



Development and evaluation of predictive models for managing Golden Eagle electrocutions
by Jeffrey William Schomburg

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management

Montana State University

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Abstract:

Four percent of 4,090 power poles examined in 1,600 km² area of central Montana electrocuted ≥ 1 golden eagle (*Aquila chrysaetos*) between 1996 and 2001. A total of 198 golden eagles were found electrocuted by power pole. I developed predictive models to discriminate between offending power poles (power poles known to electrocute ≥ 1 golden eagle) and non-offending power poles. Thirty-five candidate models describing mechanisms suspected to induce golden eagle power pole electrocutions were developed prior to data analysis. Candidate models were compared using Akaike's Information Criterion (AICc). Models with variables describing power pole characteristics, habitat, and social interactions among golden eagles were most strongly associated with electrocutions of golden eagles on power poles. I used 60% of data collected in central Montana to develop post hoc prediction models with multiple logistic regression, classification and regression tree (CART), or hybrid (combining multiple logistical regression and CART) model building techniques. Predictions for each model building technique were validated using test data (remaining 40% of data collected in central Montana). Hybrid models were most accurate (74%) in classifying offending and non-offending power poles, followed by CART models (70.2%). I used CART with all data collected from central Montana to develop a final predictive model. Final model predictions were validated using independent data collected in 1,200 km² area of northern Wyoming. Final predictive model classified offending and non-offending power poles equally as well for independent data and model data ($\geq 77.0\%$). I recommend CART and hybrid model building techniques for developing predictive models. I recommend CART for identifying interactions early in exploratory analysis or in pilot studies to reduce number of parameters analyzed when developing logistic regression models. I recommend utility companies implement my final predictive model to identify power poles to be retrofitted.

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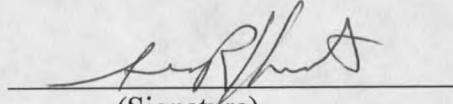
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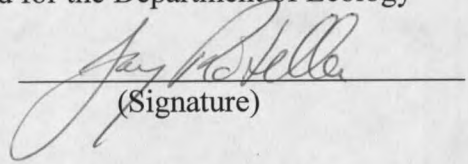
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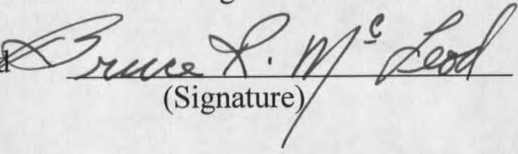
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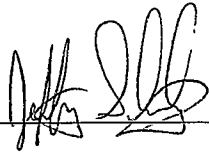
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ABSTRACT

Four percent of 4,090 power poles examined in 1,600 km² area of central Montana electrocuted ≥ 1 golden eagle (*Aquila chrysaetos*) between 1996 and 2001. A total of 198 golden eagles were found electrocuted by power pole. I developed predictive models to discriminate between offending power poles (power poles known to electrocute ≥ 1 golden eagle) and non-offending power poles. Thirty-five candidate models describing mechanisms suspected to induce golden eagle power pole electrocutions were developed prior to data analysis. Candidate models were compared using Akaike's Information Criterion (AICc). Models with variables describing power pole characteristics, habitat, and social interactions among golden eagles were most strongly associated with electrocutions of golden eagles on power poles. I used 60% of data collected in central Montana to develop post hoc prediction models with multiple logistic regression, classification and regression tree (CART), or hybrid (combining multiple logistical regression and CART) model building techniques. Predictions for each model building technique were validated using test data (remaining 40% of data collected in central Montana). Hybrid models were most accurate (74%) in classifying offending and non-offending power poles, followed by CART models (70.2%). I used CART with all data collected from central Montana to develop a final predictive model. Final model predictions were validated using independent data collected in 1,200 km² area of northern Wyoming. Final predictive model classified offending and non-offending power poles equally as well for independent data and model data ($\geq 77.0\%$). I recommend CART and hybrid model building techniques for developing predictive models. I recommend CART for identifying interactions early in exploratory analysis or in pilot studies to reduce number of parameters analyzed when developing logistic regression models. I recommend utility companies implement my final predictive model to identify power poles to be retrofitted.

INTRODUCTION

Hundreds of raptors are killed each year by electrocution on power poles (Lehman 2001). Provisions of the Migratory Bird Treaty Act (16 U.S.C. 703-712) and Eagle Protection Act (16 U.S.C. 668-668C) may result in severe penalties for many utility companies. In the case of *United States of America v. Moon Lake Electric Association Inc. (MLEA)*, 45 F. Supp. 2d 1070 (D.D.C. 1999), the government found MLEA responsible for electrocuting 17 raptors and imposed a fine of \$100,000 (Lehman 2001, Melcher and Suazo 1999).

Utility companies have responded to the raptor electrocution problem by retrofitting power poles that have electrocuted one or more raptor (Lehman 2001). Retrofitting consists of modifying power pole design to minimize raptor electrocution potential or discourage raptor use of power poles (APLIC 1996). Guidelines are available that make newly constructed power poles raptor safe (APLIC 1996).

In addition to retrofitting power poles that have electrocuted one or more raptor, NorthWestern Energy (NWE; formerly Montana Power Company) was interested in preventing raptor electrocutions. The company was concerned with an area in central Montana where power poles associated with oil fields were electrocuting golden eagles at a high rate (Milodragovich S., NWE, personal communication). Golden eagles are raptors at greatest risk of electrocution (Olendorff 1972, Smith and Murphy 1972, Boeker and Nickerson 1975, Benson 1981, O'Neil 1988, Harness and Wilson 2001). NWE's goal is to retrofit not only offending power poles (power poles known to electrocute

one or more golden eagle), but also those having a high likelihood of electrocuting golden eagles in the future.

Models predicting offending power poles or describing differences between offending and non-offending power poles (no known electrocutions of golden eagles) are not available. Criteria for designating power poles requiring retrofitting have been presented by Hamerstrom et al. (1974), Huckabee (1980), and Lehman (2001). Number of raptor electrocutions was related to power pole configuration (Benson 1981, Harness and Wilson 2001). Golden eagle electrocutions were found to be more prevalent in uncultivated grasslands and locations of greater topographical relief (Benson 1981). Distance to water, visibility, proximity to prey, availability of natural perches, and habitat with high densities of jackrabbits (*Lepus spp.*) were variables identified with raptor electrocutions, but not quantified (Baglien 1975, Boeker and Nickerson 1975, Nelson and Nelson 1976, Nelson and Nelson 1977, Association of Bay Governments 1987, APLIC 1996). Previous studies lacked analyses concerning correlations among variables identified or measured to be associated with golden eagle electrocutions. Correlated variables make it difficult to infer associations between variables measured and golden eagle electrocutions. Analysis techniques for multivariate data, therefore, may help quantify differences between offending and non-offending power poles and predict golden eagle electrocutions.

APLIC (1996) described the cause of electrocutions as “skin-to-skin, foot-to-skin, and beak-to-skin contacts with two conductors or a conductor and a ground (e.g., ground wires, lightning arrestors, and grounded metal braces)”. We are left to speculate on

factors promoting golden eagle electrocutions, because APLIC (1996) does not specify what promotes the cause of electrocutions. This study was designed to develop predictive models to assist utility companies in identifying power poles to retrofit and gain a better understanding of what promotes golden eagle electrocutions. I collected data for offending and non-offending power poles owned and operated by NWE in central Montana (Roundup study area) and by Pacific Corp in central Wyoming (Worland study area). Power poles in Roundup and Worland study areas were associated with active oil fields and responsible for electrocuting numerous golden eagles.

Objectives were to: (1) design an a priori strategy using multiple logistic regression candidate models to determine which factors best describe what promotes golden eagle electrocutions; (2) determine whether multiple logistic regression, CART, or hybrid (combining multiple logistic regression and CART) model building techniques best predict classification of offending and non-offending power poles in central Montana; (3) quantify univariate associations among golden eagle electrocutions and variables measured; and (4) determine if my final predictive model can be used to predict offending and non-offending power poles in other areas.

I offer ideas for future development of predictive models and future analysis of multivariate data. I discuss strengths and weaknesses of my final predictive model. I conclude with recommendations for utility companies and management for preventing golden eagle electrocutions.

STUDY AREA

The Roundup study area (RSA) was located in central Montana, 96 km north of Billings, Montana, in Musselshell and Rosebud counties (Fig. 1). The town of Roundup, Montana was the southeast corner of the study area. The 1,600 km² study area included a combination of transmission and distribution power poles owned and operated by NorthWestern Energy. Power lines supplied electricity for oil wells, ranch homes, and irrigation pumps. High density of oil wells in RSA affected habitat by providing cover for cotton-tailed rabbits (*Sylvilagus audubonii*) and white-tailed jackrabbits (*Lepus townsendii*). RSA is a rural setting with low human activity contributing to the attractiveness of this area for golden eagles.

Drought conditions were present throughout the 2000 and 2001 field seasons (The Drought Monitor National Drought Mitigation Center 2002). Golden eagles along with red-tailed hawks (*Buteo jamaicensis*), northern harriers (*Circus cyaneus*), ferruginous hawks (*Buteo regalis*), Swainson's hawks (*Buteo swainsonii*), bald eagles (*Haliaeetus leucocephalus*), prairie falcons (*Falco mexicanus*), American kestrels (*Falco sparverius*), great horned owls (*Bubo virginianus*), and burrowing owls (*Athene cunicularia*) were observed in the study area. Potential prey for golden eagles were white-tailed jackrabbits, cotton-tailed rabbits, black-tailed prairie dogs (*Cynomys ludovicianus*), Richardson's ground squirrels (*Spermophilus richardsoni*), yellow-bellied marmots (*Marmota flaviventris*), badgers (*Taxidea taxus*), mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), gopher snakes (*Pituophis sayi sayi*), prairie

rattlesnakes (*Crotalus viridis*), sage grouse (*Centrocercus urophasianus*), and domestic sheep (*Ovis aries*) (McGahan 1968, Olendorff 1976, Watson 1997). Topography was mostly flat with rolling hills and rock outcrops. The landscape was a mosaic of native grassland and shrub cover types with patches of ponderosa pine (*Pinus ponderosa*), black cottonwood (*Populus trichocarpa*) and cultivated fields, primarily alfalfa (*Medicago sativa*) and wheat (*Triticum spp.*). Shrub cover was dominated by big sagebrush (*Artemisia tridentata*). Other shrubs present were greasewood (*Sarcobatus vermiculatus*) and silver sagebrush (*Artemisia cana*). Cultivated fields and deciduous forests were associated with the Musselshell River drainage. The RSA was 90% privately owned with interspersed public land, BLM and state owned. The non-cultivated areas were primarily used for grazing (sheep and cattle) or oil extraction.

The Worland study area (WSA) was located 8 km east of Worland, Wyoming, 300 km south of the RSA, and comprised 1,100 km² (Fig. 1). Vegetation cover was similar to the RSA, with native grassland and big sagebrush dominating the landscape. One major difference was the absence of ponderosa pine forest. Cultivated land was minimal, and trees, principally, were restricted to drainages. Topography was more diverse, with the southeast portion of the study area being mostly flat and the remaining area dominated by a series of barren hills and narrow draws. WSA was a rural setting with low human activity. The primary use of uncultivated land was livestock grazing and oil extraction. WSA also had a greater density of oil wells and subsequently a greater density of power poles than RSA. I observed a less diverse group of raptors including Swainson's hawks, northern harriers and golden eagles. Cotton-tailed rabbits, white-

tailed jackrabbits, white-tailed prairie dogs (*Cynomys leucurus*), and pronghorn antelope were potential prey observed in the WSA. Decreased diversity of raptors and potential prey might be attributed to less time spent in the field.

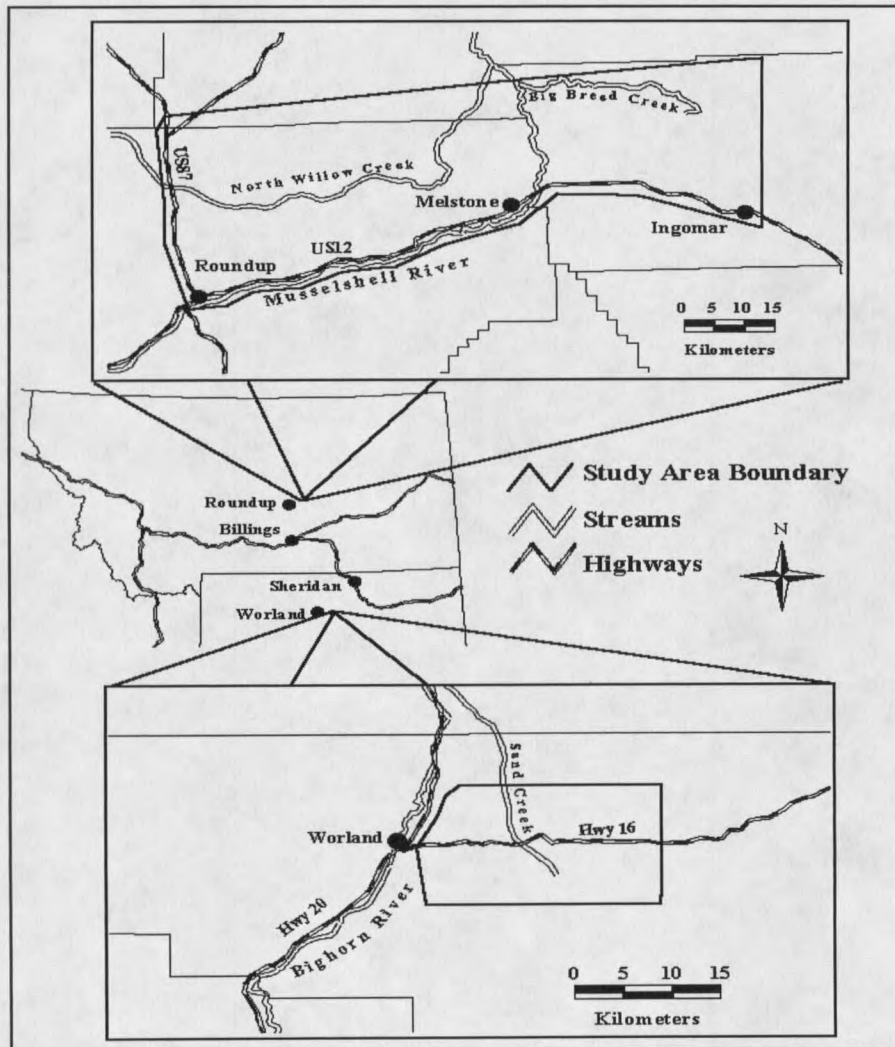


Figure 1. Roundup study area (top) for developing predictive models classifying offending (power poles electrocuting one or more golden eagle) and non-offending power poles in central Montana, USA, and Worland study area in north central Wyoming, USA for validating predictive models.

METHODS

Power Pole Surveys

A census of power poles for the RSA was performed using pedestrian or all-terrain-vehicle surveys in the summer of 2000. Surveys located geographical positions of offending power poles and identified all power poles observed to be non-offending. To reduce detection bias, search time was greater for power poles located in dense vegetation. I did not quantify differences in carcass detection between different habitats. In addition to ground surveys, carcass locations were located using raptor mortality reports filed by NWE linemen. NWE personnel began filling out mortality reports in 1996 (Appendix A). Personnel were instructed by NWE, when possible, to identify species and cause of death. Power poles electrocuting more than one golden eagle were entered into the database more than once for analysis. Cause of death included gun shot wounds, electrocutions, or mid-span collisions. Several (n = 28) reports failed to record pole number and were not included in analysis.

Collisions

Each power pole in the RSA (n = 4,090) was examined for golden eagle carcasses within a 12m-radius. The 12m-radius was used to differentiate between electrocution by power pole and collision-induced mortality. I defined three types of collision-induced

mortalities: (1) direct trauma from collision with a single line, (2) electrocution by contacting two lines simultaneously while ascending or descending between two lines without subsequent use of power poles, and (3) electrocution by pushing two lines close enough together for a bird to simultaneously touch two lines. In an attempt to reduce misclassification between electrocution by power pole and collision-induced mortality, I classified all carcasses found within 12 m of a power pole as power pole electrocutions. The 12-m radius was based on conservative estimates where power lines could not be pushed close enough together by a golden eagle to simultaneously touch two lines (D. Bauer D., NWE, personal communication). Cause of death for carcasses found beyond 12 m were defined as collision induced mortalities. Collision induced mortalities were not used in my analysis.

Data Collection-Variable Description

Data were collected in 2000 and 2001 for offending power poles discovered between 1996 and 2001. Similar data were collected for a random sample of non-offending power poles in 2000 and 2001. In the event a golden eagle carcass was discovered within 12 m of a randomly sampled power pole, another power pole was randomly selected.

Golden eagle carcasses were aged and sexed when possible. I classified carcasses into two age classes, non-adults and adults, using plumage (Jollie 1947). I sexed golden eagle carcasses using culmen, halux, and head length (Harmata and Restani 1995).

Power Pole Variables

Locations of offending power poles and the random sample of non-offending power poles were recorded in UTM (Universal Transverse Mercator) coordinates by a Geo-explorer II GPS unit. Power pole locations were imported into Arcview (ESRI 1998) geographic information system (GIS) to assist in measuring proximity of power poles to landscape features (Table 1).

Table 1. Variables measured for offending¹ power poles and a random sample of non-offending power poles for the Roundup study area.

<u>Variable</u>	<u>Description</u>	<u>Metric</u>
(1-2) SAGE ²	Total amount of sagebrush cover ($\geq 5\%$ canopy cover)	%
(3-4) GRASS ²	Total amount of native grassland cover ($< 5\%$ sagebrush canopy cover)	%
(5) AG ³	Total amount of cultivated field cover	%
(6) FOREST ³	Total amount of forest cover (deciduous or coniferous)	%
(7) XARM	Number of cross-arms attached at different heights	count
(8) POLE	Pole design	categorical
(9) PDOG	Distance to nearest prairie dog town	m
(10) TOPO	Topographical position of power pole (use of allocated codes)	ordinal ⁴
(11) LOS	Estimated from base of power pole, unobstructed line of sight distance summed over 4 cardinal directions	m
(12) DISTMM	Distance to nearest man made structure (not including power poles)	m
(13) NEST	Distance to nearest golden eagle nest known to be active within past 3 years	m
(14) ROAD	Distance to nearest road (paved or unpaved)	m
(15) WATER	Distance to nearest perennial creek, pond, or reservoir	m
(16) PERCH	Distance to nearest natural perch (rock outcrop/boulder $> 1.5\text{m}$ tall, tree $> 4.6\text{m}$ tall)	m
(17) DRAINAGE	Distance to nearest drainage	m
(28) PH	Sum of pole height differences among sample poles and their adjacent poles	m
(19) TFMR	Transformers present on power poles	y/n

¹Poles that have electrocuted at least one golden eagle

²Habitat type variable measured at two scales within four 100 m quadrats or four 1,000 m quadrats.

³Habitat type variable measured at one scale within four 1,000 m quadrats.

⁴TOPO variable was coded as a trend variable (flat = 1, bottom $\frac{1}{3}$ slope = 2, mid $\frac{1}{3}$ slope = 3, top $\frac{1}{3}$ slope = 4, hill/ridge top = 5).

Offending and non-offending power poles were classified as one of five power pole designs (Table 2). POLE variable categorized power poles based on structure, voltage, and presence of jumper wires (Figs. 2, 3). Pole structure and presence of jumper wires were associated with number of contact points and distance between contact points (Harness 1997). Higher voltage was associated with increased arcing distance; the distance electricity can travel between conductors (Benson 1981). Power poles with power lines running ≥ 34.5 kilovolts were transmission poles, power lines running < 34.5 kilovolts were distribution poles. Power poles with transformers have been associated with the highest numbers of raptor electrocutions (Harness 1997) and poles with more than one cross-arm might act as an attractant to raptors (O'Neil 1988), so I recorded number of cross-arms attached at different pole heights (XARM) and the presence of transformers (TFMR).

Table 2. Categories of POLE¹ variable describing offending² and non-offending power pole characteristics and designs for the Roundup study area.

Pole Design	Definition
TRANS	All transmission poles ³ .
JW	All distribution poles ⁴ with jumper wires ⁵ at or above the height of cross-arms or for power poles without cross-arms at or above pole top height.
NOXARM	Distribution poles ⁴ without cross-arms and jumper wires.
3PHASE	Distribution poles ⁴ without jumper wires, with ≥ 1 cross-arm having 3 power lines present.
2PHASE	Distribution poles ⁴ without jumper wires, with ≥ 1 cross-arm having 2 power lines present.

¹See Table 1 for description.

²Poles that have electrocuted at least one golden eagle.

³All transmission poles in Roundup study area transmitted 69 kilovolts.

⁴All distribution poles in Roundup study area transmitted < 34.5 kilovolts.

⁵Jumper wires serve as connectors between conductors and other energized equipment.

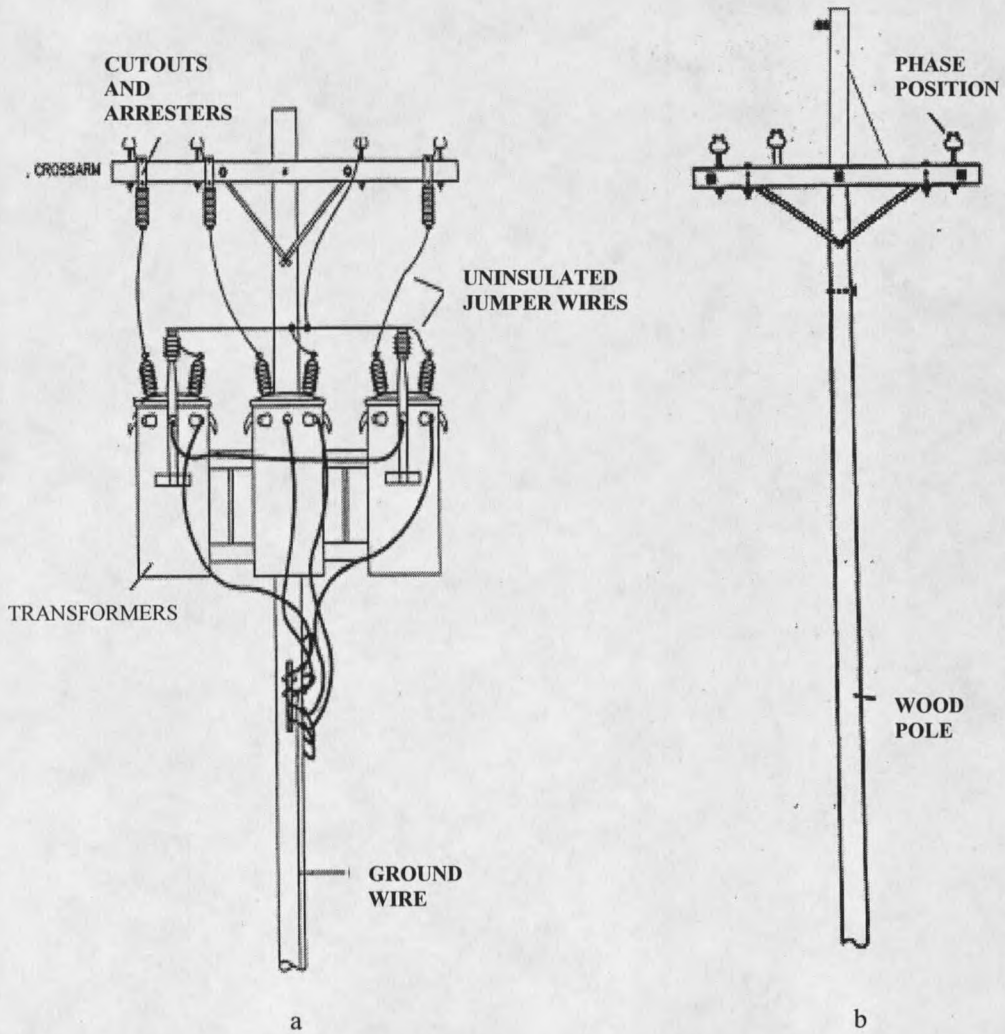


Figure 2. Typical JW (a) and TRANS (b) pole designs (see table 2) in the Roundup and Worland study areas. (courtesy of Richard Harness)

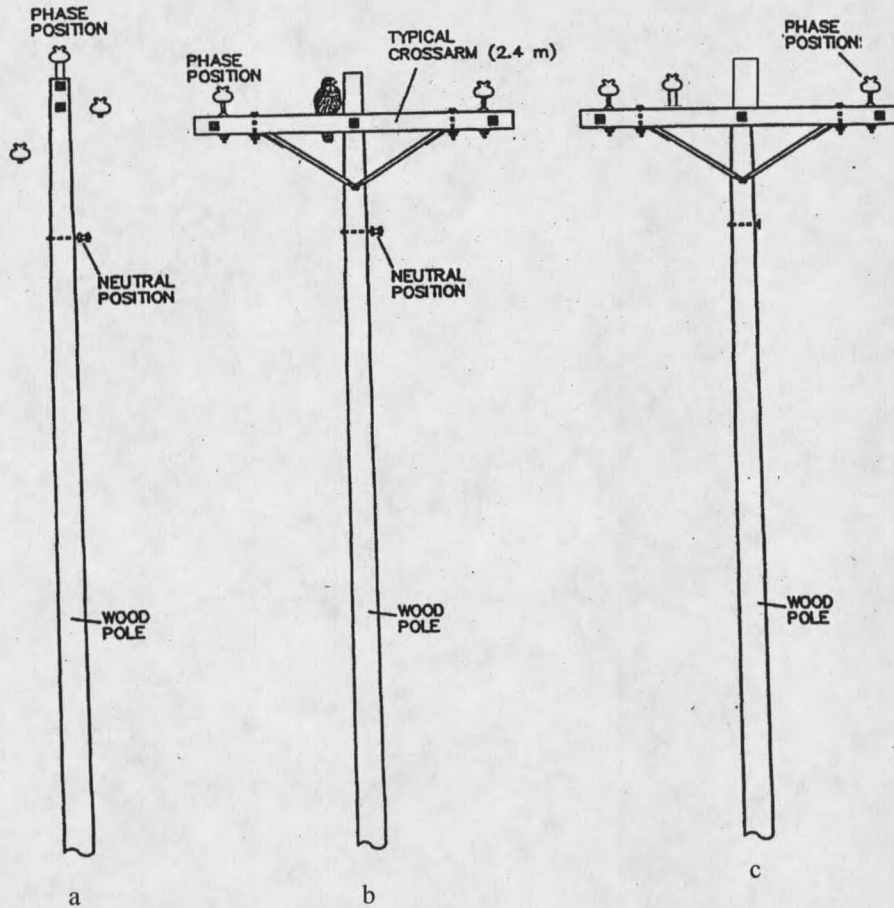


Figure 3. Typical NOXARM (a), 2PHASE (b), and 3PHASE (c) pole designs (see table 2) in the Roundup and Worland study areas. If jumper wires were present in (a), (b), or (c) they would be classified as JW pole designs (see table 2). (courtesy of Richard Harness)

Visibility Variables

Greater height advantages could enhance a golden eagle's potential for detecting of prey (Benson 1981), and topographical features can function as boundaries between two breeding pairs (Brown and Watson 1964). TOPO variable included five pole location categories based on topographical relief: flat, bottom 1/3 of slope, middle 1/3 of slope, top 1/3 of slope, and hill/ridge top. Pole location category was ranked from 1-5, lowest height advantage (1-flat, without adjacent vertical rise or slope) to greatest height advantage (5-hill/ridge top). I suspected power poles placed on higher topographical relief might also be used by golden eagles to communicate territorial boundaries. However, higher topographical relief might be associated with hills and rock outcrops visually obstructing possible communication of territorial boundaries. Two additional variables, therefore, were measured describing possible visual advantages for pole locations.

Power poles placed above adjacent poles might be more attractive to golden eagles, offering superior views of surrounding areas. The PH variable measured differences in heights between sample (offending or non-offending) poles and adjacent poles (Fig. 4). Height differences between sample poles and adjacent poles were measured by ocular estimates using increments of 1.5 m.

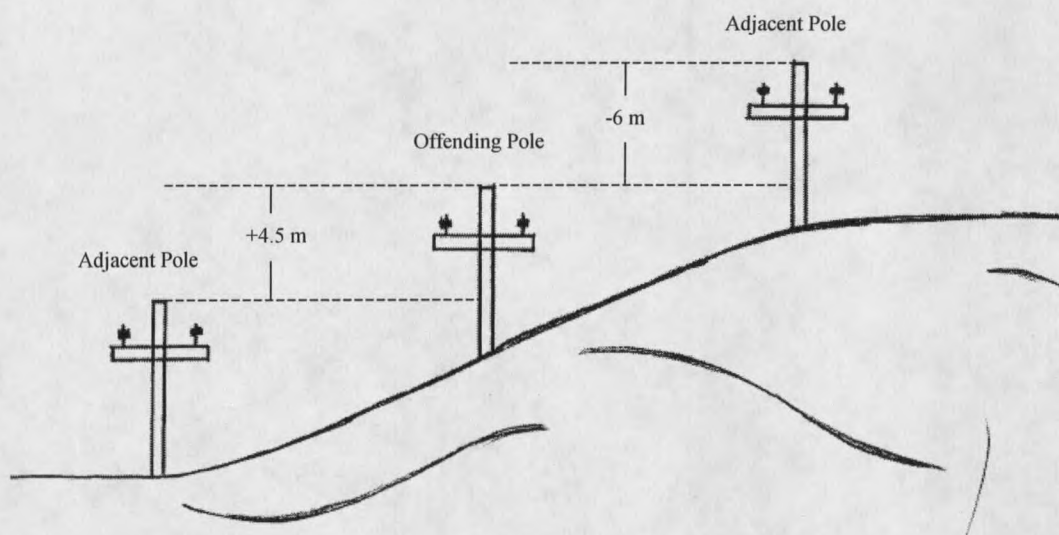


Figure. 4. PH variable (see Table 1) in the Roundup and Worland study areas. In this example, offending pole PH = -1.5 m.

Golden eagles can detect jackrabbits at distance up to 3 km (Brown and Amadon 1968); therefore, I chose 2 km as a conservative maximum distance for measuring line of sight. LOS variable measured line of sight in four cardinal directions from the base of each sample pole. Distances were measured to the point of a visual obstruction (trees, rocks, man made structures, or topography) or 2 km, and summed over four cardinal directions. If topography was considered a visual obstruction, it had to obstruct greater than 1,000 m beyond the point of topographical obstruction (Fig. 5).

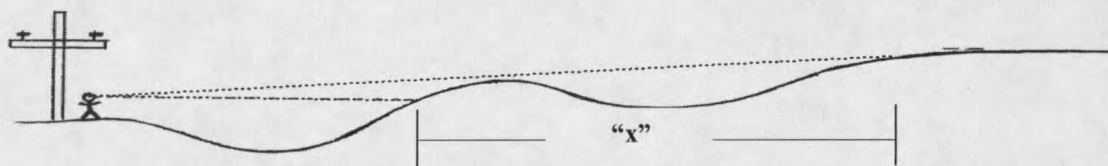


Figure 5. Determining distance for measuring LOS variable (see Table 1) when topographical features visually obstruct line of sight in the Roundup and Worland study areas. If “x” was < 1 km, topographical feature was not considered a visual obstruction and LOS measured to next closest visual obstruction or 2 km. If “x” was ≥ 1 km the topographical feature was considered a visual obstruction.

Variables Measuring Proximity to Landscape Features

I measured minimum distance to an active golden eagle nest (NEST), prairie dog town (PDOG), paved or unpaved road (ROAD), drainage (DRAINAGE), perennial stream, pond or reservoir (WATER), man-made structure (DISTMM; primarily oil wells and storage sheds), and natural perch (NP) for each offending and non-offending power pole. I measured distances by ocular estimates, range finder, or GIS. Power lines and their respective power poles were generally evenly spaced; therefore, I used number of power poles as a reference to improve accuracy of my ocular distance estimates.

Golden eagle nest locations were recorded during three years of fixed wing aerial surveys. Nests active at least once between 1999 and 2001 were included in analysis. NEST variable might relate some distance where breeding golden eagles will tolerate conspecifics. Intruding golden eagles perched on power poles too close to active nests

might result in attacks from resident eagles. Aggressive interactions among golden eagles during use of power poles might promote electrocutions. Electrocutions might also occur when fledgling eagles and adult eagles interact (grooming and feeding) while perched on power poles. I suspect aggressive and non-aggressive interactions were more probable near active nests.

I acquired prairie dog town locations in Musselshell County from Montana Fish, Wildlife, and Parks data (Newell J., Montana Dept. of Fish, Wildlife, and Parks, personal communication). I utilized ancillary GIS data layers to measure ROAD, DRAINAGE, and WATER variables. Observations during aerial surveys indicated cotton-tailed rabbits used man made structures for cover during daylight hours. In winter, white-tailed jackrabbits used a similar strategy (Flath D., Montana Dept. of Fish, Wildlife, and Parks, personal communication). Field observations also indicated cotton-tailed rabbits used drainages for foraging and cover.

Ocular estimates up to 2 km were used to measure nearest distance to natural perch (NP). I considered trees > 4.5 m tall or rock formations (outcrops or boulders) > 1.5 m tall as natural perches available to golden eagles.

Habitat Variables

Golden eagles selected sagebrush over grassland and cultivated fields in Colorado and Idaho (Craig et al. 1986, Marzluff et al. 1997). Furthermore, a greater number of eagle electrocutions occurred in fallow versus cultivated lands in six western states (Benson 1981). If relationships exist between habitat preference and power pole use, and

between power pole use and electrocutions, habitat associations might be an important predictor of golden eagle electrocutions.

I measured percent cover type at two spatial scales based on how golden eagles have been shown to select available habitat (Wiens 1973, Johnson 1980, Aebischer et al. 1993, Manley et al. 1993, Morrison et al. 1998). I defined the two spatial scales as quality habitat and forage points (Johnson 1980, Marzluff et al. 1997). Quality habitat scale represented the first decision golden eagles might make for selecting habitat and subsequent power pole use. I defined quality habitat as habitat having a high likelihood of containing lagomorphs and/or sage grouse. Lagomorphs and sage grouse are important prey items in golden eagle diets (McGahan 1968, Boeker and Ray 1971, Olendorff 1976, Steenhof and Kochert 1988). I represented quality habitat using four, square kilometer quadrats surrounding each sample pole. Quadrat size was based on existing biological information for average home range size of black-tailed jackrabbits (Smith 1990, Knick and Dyer 1997). I used average home range size for black-tailed jackrabbits because literature lacks estimates of home range size for white-tailed jackrabbits. The forage point scale represented the next decision golden eagles might make for selecting habitat and subsequent power pole use. Once an eagle is attracted to quality habitat, an eagle might choose a particular power pole based on ease of capturing prey or probability of capturing prey. Marzluff et al. (1997) used 100-m radius circles to represent habitat around prey captures. Benson (1981) observed the majority of golden eagle attempts at capturing prey were within 100 m of power poles being utilized. I

represented the forage point scale using four, hectare quadrats surrounding each sample pole.

I chose five cover types to investigate relationships between habitat and golden eagle electrocutions (Table 1). I used ocular estimates to measure percent cover within four, hectare quadrats or four, square kilometer quadrats. I chose five percent canopy cover to distinguish between sagebrush (SAGE) and grassland (GRASS) cover types (Duabenmire 1959).

Data Analysis

Data for RSA were divided randomly into two subsets. One data subset (model data set; 60% of RSA data) was used for building a priori logistic regression models, post-hoc logistic regression models, post-hoc classification and regression tree models (CART), and post-hoc hybrid models (combining CART and logistic regression). The remaining subset produced test data set (40% of RSA data). Test data set was used to compare validity of predictions between logistic regression, CART, and hybrid models with observed data.

For logistic regression models, response variable was relative probability (π) of a power pole being an offending pole (coded 1), non-offending poles were coded 0. Because sample sizes for offending poles and non-offending poles were nearly equal I arbitrarily chose $\pi = 0.50$ as the value for classifying between offending poles and non-offending poles. $\pi < 0.50$ was considered a non-offending power pole. For CART

models the response variable was categorical (offending pole or non-offending pole) producing classification trees.

All RSA data were used to build the final predictive model. Results from testing predictions with test data set determined the technique for building the final predictive model. Independent data from WSA were used to test validity of predictions of the final predictive model. I used S-Plus for all CART analyses (Vernables and Ripley 1994, Math Soft 1995) and PROC LOGISTIC for all logistic regression analyses (SAS Institute Inc. 1990).

A Priori Logistic Regression Models

Prior to data analysis, I developed a list of mechanisms hypothesized to induce golden eagle power pole electrocutions. I suspected habitat, hunting technique, social interaction, and power pole configuration were the most dominant mechanisms leading to golden eagle power pole electrocutions. I developed a set of candidate models for each mechanism (Table 3). Habitat models predicted a linkage between habitat, frequency of pole use, and electrocutions. Power Pole Configuration models predicted number of contact points, distance between contact points, and frequency of power pole use were correlated with electrocutions. Hunting Technique models predicted a relationship exists between proximity to potential prey base and power pole electrocutions. Social Interaction models predicted some variables were associated with eagles demonstrating increased rates of aggressive or non-aggressive behaviors while perched from power poles that could lead to electrocutions (Appendix B). Craig (1984) commonly observed

2-3 golden eagles sharing the same power pole. Golden eagles sharing the same power pole might decrease distance for contacting two wires thus increasing likelihood of electrocution. Brown and Watson (1964) concluded, "overt aggression is normal for golden eagles." Aggressive behavior has been observed between breeding pairs (Bergo 1987), between single adults (Dixon 1937), and subadult golden eagles (Appendix B). Furthermore, models of owls (*Bulbo* spp.) placed on power poles to deter other raptors from using power poles elicited aggressive behavior including attacks by eagles (Janss 1999).

Multiple Mechanism models were built from what I suspected as the most important variables for each of four mechanisms. This set of candidate models was an attempt to guide my exploratory analysis in determining if I should consider models containing variables from each of four mechanisms or less complex models.

I employed multiple logistic regression in building candidate models

$$\pi = e^{\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k} / 1 + e^{\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k},$$

where all coefficients were linear or pseudothreshold. Linear models predicted any change in magnitude of predictor variables resulted in a constant change in the log of the odds of being an offending power pole. Pseudothreshold models predicted the log of the odds of being an offending power pole reached an asymptote with increasing magnitude of predictor variables (Franklin et al. 2000). Log of the odds was defined as:

$$\log[\pi / 1 - \pi] = \beta_0 + \beta_1 X_1 + \dots + \beta_k X_k.$$

Table 3. Five sets of candidate logistic regression models developed a priori to data analysis to describe possible mechanisms inducing golden eagle electrocutions on power poles.

Hypothesized Model	Predicted Effects	
	Linear	Pseudo-threshold
Habitat		
1-2) $B_0 + B_1(\text{FOREST}^2)$	$B_1 > 0$	$B_1 > 0$
3-4) $B_0 + B_1(\text{AG}^2)$	$B_1 > 0$	$B_1 > 0$
5-6) $B_0 + B_1(\text{SAGE}^1) + B_2(\text{SAGE}^2)$	$B_1 > 0, B_2 > 0$	$B_1 > 0, B_2 > 0$
7-8) $B_0 + B_1(\text{SAGE}^2)$	$B_1 > 0$	$B_1 > 0$
9-10) $B_0 + B_1(\text{SAGE}^1)$	$B_1 > 0$	$B_1 > 0$
Power Pole Configuration		
11) $B_0 + B_1(\text{POLE})$	B_1	
12-13) $B_0 + B_1(\text{POLE}) + B_2(\text{XARM})$	$B_1, B_2 > 0$	$B_1, B_2 > 0$
14-15) $B_0 + B_1(\text{XARM})$	$B_1 > 0$	$B_1 > 0$
Hunting Technique		
16-17) $B_0 + B_1(\text{PDOG})$	$B_1 < 0$	$B_1 < 0$
18-19) $B_0 + B_1(\text{DISTMM})$	$B_1 > 0$	$B_1 > 0$
20-21) $B_0 + B_1(\text{PDOG}) + B_2(\text{DISTMM})$	$B_1 < 0, B_2 < 0$	$B_1 < 0, B_2 < 0$
22-23) $B_0 + B_1(\text{PDOG}) + B_2(\text{LOS})$	$B_1 < 0, B_2 > 0$	$B_1 < 0, B_2 > 0$
24-25) $B_0 + B_1(\text{DRAINAGE})$	$B_1 < 0$	$B_1 < 0$
Social Interaction		
26-27) $B_0 + B_1(\text{NEST})$	$B_1 < 0$	$B_1 < 0$
28-29) $B_0 + B_1(\text{TOPO})$	$B_1 > 0$	$B_1 > 0$
30-31) $B_0 + B_1(\text{TOTSAGE}) + B_2(\text{TOPO}) + B_3(\text{TOPO} * \text{NEST})$	$B_1 > 0, B_1 < 0, B_1 > 0$	$B_1 > 0, B_1 < 0, B_1 > 0$
Multiple Mechanism		
32-33) $B_0 + B_1(\text{PDOG}) + B_2(\text{TOPO}) + B_3(\text{SAGE}) + B_4(\text{POLE})$	$B_1 > 0, B_2 < 0, B_3 > 0, B_4 > 1$	$B_1 > 0, B_2 < 0, B_3 > 0, B_4 > 1$
34-35) $B_0 + B_1(\text{DRAINAGE}) + B_2(\text{PDOG}) + B_3(\text{SAGE}^1) + B_4(\text{DISTMM})$	$B_1 > 0, B_2 < 0, B_3 > 0, B_4 > 1$	$B_1 > 0, B_2 < 0, B_3 > 0, B_4 > 1$

Notes: Description for variable acronyms in Table 2.

¹Habitat variable measured at the forage point scale using four, 100 m² quadrats.

²Habitat variable measured at the quality habitat scale using four, 1 km² quadrats.

I used an adjusted version of Akaike's Information Criterion for small sample bias (AICc; Burnham and Anderson 1998) to select "best approximating model" for each set of candidate models. Best model for each set of candidate models representing one of four mechanisms was chosen based on lowest AICc score. I determined how close next

best model was by calculating Δ AICc and AICc weights. I evaluated mechanisms hypothesized to induce golden eagle electrocutions by comparing AICc scores of most parsimonious model for each set of candidate models. After comparing best approximating model for each mechanism, I identified overall best approximating candidate model for all five sets of candidate models based on lowest AICc score. I tested validity of predictions for best approximating model from the combined list of candidate models using test data.

Exploratory Logistic Regression Models

I used the best approximating a priori model from combined list of candidate models as a template for building my post-hoc logistic regression model. Use of a priori models as templates for post-hoc model building limits exploratory analysis, thereby strengthening my model-based inferences (Franklin et al. 2000). Adjustments were made to best approximating a priori model based on results from my a priori model building strategy. I considered further changes to best a priori model based on examination of model data set from RSA. I considered interactions, non-linear relationships, correlations, differences between means, and univariate logistic regression (Hosmer and Lemeshow 1989). Next, I employed unlimited exploratory techniques, backwards, forwards, and stepwise logistic regression, in building additional post-hoc logistic regression models. Best approximating post-hoc logistic regression model was chosen based on lowest AICc score. I used test data set to test validity of predictions for best approximating post-hoc logistic regression model.

Exploratory CART Models

De'ath and Fabricius (2000) and Lawrence and Wright (2001) recommended CART for use in the field of ecology and remote sensing. Previous studies employed CART to model nest site selection of ring necked pheasants (*Phasianus colchicus*; Clark et al. 1999), revegetation (Lawrence and Ripple 2000), fire frequencies (McKenzie et al. 2000), and watercraft disturbance to bald eagle nests (Grubb et al. 2002). Classification tree-based models are formed through binary recursive partitioning to minimize misclassification error rates (Brieman et al. 1984, Efron and Tibshirani 1991). The data set is essentially split into smaller data sets using prediction rules (splits) produced for the response variable (in this study, offending poles and non-offending poles) according to values or categories of predictor variables (Clark et al. 1999). The process is repeated to increase homogeneity of observed response at end points (terminal nodes) of classification trees (Clark and Pregibon 1992, McKenzie et al. 2000, Lawrence and Ripple 2000). Preliminary output is an overfit classification tree-based model with an extreme number of prediction rules. To eliminate unnecessary prediction rules the overfit classification tree must be pruned back to produce a more general tree.

I tested different pruning methods in constructing a more general tree. First, I pruned the overfit classification tree through inspection of the misclassification versus number nodes plot. Next, I again evaluated the overfit classification tree and removed variables used in prediction rules where I found no differences through univariate analysis between offending poles and non-offending poles using an unadjusted significance of < 0.25 . The model data set from RSA was used for univariate analysis and

subsequent variable removal. Next, I used three methods to prune the overfit classification tree with removal of certain variables. I used cross-validation in S-Plus (Venables and Ripley 1997) to determine tree size. Next, I interpreted the misclassification against number of nodes plot in S-Plus to determine tree size (McKenzie et al. 2000). My final method inspected the misclassification against number of nodes plot followed by removal of spurious prediction rules based on existing biological information. To determine best pruning method, I compared validity of pruning techniques and their respective classification tree-based models using the test data set from RSA.

Hybrid Models (CART + Logistic Regression)

Hybrid models combine two analysis techniques, multiple logistic regression and CART, for building predictive models (Steinberg and Cardell 1999). I employed two methods for building hybrid models. For each method I incorporated the classification tree-based model most accurate in predicting the RSA test data set. First method treated final terminal nodes from best classification tree as individual data sets. Next, multiple logistic regression models were built for each individual data set (terminal node). I used lowest AICc score for selecting best approximating model for each individual data set (terminal node).

The second method transformed terminal nodes from best classification tree into dummy variables (Clark et al. 1999, Steinberg and Cardell 1999, Briand et al. 2001). I transformed terminal nodes into dummy variables using "IF" statements in Microsoft

Excel. Dummy variables were added to original list of measured variables. A multiple logistic regression model was constructed using exploratory backwards-logistic regression with the complete list of dummy variables and measured variables. I used test data set to compare validity of predictions for both hybrid model-building techniques.

Validation

I used the RSA test data set to test and compare validity of predictions for two hybrid models (two methods), three CART models (three different pruning techniques), one a priori logistic regression model (lowest AICc score), and one post-hoc logistic regression model (lowest AICc score).

After determining best model building technique for predicting RSA test data set, the best model building technique was applied to all data from RSA producing a final predictive model. I tested validity of predictions for the final predictive model using independent data from WSA. Final predictive model, therefore, was tested on its ability to predict new offending power poles in a different geographical location.

Univariate Analysis

All data from RSA were used for univariate analyses. For continuous normally distributed variables, I compared offending poles and non-offending poles using 2-sample t-tests. I used Mann-Whitney U tests for continuous variables that could not be normalized. I used univariate logistic regression of categorical variables to compare estimated relative probabilities of being an offending power pole for each category.

RESULTS

Between 1996 and 2001, 198 golden eagle carcasses were located and cause of death attributed to power pole electrocution (Appendix C). Of the 132 carcasses aged, 116 (87.9%) were subadult and 16 (12.1%) were adults. Of the 85 carcasses sexed, 41 (48.2%) were females and 44 (51.8%) were males. Of 4,090 power poles existing in the Roundup study area, 4.35% electrocuted at least one golden eagle and were treated as offending poles. Of power poles electrocuting at least one golden eagle ($n = 178$), 11.2% electrocuted >1 golden eagle. Data for one or more variables were absent for three offending poles. Resultant sample size for offending power poles was 195. Non-offending power poles comprised 95.65% of power poles in the RSA. Sample size for non-offending poles was 184. Model data set from RSA (60%) contained 117 offending poles and 111 non-offending poles. Test data set from RSA (40%) contained 79 offending poles and 73 non-offending poles. Independent data set from WSA ($n = 45$) contained 26 offending poles and 19 non-offending poles.

A Priori Mechanism Models

In total, 35 a priori logistic regression models were developed to evaluate suspected mechanisms contributing to golden eagle electrocutions (Table 4). Based on minimum AICc scores, comparisons among the four a priori mechanisms hypothesized to induce golden eagle electrocutions revealed the most significant mechanism was power

pole configuration, followed by habitat. Least significant mechanism was hunting technique (Table 4). Minimum AICc indicated most parsimonious a priori model was a multiple mechanism model, which was 7.5 times more likely than next best model based on AICc weights. However, the 95% confidence intervals for all estimated parameters overlapped zero (Table 5).

Table 4. Ranking 5 sets of logistic regression candidate models developed a priori to data analysis hypothesized to describe mechanisms inducing golden eagle electrocutions on power poles. Models express the relative probability of a power pole being offending¹ as a function of power pole characteristics and location in Roundup, Montana study area.

Hypothesized Models ²	K ³	AIC	AICc	delta AICc	weight
Social Interaction					
TOPO + NEST + TOP*NEST	4	310.093	310.272	0	0.634021
NEST	2	313.902	313.955	3.683	0.100543
TOPO	2	313.915	313.968	3.696	0.099891
logTOPO+longest + logTOPO*NEST	4	314.071	314.25	3.978	0.086754
LogTOPO	2	315.080	315.133	4.861	0.055789
logTOPO*NEST	2	316.852	316.905	6.633	0.023002
Habitat					
LogFOREST ⁵	2	300.508	300.561	0	0.714927
FOREST ⁵	2	302.390	302.443	1.882	0.278991
AG ⁵	2	312.601	312.654	12.093	0.001692
LogAG ⁵	2	312.601	312.654	12.093	0.001692
SAGE ⁴ + SAGE ⁵	3	313.727	313.834	13.273	0.000938
LogSAGE ⁵	2	314.630	314.683	14.122	0.000613
SAGE ⁵	2	314.825	314.878	14.317	0.000556
LogSAGE ⁴	2	316.003	316.056	15.495	0.000309
LogSAGE ⁴ + logSAGE ⁵	3	316.591	316.698	16.137	0.000224
SAGE ¹	2	319.326	319.379	18.818	5.86E-05
Hunting Techniques					
LogPDOG	2	318.330	318.383	0	0.19464
LogPDOG + logLOS	3	318.742	318.849	0.466	0.154185
LogDISTMM	2	319.519	319.572	1.189	0.10741
logPDOG + logDISTMM	3	319.609	319.716	1.333	0.099948
PDOG	2	319.863	319.916	1.533	0.090437
DISTMM	2	319.903	319.956	1.573	0.088646
LogDRAINAGE	2	319.916	319.969	1.586	0.088072
DRAINAGE	2	319.917	319.97	1.587	0.088028
PDOG + LOS	3	320.765	320.872	2.489	0.056073
PDOG + DISTMM	3	321.852	321.959	3.576	0.032562
Pole Characteristics					
POLE	5	281.640	281.91	0	0.514135
logXARMS + POLE	6	282.769	283.149	1.239	0.276714
XARMS + POLE	6	283.329	283.709	1.799	0.209136
LogXARMS	2	303.650	303.703	21.793	9.52E-06
XARMS	2	304.804	304.857	22.947	5.35E-06
Multiple Mechanism					
PDOG + TOPO + SAGE ⁵ + POLE	8	277.203	277.861	0	0.931439
logPDOG + logTOPO + logSAGE ⁵ + POLE	8	282.421	283.079	5.218	0.068561
logDRAINAGE + logPDOG + SAGE ⁵					
+ logDISTMM	5	317.564	317.834	39.973	1.95E-09
DRAINAGE + PDOG + SAGE ⁴ + DISTMM	5	325.203	325.473	47.612	4.27E-11

¹Poles that have electrocuted at least one golden eagle.

²See Table 2 for variable description.

³Number of estimated parameters.

⁴Cover type variable measured with 4 100 m² quadrats.

⁵Cover type variable measured with 4 1 km² quadrats.

Table 5. Variables associated with most parsimonious a priori logistic regression model for predicting relative probability of a pole being an offending¹ power pole in Roundup, Montana study area.

Variable ³	β	SE β	p-value	95%CI	
				lower	upper
Intercept ⁴	-4.1642	59.5608	0.9443	-120.90	112.57
PDOG	0.000193	0.000099	0.0514	-0.0000010	0.000387
TOPO	0.2084	0.1096	0.0572	-0.0064	0.4232
SAGE ⁵	0.0052	0.00549	0.3435	-0.00556	0.01596
JW	3.9396	59.5595	0.9473	-112.797	120.676
2PHASE	-10.552	238.2	0.9647	-477.424	456.32
3PHASE	2.2027	59.5591	0.9705	-114.533	118.943
NOXARM	0.3933	59.5655	0.9947	-116.355	117.142

¹Poles that have electrocuted at least one golden eagle.

³See Table 2 for variable acronym description.

⁴Define intercept as TRANS (transformer pole design).

⁵Variable measured at quality habitat scale, four 1 km² quadrats.

Exploratory Multiple Logistic Regression Models

The best a priori model suggested that parts of all four mechanisms (Table 4) should be incorporated into post-hoc model building. To increase precision of parameter estimates for best a priori model (Table 5), I reconfigured DESIGN variable into three categories (originally five; Table 6). I also replaced SAGE with FOREST measured at quality habitat scale based on best a priori habitat model (Table 4). NEST was added to TOPO for a better fit based on best a priori social interaction model (Table 4). Because NEST and TOPO were correlated ($r = 0.38$, p -value = 0.00), I replaced TOPO with PH. PH and TOPO both described visual advantages for power pole locations. However, I assumed PH measured visual advantage of pole locations at a finer scale. The addition of

the quadratic term for PH variable also improved fit. Adjustments to best a priori model resulted in a reduction of 26.824 AICc units, indicating a better fit. All coefficients in this model were more precise, no 95% confidence interval overlapped zero (Table 7). The post-hoc model where I adjusted most parsimonious a priori model was the better approximating model among other exploratory models built by backwards, forwards and stepwise exploratory logistic regression.

Table 6. Categories of reconfigured POLE¹ variable used in building post-hoc logistic regression models predicting relative probability of power poles being offending² in Roundup, Montana study area.

Category	Definition
LETHAL	All transmission poles (TRANS) and all distribution poles with jumper wires at or above the height of cross-arms or poles without cross-arms, pole tops (JW).
3PHASE	Distribution poles absent of jumper wires, minimum of one cross-arm having three phases present.
NONLETHAL	Distribution poles absent of cross-arms and jumper wires (NOXARM) and distribution poles absent of jumper wires, minimum of one cross-arm having two phases present.

¹see Table 2 for variable description.

²Poles that have electrocuted at least one golden eagle.

Relationship between PDOG and response variable was positive, opposite to what I hypothesized a priori (Table 2). Therefore, a second post-hoc model was constructed removing the PDOG variable. Test data set was used to compare predictions of most parsimonious post-hoc logistic regression models and a priori logistic regression model to determine how well they distinguished between offending and non-offending poles. Test data set confirmed the model with lowest AICc score (including PDOG variable) was the best predictor of 3 logistic regression models (Table 8).

Table 7. Variables associated with most parsimonious post-hoc logistic regression model for predicting offending¹ power poles and non-offending² power poles in Roundup, Montana study area.

Variable ³	B	SE β	P-value	95%CI	
				lower	upper
Intercept ⁴	1.1449	0.3879	0.003	0.3846	1.9050
PDOG	0.0003	0.0001	0.003	0.0001	0.0005
PH	0.0305	0.0136	0.025	0.0038	0.0572
PH ²	0.0011	0.0005	0.035	0.0001	0.0022
NEST	-0.0002	7.011E-05	0.032	-0.0003	-1.3E-05
TREE1000	-0.1665	0.0602	0.006	-0.2846	-0.0485
MS2/NOXARM	-4.4330	1.1750	0	-6.7360	-2.1300
MS	-1.9804	0.3647	0	-2.6952	-1.2656

¹Poles that have electrocuted at least one golden eagle.

²Poles that were not found to have not electrocuted at least one golden eagle.

³See Table 2 for description of variables.

⁴Intercept estimate represents transmission power poles and power poles with jumper wires.

The best multiple logistic regression model indicated golden eagle electrocutions were associated with pole design. Furthermore, the best multiple logistic regression model indicated golden eagle electrocutions were positively associated with proximity to prairie dog towns, negatively associated with proximity to active golden eagle nest, and negatively associated with percent forest cover at the quality habitat scale. The quadratic structure of PH variable indicated higher probability of being an offending power pole at low and high extremes of the PH variable.

Table 8. Ranking most parsimonious post-hoc logistic regression models (1,2) and most parsimonious a priori logistic regression model (3) based on lowest AICc and accuracy in predicting the test data set (see text) for power poles in Roundup, Montana study area.

Model ^a	AICc	Ratio of Poles Classified Correctly	Percent Correct
1 POLE + FOREST ^b + PH + (PH) ² + NEST + PDOG	251.038	101/151	66.9%
2 POLE + FOREST ^b + PH + (PH) ² + NEST	258.779	97/151	64.2%
3 POLE+TOPO+PDOG+SAGE ^b	277.862	89/151	58.9%

Note: For all logistic regression models the response variable was the relative probability (π) of a power pole being an offending pole (coded 1), non-offending poles were coded 0. $\pi < 0.5$ were classified as non-offending poles. $\pi \geq 0.5$ were classified as offending poles.

^aSee Table 2 for explanation of variable acronyms.

^bCover type variables measured at the quality habitat scale, four 1 km² quadrats.

Exploratory CART Models

In the first overfit classification tree (Appendix D), pruning based on interpreting misclassification versus number nodes plot recommended a tree with 11 terminal nodes. Since first overfit classification tree (Appendix D) used several predictor variables where no differences were found between offending and non-offending ($\rho > 0.54$), I eliminated DRAINAGE, ROAD, WATER, DISTMM, and PDOG variables. I used remaining predictor variables to build a second overfit classification tree (Appendix D). Cross-validation recommended pruning this classification tree to two terminal nodes (Appendix D). I interpreted misclassification versus number of nodes plot (Appendix D) as recommending classification trees with 6, 12, and 16 terminal nodes (Appendix D). Another classification tree was constructed based on my interpretation of the

misclassification versus number of nodes plot (12 terminal node tree) and subjective adjustments to the 12 terminal node tree based on literature regarding golden eagle ecology. Adjustments to the classification tree included pruning the 12 terminal node classification tree to 10 terminal nodes and changing results of the prediction rule for PERCH variable (Fig. 6). Because PERCH prediction rule classified power poles as non-offending poles for both directions of the split, I suspected class membership for PERCH prediction rule was incorrect. Therefore, I changed class membership of PERCH prediction rule by classifying power poles > 1550 m from a natural perch as offending. Power poles ≤ 1550 m from a natural perch remained classified as non-offending poles. Testing validity of all (6) classification trees using test data set indicated 10 terminal node classification tree (Fig. 6) was best predictor of test data. The 10 terminal node classification tree utilized 4 of 5 variables retained in the best post-hoc logistic regression model.

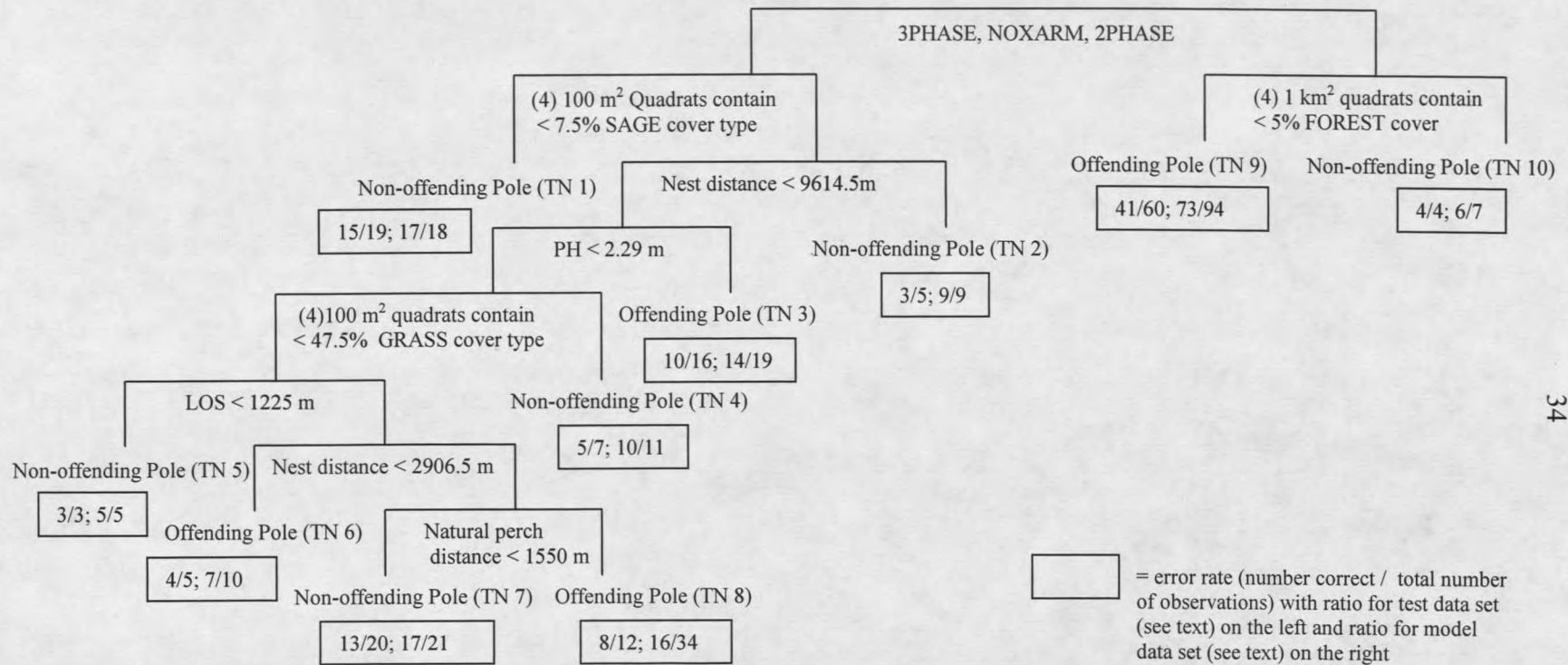


Fig. 6. Classification tree classifying offending and non-offending power poles constructed with model data set (see text) from Roundup Study Area. The classification tree was pruned based on reduction in misclassification versus number of node plot in S-Plus and complimented by subjective pruning and prediction rule adjustment based on existing biological information. Prediction rules for each split indicate branching to the left (TN = terminal node).

Exploratory Hybrid Models

The best hybrid model for predicting the test data was one where I treated final terminal nodes from the best classification tree (Fig. 6) as individual data sets and applied logistic regression. Logistic regression models lowered AICc scores for two of 10 terminal nodes.

Terminal Node 3 (Fig. 6) $\{\text{logit}(p) = 5.9363 + \text{DRAIN} * -0.0103\}$

Terminal Node 7 (Fig. 6) $\{\text{logit}(p) = -4.3256 + \text{LOS} * 0.00075\}$

Overall accuracy for predicting test data was 6% greater than the second hybrid model where terminal nodes from the best classification tree (Fig. 6) were transformed into dummy variables and added into the original list of predictor variables for logistic regression (Table 9). Constructing both hybrid models using the two terminal node classification tree (Appendix D) also confirmed the best hybrid model was one where I treated terminal nodes as individual data sets and applied logistic regression (Table 9).

Final Comparisons of Model Building Techniques

The best model building technique for predicting power poles using test data was the hybrid method of applying logistic regression to terminal nodes of the best classification tree (Table 9). In total 83.3% of offending poles and 64.4% of non-offending power poles were correctly classified. The next best model (10 terminal node classification tree-based model; Table 9, Fig. 6) classified 80% of offending and 59% of non-offending poles correctly.

Table 9. Ranking multivariate prediction models based on validity of predictions for classifying offending¹ and non-offending² poles using the test data set (see text) from Roundup, Montana study area.

Model	Model Type	Ratio of Poles	
		Correctly Classified	Percent Correct
Log Regression Applied to Classification Tree of 10 Terminal Nodes	Hybrid	112/151	74.2%
Classification Tree with 10 Terminal Nodes (5 variables removed)	CART	106/151	70.2%
Classification Tree with 12 Terminal Nodes (5 variables removed)	CART	105/151	69.5%
Log Regression Applied to Classification Tree of 2 Terminal Nodes	Hybrid	104/151	68.9%
Dummy Variables from Classification Tree of 10 Terminal Nodes for Log Regression	Hybrid	102/151	67.5%
POLE+FOREST ⁴ +PH+(PH) ² +NEST+PDOG	Exploratory Logistic Regression	101/151	66.9%
Dummy Variables from Classification Tree of 2 Terminal Nodes for Log Regression	Hybrid	100/151	66.2%
Classification Tree with 16 Terminal Nodes (5 variables removed)	CART	100/151	66.2%
Decision Tree with 6 Terminal Nodes (5 variables removed)	CART	99/151	65.6%
POLE+FOREST ⁴ +PH+(PH) ² +NEST+PDOG	Exploratory Logistic Regression	97/151	64.2%
Classification Tree with 2 Terminal Nodes (5 variables removed)	CART	91/151	60.3%
POLE+TOPO+PDOG+SAGE ⁴	A Priori Logistic Regression	89/151	58.9%

¹Poles that have electrocuted at least one golden eagle.

²Poles that were not found to have not electrocuted at least one golden eagle.

³See Table 2 for delineation and description of variables.

⁴Cover type measured at the quality habitat scale with four, 1 km² quadrats.

Univariate Analysis

Univariate logistic regression for each pole design category (Table 2) indicated JW ($\pi = 0.7439$, 95% CI = ± 0.0440) and TRANS ($\pi = 0.6506$, 95% CI = ± 0.0481) poles were more likely to be an offending pole than other pole designs. NOXARMS ($\pi = 0.0714$, 95% CI = ± 0.0260) and 2 PHASE ($\pi = 0.0769$, 95% CI = ± 0.0269) poles were less likely to be offending poles than 3PHASE poles ($\pi = 0.4171$, 95% CI = ± 0.0497). JW and TRANS pole designs accounted for 62.5% ($n = 16$) of adult golden eagle electrocutions.

Habitat within four 1-km² quadrats for offending poles had more sagebrush ($\bar{x} = 71.75$, SE = 1.94) than non-offending poles ($\bar{x} = 58.97$, SE = 2.47) and less forest ($\bar{x} = 0.23$, SE = 0.11) than non-offending poles ($\bar{x} = 3.21$, SE = 0.69). Habitat surrounding locations of offending poles within four 100-m² quadrats had more sagebrush ($\bar{x} = 69.28$, SE = 2.40) than non-offending poles ($\bar{x} = 59.57$, SE = 2.96). No offending pole contained irrigated agriculture within a 1-km² quadrat. Offending poles were more likely to be in locations offering visual advantages over non-offending poles ($df = 377$, t -test, $P < 0.001$ for PH and LOS variables). Univariate logistic regression indicated poles placed on hill/ridge tops ($\pi = 0.6607$, 95% CI = ± 0.0615) were more likely to be offending than flat topography ($\pi = 0.4325$, 95% CI = ± 0.0643). Offending power poles were closer to golden eagle nests ($df = 377$, t stat = 3.56, $P < 0.001$) and farther from natural perch strata ($df = 377$, t stat = -2.416, $P = 0.016$). Offending power poles were not placed closer to

landscape features associated with prey ($df = 377$, Wilcoxon rank-sum test, $P > 0.403$ for WATER, PDOG, DRAIN, and DISTMM covariates).

CART With Complete Data Set

A classification tree-based model was constructed employing the complete data set ($n = 195$ offending poles, $n = 184$ non-offending poles) from RSA. The classification tree was pruned by combining interpretation of misclassification versus number of nodes plot with what I considered valid splits based on existing biological information. The pruning technique was consistent with best pruning strategy found in analyzing the model data set from Roundup study area. However, changes were not made to class memberships of prediction rules. The classification tree consisted of 12 terminal nodes (Fig. 7). The tree classified power poles from the model data set with overall accuracy 77.04 %. In total, 85.1% of offending power poles and 68.5 % of non-offending power poles were classified correctly. Seventy-four percent of power poles classified as offending by the classification tree were observed to be offending poles, likewise 81.3% for non-offending poles. The addition of logistic regression improved fit in only 1 of 11 terminal nodes and improved overall accuracy by 0.26 %. Because the hybrid technique of applying logistic regression to terminal nodes provided little improvement in my predictions and since the classification tree has the advantage of being able to convert to a dichotomous key for easy field application, I considered the classification tree with 12 terminal nodes as my final predictive model (Fig. 7).

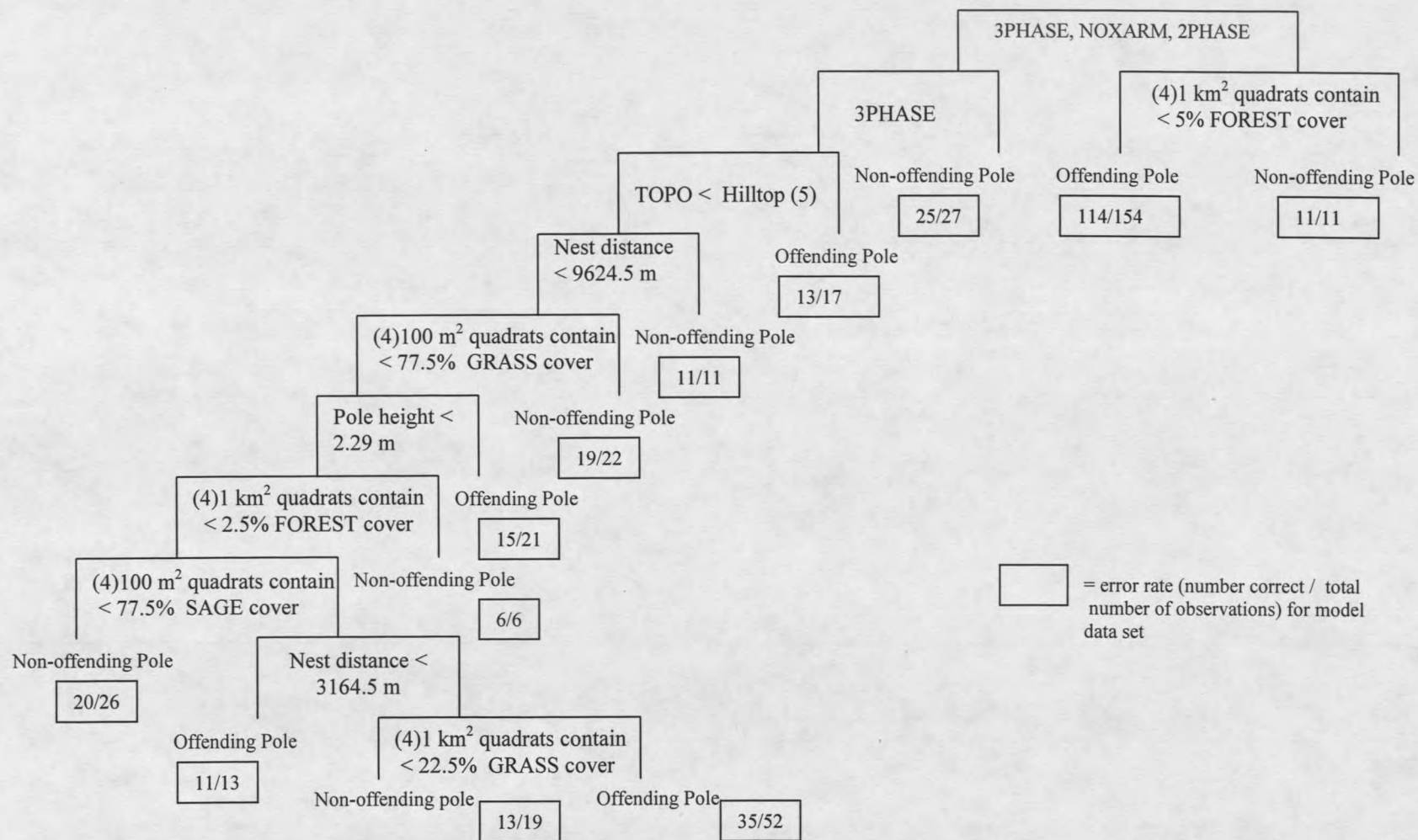


Fig. 7. Classification tree of offending and non-offending power poles using complete data set (see text) from the Roundup study area. The classification tree was pruned based on reduction in misclassification versus number of node plot in S-Plus and complimented by subjective pruning based on existing biological information. Prediction Rules for each split indicate branching left.

Validation of Final Predictive Model

The final predictive model (Fig. 7) predicted independent data (power poles from WSA) with an overall accuracy of 77.8%. Locations of active golden eagle nests in the Worland study area were not available. Therefore, NEST variable as a prediction rule was omitted from the final predictive model during validation with independent data set. In total, 88.5% of the offending poles and 63.0% of non-offending poles were correctly classified.

DISCUSSION

Comparisons Among Model Building Techniques

Based on comparisons among model building techniques (Table 9) the hybrid model (multiple logistic regression run on terminal nodes) was the better model building technique for predicting class of power poles. CART alone, however, performed nearly as well (Table 9). My results suggest multiple logistic regression had difficulty modeling complex interactions between predictor variables relative to response, a result consistent with previous studies (Lawrence and Ripple 2000, McKenzie et al. 2000). Exploratory logistic regression analysis, however, did not include interactions between DESIGN (categorical variable) and continuous variables. Lack of exploration for interactions between DESIGN and continuous variables might have reduced accuracy of multiple logistic regression models. Conversely, further exploration with additional predictor variables would have led to more serious data dredging.

As a practical matter, I recommend classification tree-based models (Fig. 7), over other predictive models constructed for this study for two reasons. First, the classification tree-based predictions performed nearly as well in both RSA and a different geographical location (WSA). Second, since no accuracy in predictions was lost, the model easier to employ is more likely to be used by the utility industry.

Suggestions for Data Analysis

My results indicate CART can be a useful tool for isolating important interactions prior to analyzing data with multiple logistic regression. Results from hybrid models confirmed the value of CART in reducing number of parameters considered during exploratory analysis. For example, the shallow classification tree of 2 terminal nodes (Appendix D; dividing data set into 2 subsets) combined with multiple logistic regression outperformed other exploratory analyses for building logistic regression models. To improve accuracy in multiple logistic regression models, further exploration with additional interaction terms or transformed predictor variables would be required. CART can be valuable in reducing number of parameters used to explore for interactions, especially in studies where existing biological information is absent of data regarding direct interactions between predictor variables and a response.

Furthermore, CART can direct exploration for more complex interactions than traditional bilinear interactions with product terms. Product terms test one form of interaction where slope between predictor variable and response changes linearly with unit changes of second predictor variable (Jaccard 1990). Partitioning data into subsets based on decision rules for predictor variables using tree-based models allows for interactions where relationships between predictor variables and response change shape, not just slope. For example, data that is split into two subsets based on an initial decision rule from a tree-based model would allow different shapes and directions for relationships between a predictor variable and response for each subset of data.

I recommend use of CART in pilot studies to assist determining scope of major studies. Studies too broad in scope where definitive subsets of observations are not identified might run the risk of excessive exploratory analysis, ignoring complex interactions and weakening attempts at constructing candidate models a priori to data analysis. Utilizing CART in pilot studies could identify homogeneous subsets of observations and, therefore, assist in development of study designs and validate inclusion of interaction terms for building candidate models.

Contrary to what Steinberg and Cardell (1999) postulated, the hybrid model where I treated final terminal nodes from classification trees as individual data sets and apply logistic regression was more accurate in power pole classification than the hybrid model with dummy variables (transforming terminal nodes into dummy variables for multiple logistic regression). The hybrid model with dummy variables (transformed terminal nodes) is restricted to changing the intercept for observations in different terminal nodes, but not slope unless interactions are explored between dummy variables and other continuous variables. The hybrid method of treating terminal nodes as individual data sets is simpler, offering greater opportunities for different intercepts and slopes without exploring for interactions. I would expect better results with the dummy variable method if interactions were explored between measured variables and the transformed dummy variables.

Validity of Predictive Model

My final predictive model demonstrated high predictive powers in identifying offending and non-offending power poles. To assess how well offending power poles were classified I calculated producer's accuracy and user's accuracy. Producer's accuracy for offending poles is defined as number of correctly classified offending poles divided by total number of offending poles (Lillesand and Kiefer 2000). Producer's accuracy for offending poles in RSA was 85.1%; producer's accuracy for offending poles in WSA was 88.5%. High producer's accuracy indicated my final predictive model would be accurate in identifying offending power poles in need of retrofitting, key to preventing golden eagle electrocutions. User's accuracy for offending poles is defined as number of correctly classified offending poles divided by the total number of poles classified as offending (Lillesand and Kiefer 2000). User's accuracy for offending poles in RSA was 73.5%; user's accuracy for offending poles in WSA was 76.7%. High user's accuracy indicated my final predictive model would limit unnecessary retrofitting of non-offending power poles, key to minimizing cost in preventing golden eagle electrocutions. The final predictive model appeared to predict power poles beyond the sample frame of model data. The inability to include NEST prediction rules, however, weakened my assessment of how well the model predicted the independent data set.

Interpretation of Predictor Variables and Mechanisms

Comparisons among mechanisms using my a priori strategy with multiple logistic regression found pole configuration most likely to induce golden eagle electrocutions. The model using pole design categorical variable was the best approximating model among the subset of candidate models describing power pole configuration. My findings were consistent with previous research where strong associations were found between raptor electrocution and power pole configuration (Benson 1981, Harness 1997).

Importance of pole design variable was further illustrated as initial split in final predictive model (Fig. 7) used pole design variable. Initial partition of the final predictive model identified power poles with jumper wires or transmission power poles (Fig. 2) as more likely to electrocute golden eagles than power poles < 69 KV or absent of jumper wires. I propose power poles with jumper wires or ≥ 69 KV should be modeled separately from other power pole designs. However, not all pole designs with ≥ 69 KV have the same distances between conductors (Harness 2001). Only power poles with narrow enough separation for a golden eagle to make contact between two conductors should be considered in this case.

When I examined power poles with jumper wires or ≥ 69 KV, percent forest cover at quality habitat scale was the lone variable that distinguished between offending and non-offending power poles. Additional splits in CART decreased accuracy in predicting poles with jumper wires or ≥ 69 KV. Furthermore, when I applied multiple logistic regression to data subsets from terminal nodes 1 and 2 in the final model (Fig. 7),

it failed to improve statistical fit. I hypothesize a negative relationship exists between percent forest cover adjacent to power poles with jumper wires or with ≥ 69 KV and frequency of power poles use by golden eagles. I hypothesize a positive relationship exists between use of power poles with jumper wires or ≥ 69 KV and golden eagle electrocutions. I suggest no inferences be made beyond frequency of power pole use by golden eagles for classifying power poles with jumper wires or ≥ 69 KV, and no further generalizations for power poles with jumper wires or ≥ 69 KV should be made between the remaining variables and golden eagle electrocutions. Forest and cultivated fields were highly correlated in my study; therefore, additional research is required to test these hypotheses.

I suggest the importance of percent forest cover at quality habitat scale is explained by golden eagles having the option of choosing natural perches over power poles. Baglien (1975) observed that man-made perches were not attractive to golden eagles in habitat where natural perches such as trees and rock outcrops were readily available. Furthermore, records on raptor electrocutions rarely find forest-dwelling raptors electrocuted (Switzer 1977, Benson 1981, Wilson and Colson 1987, APLIC 1996). Thus, I hypothesize a negative relationship exists between percentage of forest cover surrounding power poles and use of power poles by golden eagles.

My finding of sub-adult golden eagles being 8.25x more likely than adult golden eagles to be electrocuted was consistent with previous work (Boeker and Nickerson 1975, Benson 1981, Harness 1997, Harness and Wilson 2001). I suspect the greater number of sub-adult electrocutions is related to power pole configuration. Sub-adults lack agility in

flight making it clumsy to land and takeoff safely (APLIC 1996). Sub-adults would, therefore, have a more difficult time maneuvering around additional live wires (Nelson and Nelson 1976, 1977).

Following initial split in final predictive model, power poles were further separated by the pole design categorical variable. Power poles having cross arms and three conductors (3PHAES poles, Fig. 3) were separated from power poles with only two conductors (Fig. 3) or power poles without cross arms (Fig. 3). The two latter power pole designs were classified as non-offending unless jumper wires were present. Power poles having jumper wires with no cross arms or only two conductors were delineated into offending and non-offending power poles based on the presence of forest cover. The final predictive model suggests classifying 3PHASE poles is more complex and requires further description of pole location.

Predictor variables measuring proximity to potential prey base did not assist in classifying 3PHASE poles. Comparisons among candidate models revealed prey based models as the poorest predictor of golden eagle power pole electrocutions (Table 2). Furthermore, no relationships were found between distance to potential prey base and golden eagle power pole electrocutions through univariate analysis. The data did not indicate as suggested by Benson (1981) or APLIC (1996) that hunting from power poles promotes golden eagle power pole electrocutions. Because golden eagles concentrate near high prey density (Brown and Watson 1964), I believe power poles closer in proximity to a prey base would be used more frequently. However, I suspect golden eagles often still-hunt from power poles in close proximity to a prey base (Benson 1981),

and non-aggressive social interactions would occur less frequently between golden eagles when still-hunting. My results suggest, therefore, that increased frequency in power pole use for 3 PHASE poles combined with decreased likelihood of non-aggressive social interactions between golden eagles would not promote golden eagle power pole electrocutions.

Predictor variables measuring habitat did assist in classifying 3PHASE poles. A positive relationship was found (through univariate analysis) between amount of sagebrush cover at the forage point and quality habitat scales and golden eagle power pole electrocutions. Previous studies have found golden eagles select sagebrush habitat over grasslands and cultivated fields (Craig et al. 1986, Marzluff et al. 1997). I suspect golden eagles are attracted to power poles located in sagebrush habitat and still-hunt from poles adjacent to sagebrush cover, but do so less often than power poles in close proximity to a potential prey base. I suggest golden eagles utilizing poles at greater frequencies for purposes other than still-hunting would socially interact (non-aggressively) more often. Therefore, I suspect increased frequency in power pole use for 3PHASE poles combined with increased likelihood of non-aggressive social interactions between golden eagles would promote golden eagle power pole electrocutions.

The final predictive model further demonstrated the importance of social interactions in promoting and predicting golden eagle electrocutions by utilizing variables measuring proximity to active golden eagle nests (NEST) and categorizing topographical relief of pole placements (TOPO) early in the classification tree (Fig. 7). I suspect electrocutions that occurred at close proximity to active golden eagle nests were caused

by social interactions among fledglings or adults and their non-progeny, or by poor flight skills of fledglings. I suspect electrocutions induced by social interactions at slightly greater distances from active golden eagle nests were a result of agonistic behavior between territorial golden eagles.

Limitations in Final Predictive Model

I believe two factors prevented higher accuracy in predictions from the final predictive model. First, my analysis assumed that all golden eagle carcasses electrocuted by power poles in the study area were detected. There is a possibility that a number of the power poles classified as non-offending poles had electrocuted at least one golden eagle with the carcass being undetected or removed. I tried to control for this potential bias by inspecting each power pole in the RSA. Second, incorrect classification for cause of death for golden eagle carcasses could be a source of bias in classifying offending power poles. I felt the most likely cause excluding power pole electrocution was gun shot wounds (Watson 1997). I attempted to control for this bias by examining each carcass for signs of gun shot wounds. Furthermore, I assumed if eagles were being shot in RSA I would have found differences between offending and non-offending poles for the variable measuring nearest distance to road (paved or unpaved). I suspect if eagles were shot in RSA, assailants would have retrieved them.

Conclusions based on my analysis, therefore, are stated cautiously with acknowledgement of potential bias in the classification of offending and non-offending

power poles. Potential bias in classification of power poles, however, might explain errors in classification by the final predictive model. Power poles having electrocuted a golden eagle that was removed, might be classified as offending by the final predictive model but observed to be non-offending. Final predictive model, therefore, might be more accurate in identifying offending and non-offending power poles than my results show.

Practical Applications for Utility Companies and Management

I developed a predictive model that may assist utility companies in identifying which power poles to retrofit. I transformed my final predictive model into a user-friendly dichotomous key (Appendix E) for field application. Power poles classified as offending by dichotomous key (Appendix E) indicate the necessity to retrofit.

Management and utility companies should consider retrofitting all power poles with jumper wires that are not adjacent to forest cover at the quality habitat scale.

Transmission poles, similar in configuration to those found in the RSA (Fig. 2), not adjacent to forest cover at the quality habitat scale should be considered for retrofitting.

Other pole designs should be classified into: (1) distribution poles without crossarms; (2) distribution poles with cross-arms and 2 phases; and (3) distribution poles with cross-arms and 3 phases. Distribution poles without cross-arms might not require retrofitting unless jumper wires are present. Distribution poles with cross-arms but having only 2 phases also might not require retrofitting unless jumper wires are present, but further

research is required for 2-phase configurations since recommendations are based on a small sample size. Distribution poles with cross-arms having 3 phases and lacking jumper wires are not as straightforward. The majority of decision rules in the dichotomous key (Appendix E) refer to classifying distribution poles with cross-arms having 3 phases and lacking jumper wires. Distribution poles with cross-arms having 3 phases and lacking jumper wires require careful implementation of the dichotomous key (Appendix E).

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APPENDICES

APPENDIX A

RAPTOR MORTALITY REPORTS

circle one LETHAL or CONTROL pole
control pole # _____

Date _____
Pole # _____

of carcasses found _____
Date Recovered _____

circle one M / F _____
Age _____
Cause of Death _____
Location of Lesions _____

Pole UTM _____

Line size _____
Direction of line (bottom crossbar) _____

(Top crossbar) _____

Pole Description (eg. single crossarm) _____
(eg. midspan, lateral tap) _____

Drawing: _____ Other _____

Terrain circle one	flat	no slope (0-5deg.)	smooth landscape
	hilly	slight slope (6-20deg)	broken landscape
		moderate slope (21-40deg.)	a. dry drainages
		steep slope (>40 deg.)	b. wet drainages

Description _____

Topographic placement circle one

A	B	C	D	E	F
saddle	ridge top	slope($\frac{1}{3}$)	valley bot.	hill top	flat

Describe _____

of Cover Types-100 meter radius plot

1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____

- _____ meter radius plot

1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____

% of Cover Types

-100 meter radius plot

- _____ meter radius plot

Was Sage brush a Cover Type? Y / N if yes continue, if no skip to next section.

of Sagebrush Patches in 100 meter radius plot _____

Visual estimate of % canopy cover in each patch 1 _____ 4 _____

2 _____ 5 _____

3 _____ 6 _____

Ave _____ %

Visual estimate # of Sagebrush Patches in _____ meter radius plot _____

Visual estimate of % canopy cover in each patch

Ave _____ %

Nearest Distance(_____ paces = _____ meters) to

Man-made structure _____ V/P, describe struture _____

describe likely use(low medium high) _____

Washout/drainage _____ V/P, describe moisture (dry wet water) _____

estimate width _____

Water _____ V/P, describe type (pond creek river) _____

water fowl present _____

Road _____ V/P, Describe type (trail gravel paved) _____

Eagle Nest _____ V/P Type (cliff tree) _____

Natural Perch

Tree _____ V/P Hght of tree _____

Topographical placement of tree _____

Rock _____ V/P Type (outcrop boulder) _____

Hght of rock _____

Prairie Dog Town _____ V/P

Vertical distance or height difference between adjacent poles

visual estimate pole a _____

pole b _____

Line of sight in four cardinal directions visual estimate

N _____

E _____

S _____

W _____

describe any visual obstruction and direction within 300m of

pole _____

Wind direction during data collection _____ speed _____

Direction of wide part of crossarm _____

Notes:

RAPTOR MORTALITY REPORT

1. Date of Discovery: _____
 2. Number of birds, species, and sex (if known): _____
may consult 1967 raptor I.d. guide
 Cause of Death Check One: Electrocutation: _____
 Collision: _____
 Gunshot: _____
 Unknown: _____
 3. Location: County _____
 Nearest P.O. _____
 Pole No. _____
 Township _____ Range _____ Section _____
 4. Vegetation type: forest _____ grassland _____ Cropland _____
 5. Terrain: hilly _____ flat _____
 (check one)
 6. Pole type: Line size (kV) _____
 check one: no crossarm _____
 no crossarm with transformer _____
 single crossarm _____
 double crossarm _____
 Other (describe) _____

 7. Disposition of carcass: Left at site _____
 check one: Notified MDFWP _____ Notified USWFS _____
 8. Reported by: Name _____
 Address _____
 Phone _____
 Agency _____
- Send report to: Sam Milodragovich
 The Montana Power Company
 Environmental Department
 40 East Broadway
 Butte, Montana 59701
 723-5454, extension 73102

APPENDIX B

SHORT COMMUNICATION: EYE WITNESS ACCOUNT
OF A GOLDEN EAGLE ELECTROCUTION

INTRODUCTION

Golden eagles (*Aquila chrysaetos*) are at risk of power pole electrocution (Smith and Murphy 1972, Olendorff 1972, Boeker and Nelson 1975, Benson 1981, O'Neil 1988, Harness and Wilson 2001). To remedy golden eagle electrocutions, previous studies have focused on factors that would assist in identifying offending power poles (power poles observed to have electrocuted ≥ 1 golden eagle) through power pole location and power pole configuration. Accounts of actual golden eagle electrocutions if observed, have not been published. Nelson and Nelson (1976, 1977) filmed a trained golden eagle perching on and flying from power poles to gain further insight into the causes of golden eagle electrocution. Herein I describe events resulting in a golden eagle electrocution on a power pole in the wild.

ENVIRONMENT

I witnessed a golden eagle electrocution 16 km northeast of Melstone, Montana in open habitat dominated by native grassland and big sagebrush (*Artemisia tridentata*). Topographical placement of the offending power pole was hilltop, 5 m above adjacent power poles, with unobstructed views in four cardinal directions. There were two active golden eagle nests within five km; closest was 1.6 km to the WNW. Temperature was 32° C, wind out of the south at 16 kph, and 0% cloud cover.

EVENT

On 7 July 2000 at 1238h a subadult male golden eagle was perched on the pole-top of a 3-phase midspan 1.2kv distribution pole (Fig. 3). Pole design included parallel double cross arms at equal height. Transformers and jumper wires were not present. Pole top was approximately .25 m above the parallel cross arms. Shortly thereafter, an adult golden eagle was observed soaring approximately 20 m above the perched subadult golden eagle. The adult circled above the subadult in 100-m radius circles for two repetitions and then left my field of view. The perched subadult golden eagle showed no apparent signs of agitation or stress and preened under its right wing.

At 1248h I moved forward to avoid a female pronghorn antelope (*Antilocapra americana*) agitated by my presence. I drove within 350 m of the perched subadult golden eagle at which point I again detected the adult golden eagle. The adult was observed gliding 7 m above the perched subadult. Afterward the adult returned to soaring circuitously above the perched eagle for a brief period before initiating undulating flight east of power pole. The perched eagle was facing SW, and the adult passed the power pole to the south and ended 300 m W of the power pole. The adult returned west of the pole before repeating its undulating flight display, flying east to west. With each repetition of undulating flight, the low point of the undulation would draw closer to the ground. At 1253h, the adult had performed three repetitions of undulating flight moving east to west. Following the third repetition the perched subadult golden eagle began to vocalize with a "bark" like call. The adult golden eagle continued

to perform undulating flight with the low point being 2 m above the pole top and passing 10 m to the south of the perched eagle.

Upon final undulating flight display the adult gained altitude and went into a swift dive towards the perched subadult eagle. The bottom of the dive was within 3 m of the perched eagle at a 20 degree angle from horizontal. The dive ended east of the power pole. The adult proceeded to glide past the pole to the west gained altitude and went into a second dive. This dive was different as the eagle flew with less velocity. When the adult reached the perched subadult eagle the adult pulled up slightly above the perched eagle as if to land directly on the perched subadult golden eagle. As the adult pulled up with wings perpendicular to the ground, it instantaneously extended its legs and presented its talons. Up to this point no movements were made by the perched subadult golden eagle, only vocalizations.

To counter the attack, the perched subadult eagle hopped off the pole top and presented its own talons upwards. As the subadult eagle presented its talons its wings were extended, its body positioned in a backward "C", with its back earthward. The talons of both birds made contact briefly when the subadult eagle, in a supine position, wings outstretch, began to lose altitude. During the confrontation the adult golden eagle maintained its altitude as the subadult golden eagle slowly lost altitude. The subadult lost altitude very slowly with wings extended. When the subadult's wings made contact with two power lines an audible "snap" of electricity was emitted without sparks and subadult golden eagle fell immediately to the ground. The electrocution was unspectacular both

visually and audibly. I inspected the eagle as the adult golden eagle soared 10 m above the carcass. The subadult golden eagle was lying supine with wings flexed in towards its body, right eye closed, and 2.25 m from base of power pole. Following examination of the carcass, I observed the adult circling above two more times before departing to the southeast. The adult golden eagle did not return for the remaining two hours I was present.

The dead subadult golden eagle was immediately refrigerated after data compilation and was refrigerated until necropsy. Necropsy was unable to assign cause of death. The eagle was a male, in good health, and showed no signs of electrocution.

DISCUSSION

A safety perch above the power pole probably would not have prevented electrocution. Instead, a Kaddis guard on the center phase extending approximately 3.5 m in each direction from the power pole may have prevented this electrocution.

I believe both eagles were at risk of being electrocuted if contact between talons was more substantial. In fact, pairs of golden eagles with one or both feet clutching the others have been found in Roundup study area. Furthermore, the adult golden eagle appeared in danger of colliding with power lines while performing its undulating flight pattern. I found 11% ($n = 20$) of offending power poles in RSA, had two golden eagle carcasses. I have also collected data on great horned owl electrocutions. I have observed that 64% ($n = 11$) of great horned owl (*Bubo virginianus*) carcasses were found with a

second raptor carcass, either a great horned owl, golden eagle, or bald eagle (*Haliaeetus leucocephalus*). Possibly, interspecies interactions resulting in electrocutions also occur.

APPENDIX C

RAPTOR CARCASS DATA

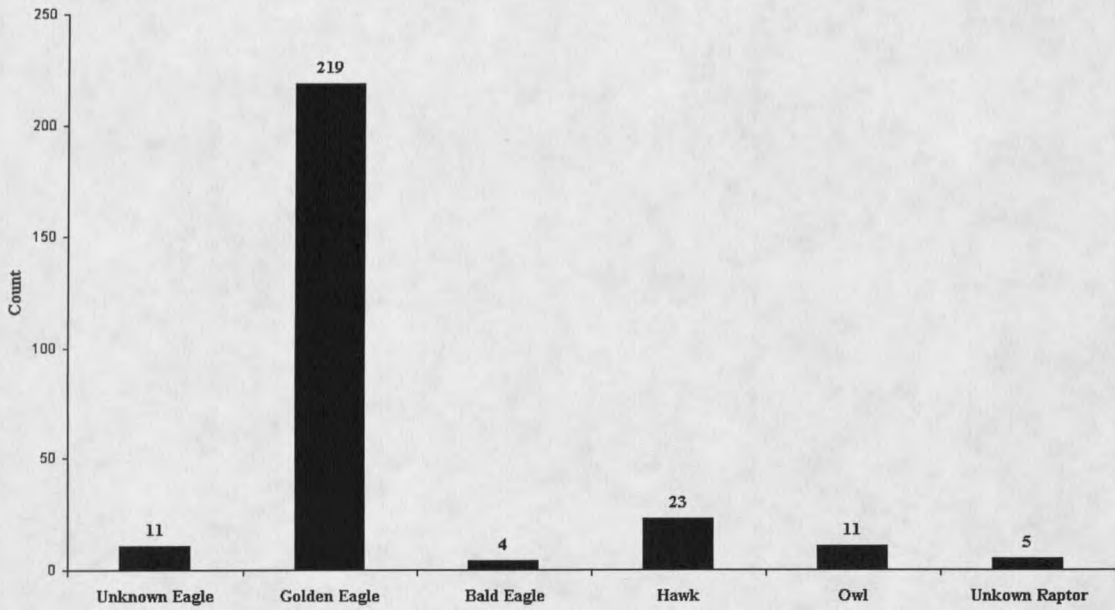


Fig. 8. All raptor power line mortalities by species discovered in Roundup, Montana study area.

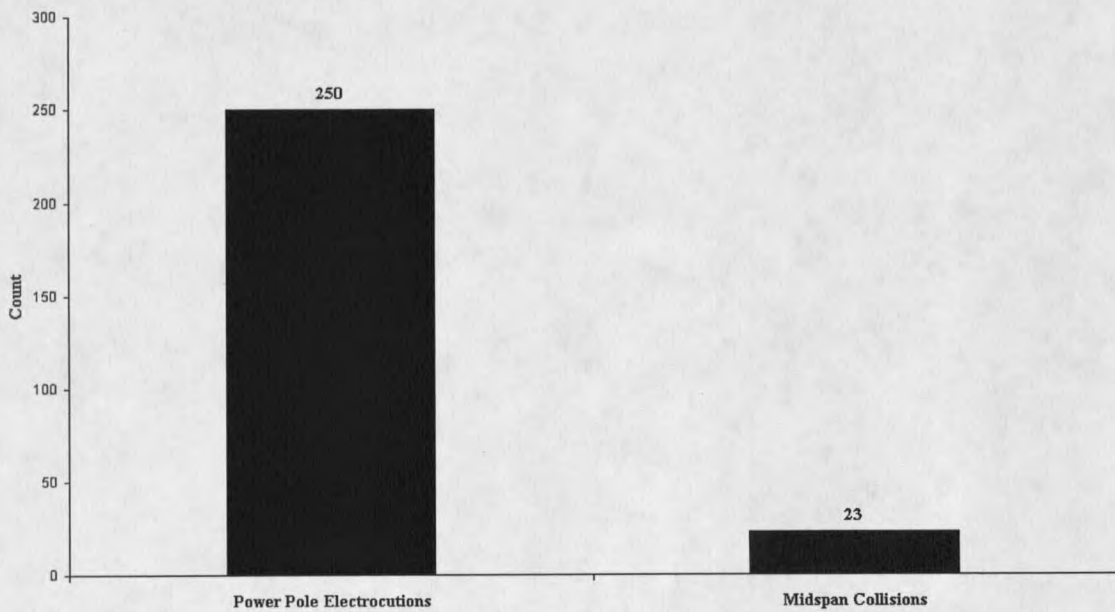


Fig. 9. Types of raptor mortalities by power lines in Roundup, Montana study area.

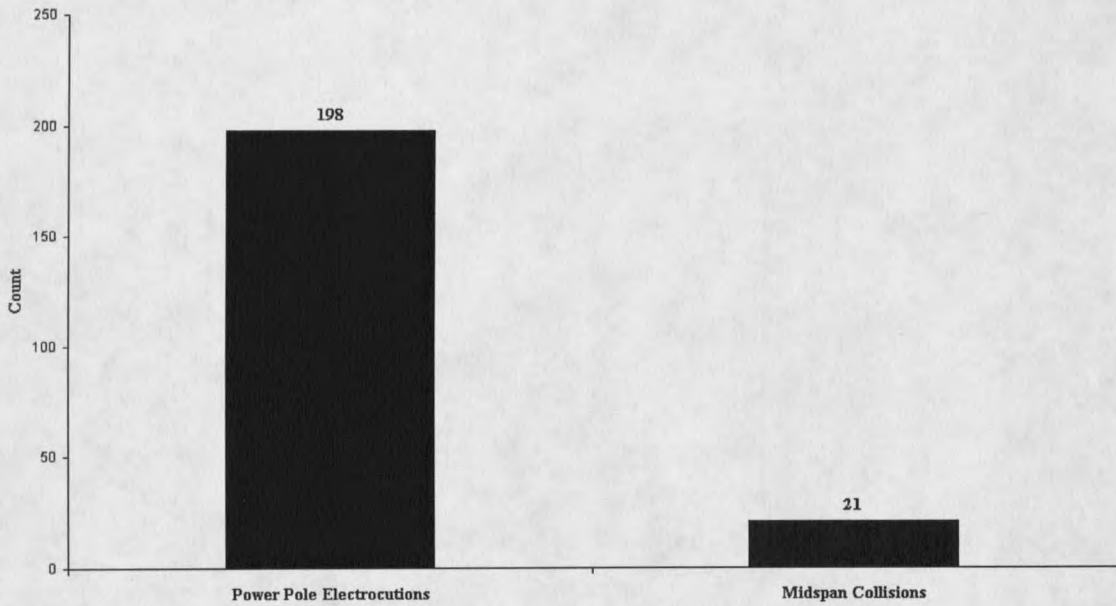


Fig. 10. Types of golden eagle mortalities by power lines in Roundup, Montana study area.

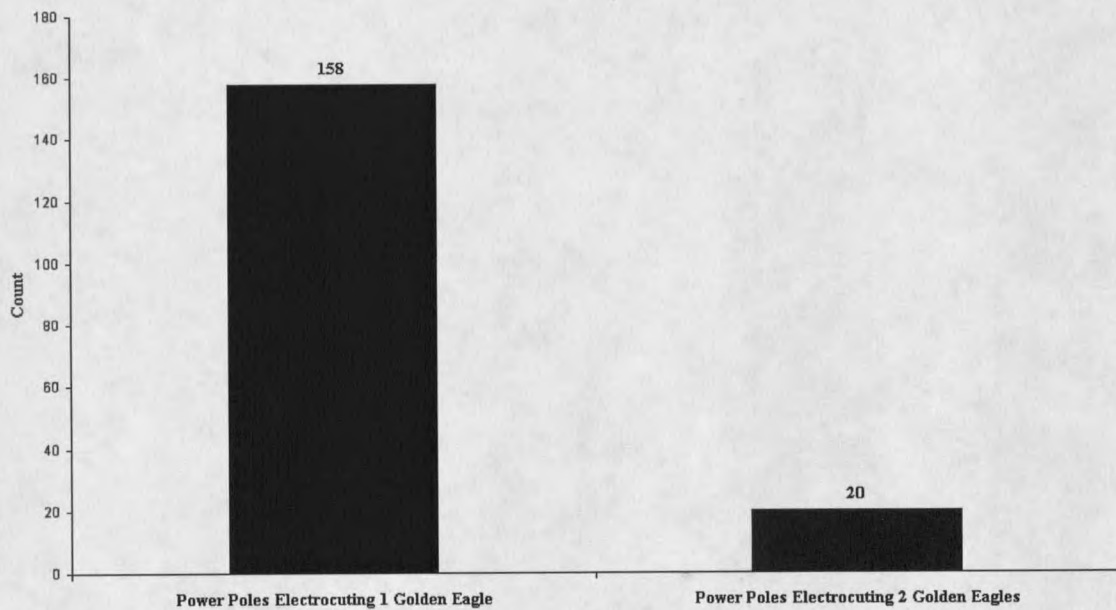


Fig. 11. Number of power poles electrocutting 1 or 2 golden eagles in Roundup, Montana study area.

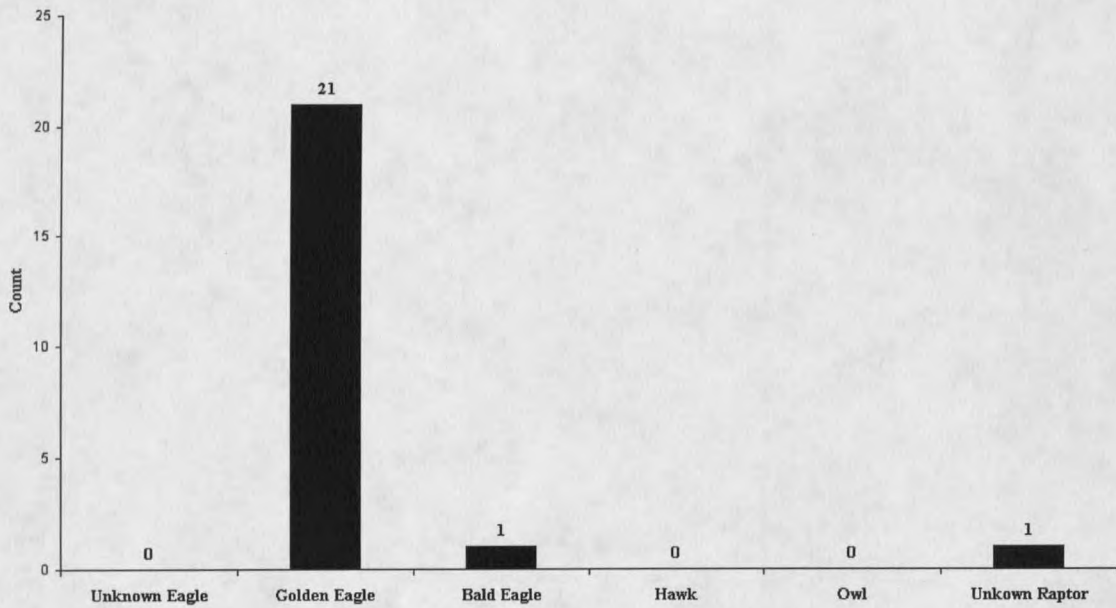


Fig. 12. Collision-induced mortalities by species discovered in Roundup, Montana study area.

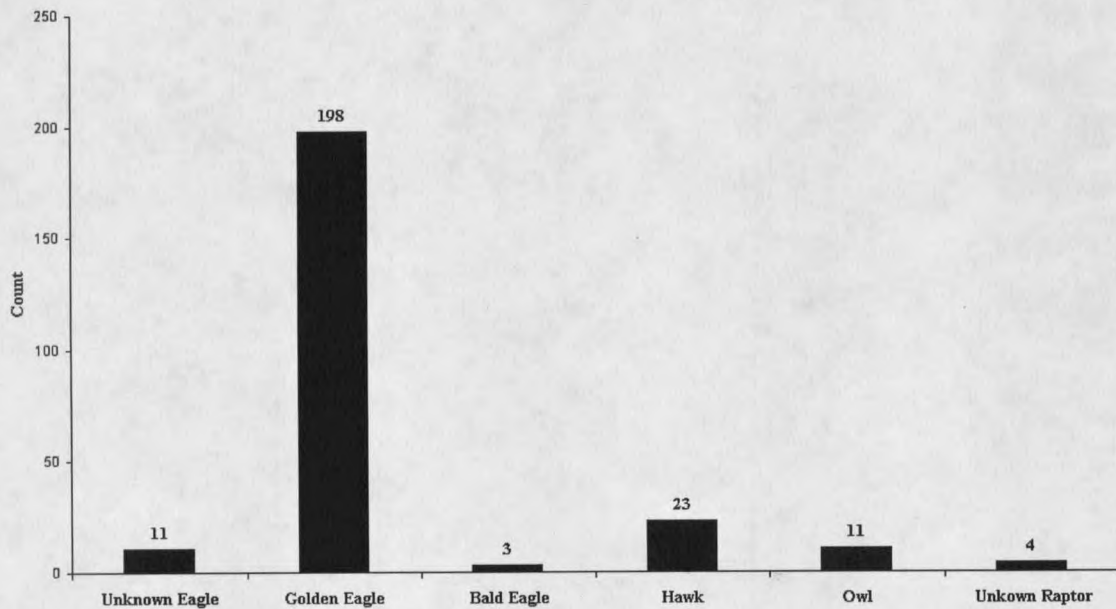


Fig. 13. Power pole electrocutions by species discovered in Roundup, Montana study area.

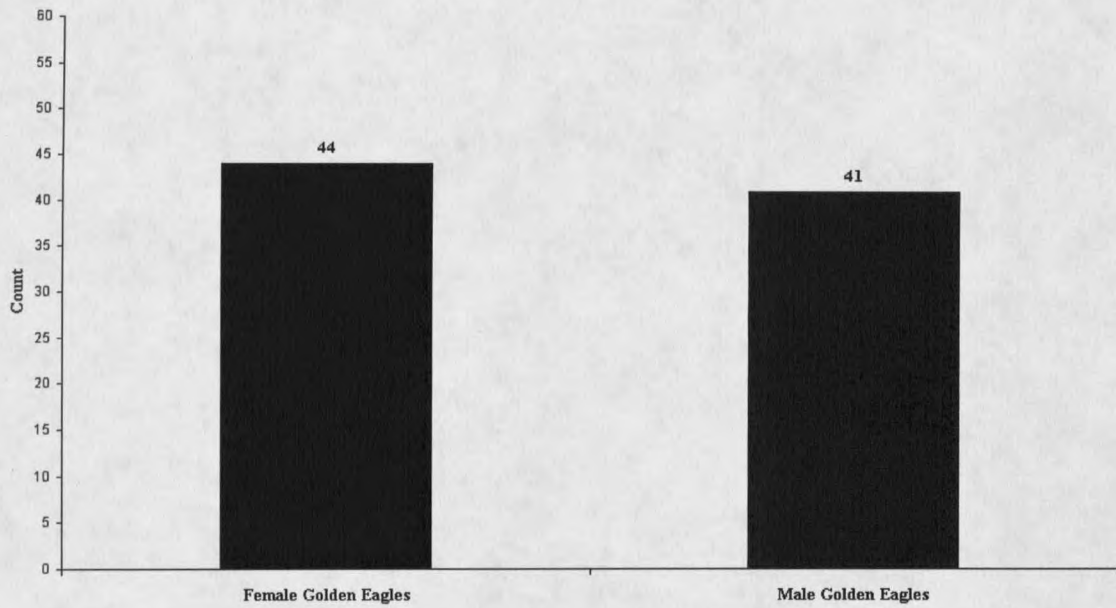


Fig. 14. Sex of golden eagle power pole electrocutions discovered in Roundup, Montana study area.

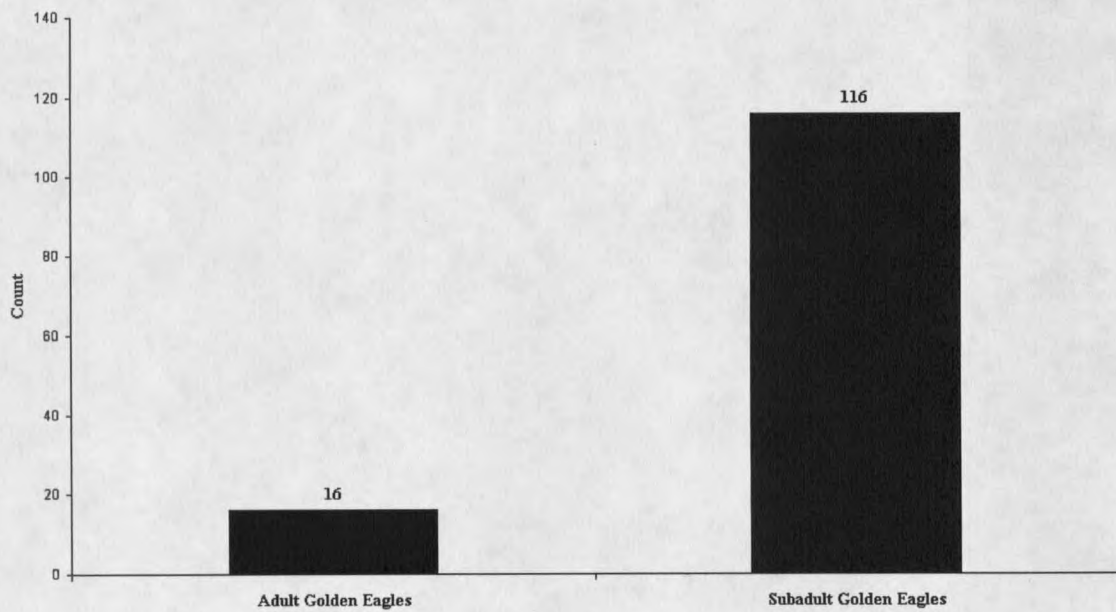


Fig. 15. Age of golden eagle power pole electrocutions discovered in Roundup, Montana study area.

