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

Abstract:
Four percent of 4,090 power poles examined in 1,600 km^2 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 ≥ I 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 (≥ 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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APPROVAL

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Jeffrey William Schomburg

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Four percent of 4,090 power poles examined in 1,600 km^2 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 km^2 area of northern Wyoming. Final predictive model classified offending and non-offending power poles equally as well for independent data and model data (≥ 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, lightening 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 km^2 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 virginanus*), 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 (*Artemesia tridentata*). Other shrubs present were greasewood (*Sarcobatus vermiculatus)* and silver sagebrush (*Artemesia 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 km^2 (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.

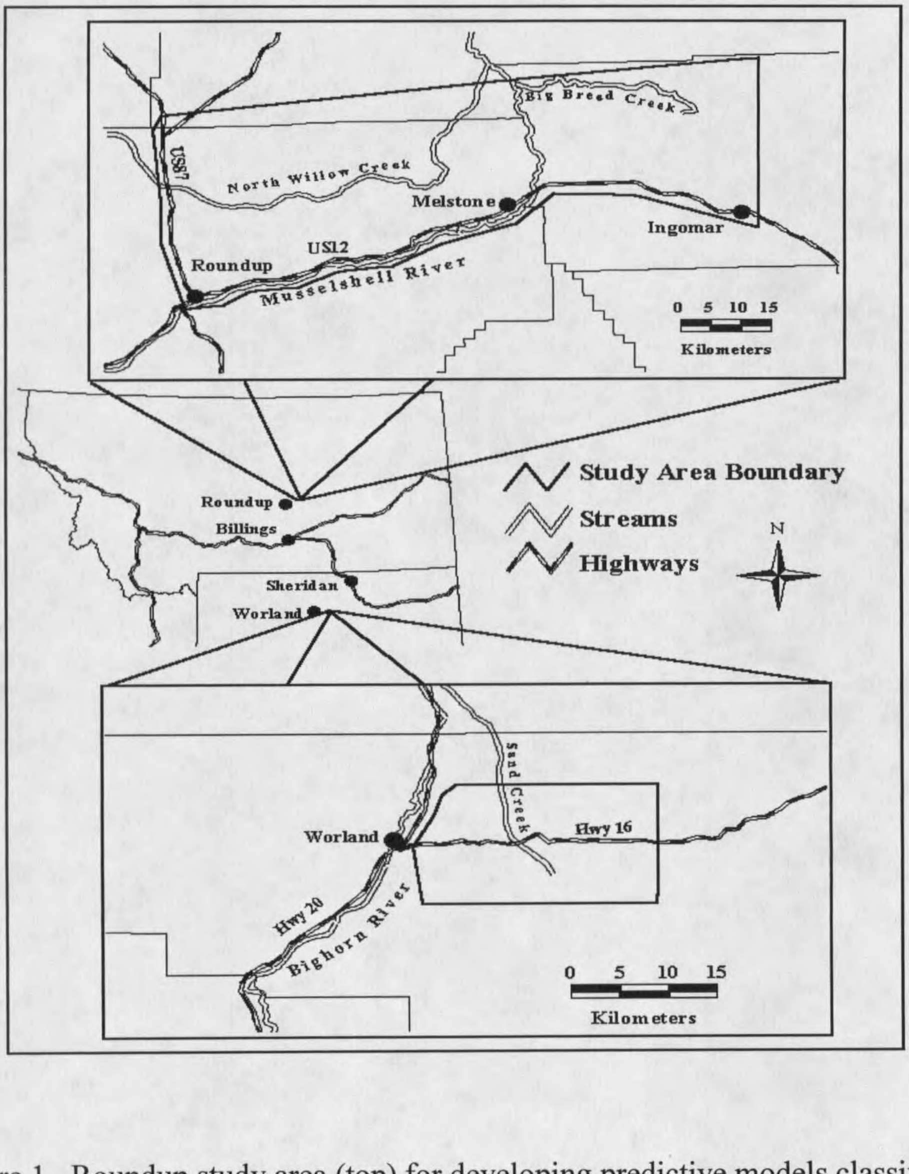

Figure 1. Roundup study area (top) for developing predictive models classifying offending (power poles electrocuting one or more golden eagle) and non-offending power poles in central Montana, USA, and Worland study area in north central Wyoming, USA for validating predictive models.

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 offending[1] power poles and a random sample of non-offending power poles for the Roundup study area.

Variable	Description	Metric
(1-2) SAGE[2]	Total amount of sagebrush cover (≥ 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 > 1.5m tall, tree > 4.6m 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

[1]Poles that have electrocuted at least one golden eagle

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

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

[4]TOPO variable was coded as a trend variable (flat = 1, bottom ⅓ slope = 2, mid ⅓ slope = 3, top ⅓ slope = 4, hill/ridge top = 5).