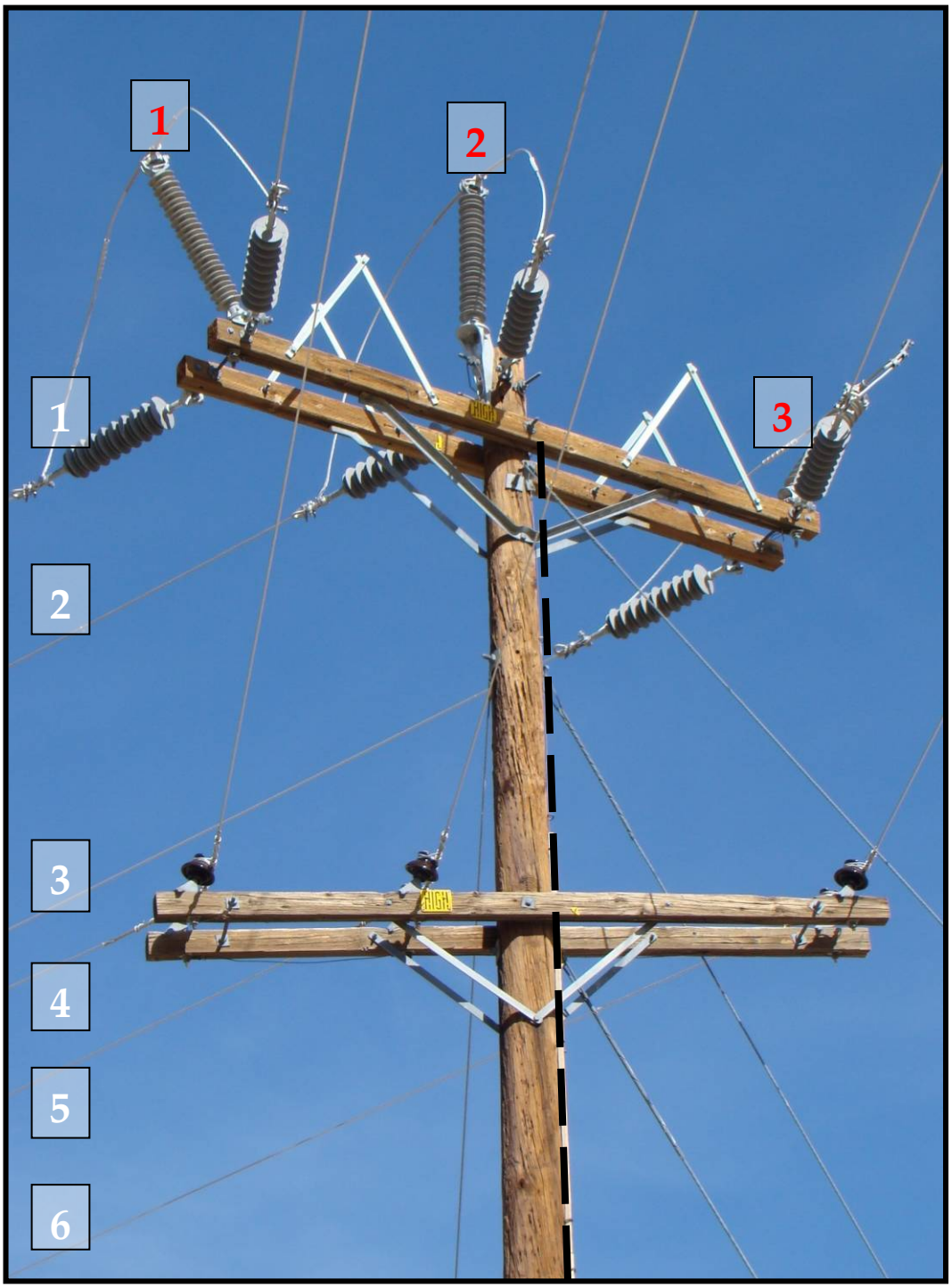
Figure 39: Example Strcture Number 1



Red text boxes: count of jumpers. White text boxes: count of phases. Black dotted lines = presence of grounding (illustrated because ground wire is obscured by pole). Probability of electrocution = 0.734 assuming habitat = 0 (See *Appendix A Prediction Calculator*).

Source: EDM International, Inc.

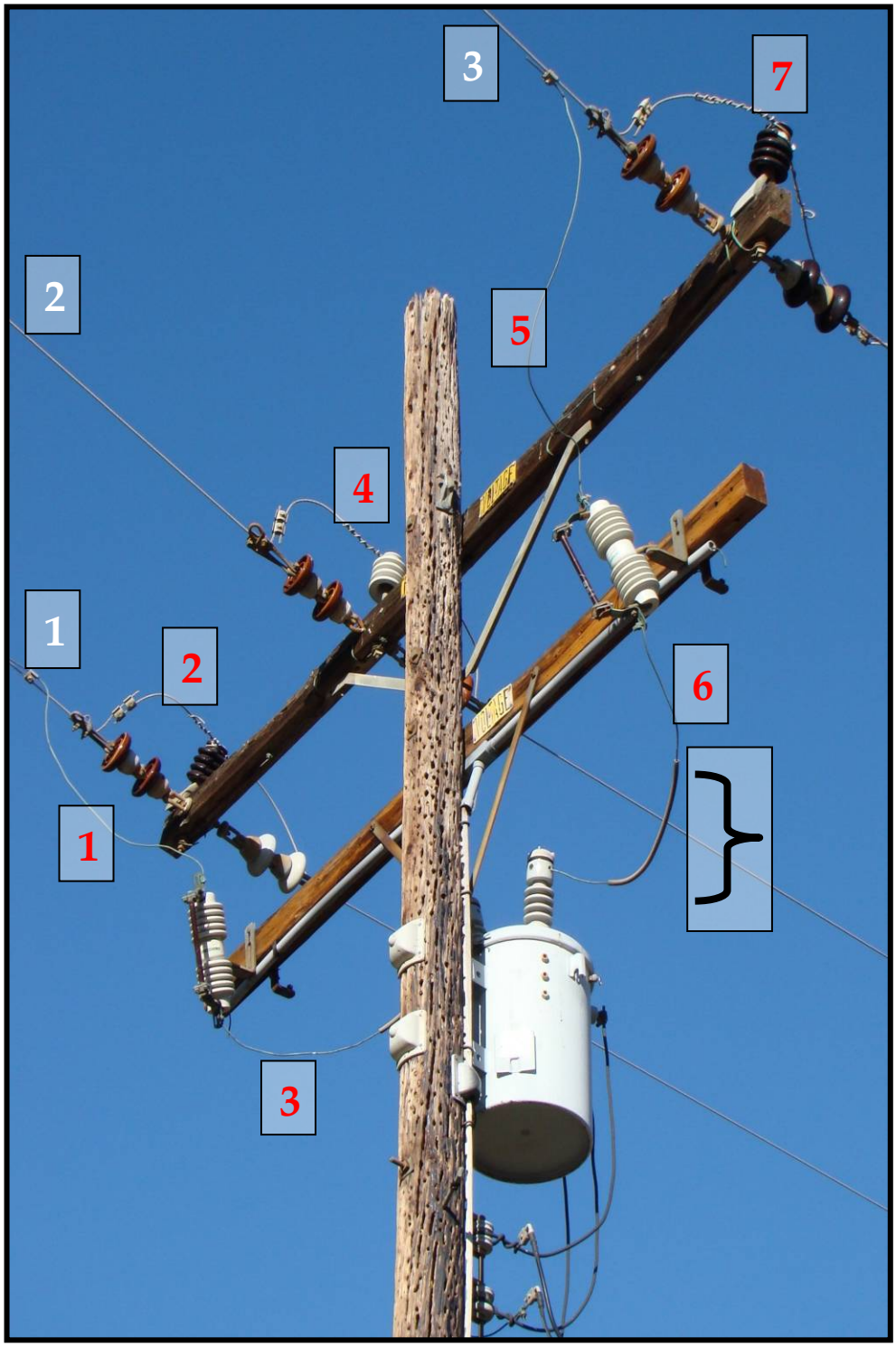
Figure 40: Example Structure Number 2



Red text boxes: count of jumpers. White text boxes: count of phases. Black dotted lines = presence of grounding (illustrated because ground wire is obscured by pole). Probability of electrocution = 0.677 assuming habitat = 0 (See *Appendix A Prediction Calculator*).

Source: EDM International, Inc.

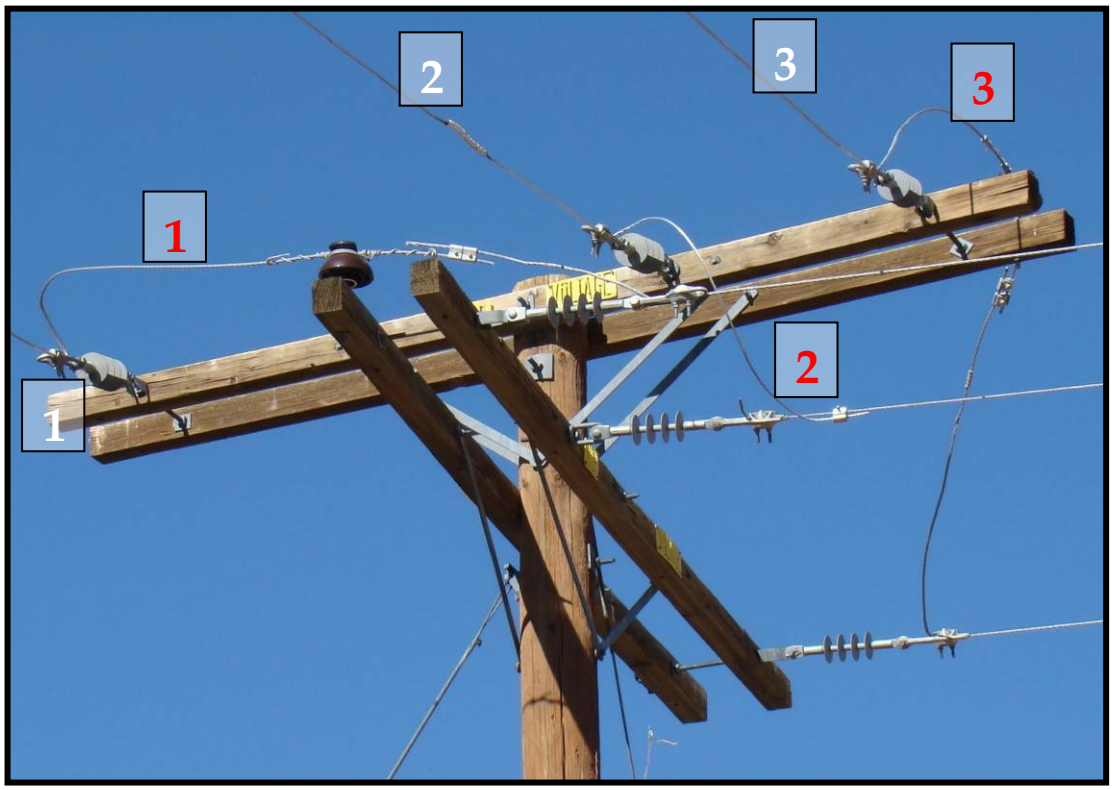
Figure 41: Example Structure Number 3



Red text boxes: count of jumpers. White text boxes: count of phases. Black bracket: partially covered jumper is counted as exposed and energized. No exposed pole-top grounding exists (grounded transformer case is not counted). Probability of electrocution = 0.534 assuming habitat = 0 (See *Appendix A Prediction Calculator*).

Source: EDM International, Inc.

Figure 42: Example Structure Number 4



Red text boxes: count of jumpers. White text boxes: count of phases. No exposed pole-top grounding exists (guy wires are insulated below the frame of the photo). Probability of electrocution = 0.444 assuming habitat = 0 (See *Appendix A Prediction Calculator*).

Source: EDM International, Inc.

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APPENDIX A:
Prediction Calculator

DIRECTIONS (Paste this into cells A1:D28).

1) Copy this ENTIRE table into a Microsoft Excel worksheet.

2) Enter structure parameters in cells with double borders. | example

3) Read predicted probability of electrocution from shaded cell. | example

INPUT VALUES (Descriptors of Structures)

	Number of Jumpers (0 - n). All exposed or partially exposed jumpers including splices.
	Number of Phases (0 - n). All primary conductors including transmission, distribution, and underbuild.
	Presence of Grounding (0 or 1). 0 indicates no grounding, 1 indicates grounding.
	Presence of Open Unpaved Habitat (0 or 1). 0 indicates ≥ 50% of landscape within 200 m is closed or paved.

OUTPUT VALUE (Probability of Electrocution)

=B28

Output value 1.00 - 0.80 = extreme risk	* Within risk categories, higher scores indicate higher predicted risk.
Output value 0.79 - 0.60 = high risk	* Within risk categories, higher scores indicate higher predicted risk.
Output value 0.59 - 0.40 = medium risk	* Even low and medium risk structures can be dangerous in some circumstances.
Output value 0.39 - 0.00 = low risk	* Even low and medium risk structures can be dangerous in some circumstances.

CALCULATIONS (Do not alter these cells)

Parameter Name	Parameter Estimate
Intercept	-0.931669606
Jumpers	0.090478369
Phases	0.145055166
Grounding	0.532028911
Habitat	-0.551507928
Inverse Logit	1/(1+(EXP(Y*-1)))
Y =	=(B21)+(A7*B22)+(A8*B23)+(A9*B24)+(A10*B25)
P =	=1/(1+(EXP(B27*-1)))

APPENDIX B:
List of Scientific Names

The following table provides scientific names for all species referenced in the text of this document.

Common Name	Latin Name	Common Name	Latin Name
Acorn woodpecker	*Melanerpes formicivorus*	Greater roadrunner	*Geococcyx californianus*
American crow	*Corvus brachyrhynchos*	Gull species	*Laridae* species
American kestrel	*Falco sparverius*	Hawk species	*Buteo* species
American white pelican	*Pelecanus erythrorhynchos*	Mute swan	*Cygus olor*
Bald eagle	*Haliaeetus leucocephalus*	Northern flicker	*Colaptes auratus*
Barn owl	*Tyto alba*	Northern harrier	*Circus Cyaneus*
Blackbird species	*Icteridae* species	Osprey	*Pandion haliaetus*
Brown pelican	*Pelicanus occidentalis*	Owl species	*Stigidea or Tytonidae* species
California condor	*Gymnogyps californianus*	Parrot species	*Psittacidae* species
Canada goose	*Branta canadensis*	Pelican species	*Pelicanidae* species
Common peafowl	*Pavo cristatus*	Peregrine falcon	*Falco peregrinus*
Common raven	*Corvus corax*	Prairie falcon	*Falco mexicanus*
Cooper's hawk	*Accipiter cooperii*	Raptor species	*Accipitridae* species
Corvid species	*Corvidae* species	Red-shouldered hawk	*Buteo lineatus*
Dove species	*Columbidae* species	Red-tailed hawk	*Buteo jamaicensis*
Duck species	*Anus* species	Rock pigeon	*Columbia livia*
Egret species	*Ardeidae* species	Rough-legged hawk	*Buteo lagopus*
European starling	*Sturnus vulgaris*	Sandhill crane	*Grus canadensis*
Falcon species	*Falconidae* species	Sparrow species	*Emberizidae* species
Ferruginous hawk	*Buteo regalis*	Swainson's hawk	*Buteo swainsoni*
Golden eagle	*Aquila chrysaetos*	Turkey vulture	*Cathartes aura*
Goose species	*Branta* species	Western scrub Jay	*Aphelocoma californica*
Great blue heron	*Ardea herodias*	Wild turkey	*Meleagris gallopavo*
Great egret	*Ardea alba*	Woodpecker species	*Picidae* species
Great horned owl	*Bubo virginianus*		