Prevention of Golden Eagle Electrocution

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Section 4

RESULTS AND DISCUSSION

The problem of raptor electrocutions is obviously linked to bird behavior. The intricacies of how and why raptor electrocutions and behavior are related are not readily apparent. Some insights that illuminate the problem and specifics involved have come with analysis of the data. Speculation on the whys and hows requires a systems approach in this study rather than considering each site a unique problem. How does the raptor interact with its surroundings? The following examination of data acquired in this study is an attempt to answer this question.

RAPTOR MORTALITIES BY SPECIES, AGE AND TEMPORAL OCCURRENCE

A total of 416 carcasses was found along the 24 sections of powerline. Golden Eagles represented 82.5% (343). Buteos collectively made up the next largest percent of mortalities with 51 birds (12.3%). Thirty of the buteo carcasses (58.8%) could not be identified to species and were placed in the unknown buteo category. These 30 carcasses represented 7.2% of the total mortalities. Ravens represented 3.1% of the mortalities with 13 being found. This is the second largest percentage of mortalities if the buteos are not grouped (Table 1). Three Great Blue Herons (Ardea herodius) were included in the total.

Because many carcasses were highly decomposed, age at death could not be determind. Only 52 Golden Eagle carcasses were fresh enough to determine age. Of these, three (5.8%) were adult, 28 (53.8%) were immature and 21 (40.4%) were subadult.

Other raptors that could be aged by plumage were Red-tailed Hawks, four adults (57.1%) and three immatures (42.5%); Swainson's Hawks, one adult; Ferruginous Hawks, three adults

Table 4-1. Total avian mortalities.

Species	Number	Percent
Golden Eagle (Aquila chrysaetos)	343	82.45
Raven (Corvus corax)	13	3.13
Red-tailed Hawk (Buteo jamaicensis)	7	1.68
Rough-legged Hawk (Buteo lagopus)	9	2.16
Ferruginous Hawk (Buteo regalis)	4	0.96
Swainson's Hawk (Buteo swansoni)	1	0.24
Unknown Buteo	30	7.21
Total Buteo	51	12.26
Prairie Falcon (Falco mexicanus)	3	0.72
Great Horned Owl (Bubo virginianus)	2	0.48
Marsh Hawk (Circus cyaneus)	1	0.24
Great Blue Heron (Ardea herodias)	3	0.72
Total	416	100.00

(75.0%) and one immature (25.0%); Prairie Falcons, three immatures; and one adult Marsh Hawk. Of the above sixteen non-eagle raptors that could be aged nine (53.3%) were adults.

Boeker (1975) found that 89.0% (N=281) of the electrocuted raptors reported to the U.S. Fish and Wildlife Service in 1972 and 1973 from 18 states were Golden Eagles. One more year of data raised the value to 90.0% (N=419) (Boeker and Nickerson 1975). Olendorff (1972) found 19 electrocuted raptors on the Pawnee National Grassland, Colorado. Seventeen (89.5%) were Golden Eagles. All eagles found in that study were immature. Nelson and Nelson (1975:230) indicate that in a Department of Interior count of electrocuted eagles (N= 300) "almost 98% of the electrocution victims were young birds." None of these studies gave details regarding age of non-eagle raptors, probably because of the small proportion of mortalities they represent.

The age distribution of electrocuted raptors found along the powerlines observed varied between Golden Eagles and non-eagle raptors. Nelson and Nelson (1975) felt that the high proportion of young eagles electrocuted was due to inexperience in flight. This undoubtedly accounts for a large part of the problem but it is likely that other factors were involved. Two such factors are: (1) the large number of young produced each year represents a major portion of the population in wintering and migration periods and probably the largest proportion of birds that come in contact with powerlines, and (2) the hunting behavior of young birds differs from adults because of inexperience, and may create a greater problem for these individuals. These factors will be discussed in the section on hunting behavior.

For those raptors that an approximate electrocution date could be determined, the majority of Golden Eagles, 28 (80.6%), died during the wintering period (Table 2). When classified together the other raptor species showed the largest mortality rate, 45.8%, during the courtship/nesting period (Table 3).

Table 4-2. Golden Eagle mortalities by seasonal activity period.

Wintering	Court/Nest	Fledging	Migration
80.56%	8.33%	5.56%	5.56%
(28)	(3)	(2)	(2)

Table 4-3. Occurrence of non-eagle mortalities by seasonal activity period.

Wintering	Court/Nest	Fledging	Migration
16.67%	45.83%	29.17%	8.33%
(4)	(11)	(7)	(2)

Discussion of temporal occurrence of Golden Eagle electrocutions will be deferred to the section on eagle behavior. Because so few electrocuted individuals of each non-eagle species were found it is difficult to make anything but a general statement concerning the possible reasons for the timing of these mortalities. Discussion of some raptor behavior may shed light on this phenomenon.

Along the Neiber Dome line two electrocuted adult Red-tailed Hawks were found. Both were killed on poles with nests. Both poles were adjacent to each other and although the time of death of only one of the birds could be determined, it appears that both were killed during nest building. The high proportion of adult mortalities in the courtship/nesting season might indicate that nest building activities were responsible for at least a portion of these deaths. Normally it is difficult for smaller raptors to make contact with conductors on this configuration. The additional activity involved in nest building creates repeated and prolonged exposure to hazardous conditions, increasing the chance of electrocution. Mortalities were observed at two sites where Ravens nested on poles. Newton (1979) indicated that many raptors winter at lower latitudes than those at which they breed. More mortalities of non-eagle raptors can be expected in this period than in other seasons because many of these birds winter at latitudes lower than areas included in this study and return north in the spring.

RELATIVE ABUNDANCE OF RAPTORS

The number of species of raptors, index of relative abundance and distance traveled per bird observed are found in Table 4 for powerlines and Table 5 for transects driven. The Raven was the most commonly observed bird with Golden Eagles being second. Ravens were included because they have been considered an ecological equivalent to raptors in their predatory behavior (Craighead and Craighead 1956).

Ravens, Golden Eagles, Red-tailed Hawks and Kestrels were the four most common birds observed. Although other researchers

Table 4-4. Frequency of raptor and raven sightings along transect roads, relative abundance and distance traveled per individual bird sighted.

Species	Number observed	Index of* relative abundance	Km traveled per bird
Raven (Corvus corax)	499	194.5	5.1(3.2)**
Golden Eagle (Aquila Chrysaetos)	131	51.1	19.6(12.2)
Kestrel (Falco sparverius)	98	38.2	26.2(16.3)
Rough-legged hawk (Buteo lagopus)	88	34.3	29.2(18.1)
Red-tailed Hawk (Buteo jamaicensis)	74	28.9	34.7(21.5)
Turkey Vulture (Cathartes aura)	55	21.4	46.6(30.0)
Ferruginous Hawk (Buteo regalis)	38	14.8	67.5(41.9)
Marsh Hawk (Circus cyaneus)	23	9.0	111.5(69.3)
Prairie Falcon (Falco mexicanus)	18	7.0	142.5(88.6)
Swainson's Hawk (Buteo swainsoni)	17	6.6	150.9(93.8)
Burrowing Owl (Speotyto cunicularia)	7	2.7	366.5(227.7)
Short-eared Owl (Asio flammeus)	3	1.8	855.1(531.3)
Goshawk (Accipiter gentilis)	1	0.4	2565.1(1593.9)

*Woffinden and Murphy (1977).
**Miles traveled per bird.

Table 4-5. Frequency of raptor and raven sightings along powerlines, relative abundance and distance traveled per individual bird sighted.

Species	Number observed	Index of* relative abundance	Km traveled per bird
Raven (*Corvus corax*)	514	548.3	1.8(1)**
Golden Eagle (*Aquila Chrysaetos*)	116	123.7	8.1(5.0)
Kestrel (*Falco sparverius*)	64	68.3	14.7(9.1)
Red-tailed Hawk (*Buteo jamaicensis*)	32	34.1	29.3(18.20)
Marsh Hawk (*Circus cyaneus*)	30	32.0	31.3(19.4)
Swainson's Hawk (*Buteo swainsoni*)	29	30.9	32.3(20.1)
Ferruginous Hawk (*Buteo regalis*)	28	29.9	33.5(20.8)
Turkey Vulture (*Cathartes aura*)	28	29.9	33.5(20.8)
Rough-legged Hawk (*Buteo lagopus*)	24	25.6	39.1(24.3)
Prairie Falcon (*Falco mexicanus*)	13	13.9	72.1(44.8)
Great Horned Owl (*Bubo virginianus*)	6	6.4	156.2(97.1)
Short-eared Owl (*Asio flammeus*)	6	6.4	156.2(97.1)
Bald Eagle (*Haliaeetus leucocephalus*)	4	4.3	234.4(145.6)
Cooper's Hawk (*Accipiter cooperii*)	1	1.1	937.4(582.5)
Sharp-shinned Hawk (*Accipiter striatus*)	1	1.1	937.4(582.5)
Crow (*Corvus brachyrhynchos*)	1	1.1	937.4(582.5)

*Woffinden and Murphy (1977).
**Miles traveled per bird.

do not include Ravens, the results of various studies of raptor abundance in the West show similar species composition (Enderson 1965, Johnson and Enderson 1972, Rodney 1976, Woffinden and Murphy 1977, Craig 1978).

LIVE GOLDEN EAGLE ABUNDANCE BY AGE

The ages of 183 live Golden Eagles observed along the transects were determined.Fifty-nine (32%) were adults and 124 (68%) were immatures or subadults. Neimeyer (1976) observed a high percent (75%) of immatures and subadults in his Montana trapping results (see section on intraspecific interaction). In Utah, Woffinden and Murphy (1977) observed almost equal percentages of each classification with 35 (53%) adults and 31 (47%) in the immature/subadult category. Boeker and Ray (1971) found that of those birds observed in Texas and New Mexico, 66% were adults and 34% were immature/subadult. They found variation in the migration patterns of adults and immatures, with more immatures moving through their study areas in the beginning and end of the wintering period.

Seasonal Variation in Abundance

Golden Eagles were recorded and classified according to their yearly temporal occurrence along powerlines. During winter, 40.7% of the total was observed. Migration, courtship/nesting and fledging periods follow with 27.4%, 20.7% and 11.1% respectively. To determine relationships between rabbits and Golden Eagle abundance, correlation coefficients were calculated for each time period. Calculations were based on numbers of rabbits and eagles observed per mile of line walked. The correlation coefficients (r) for these analyses were: winter, 0.691; courtship/nesting, 0.247; fledging, 0.093; and migration, 0.417. The wintering and migration values were significant ($P > 0.01$ and $P > 0.05$, respectively). Values for the courtship/nesting and fledging periods were non-significant.

Correlation coefficients were calculated for rabbit and Golden Eagle abundance across seasons and areas where each rabbit species was present. Areas where only jackrabbits were present had a correlation coefficient of -0.130. Values for the mixed and cottontail only areas were -0.069 and 0.838 respectively. The correlation coefficient for cottontails and Golden Eagles was significant ($P > 0.01$). Values for the jackrabbit only and mixed species areas were non-significant.

Galushin (1974:131)) discussed nomadism of raptors due to fluctuations in prey abundance in both breeding birds and yearlings. He states: "Nomadism in search of food represents an active method of selecting favorable living conditions and one that must enhance the possibility of food specialization, with all its behavioral, physiological and morphological consequences." Newton (1979) indicated juvenile raptors in winter move farther than adults in migrations, while older birds remain on the breeding grounds as long as prey are available. During winter, when small mammals and reptiles are hibernating and many birds have migrated, raptors are forced to either migrate, specialize in their foraging, or both. Many raptors move to areas of greater prey abundance (e.g., Swainson's Hawks, Snowy Owls, Rough-legged Hawks, Bald Eagles). Variable movements in raptors associated with changes in prey abundance over seasons and years have been noted (Glover 1952, Serventy 1953, Lack 1954, Keith 1963, Sulkava 1964, Newton 1979). Changes in Golden Eagle abundance due to food availability have been documented (Murphy 1975, Tjernberg 1977).

Variation of Golden Eagle numbers in the areas studied was probably due to the temporal and spatial abundance of food. It is likely that high correlations between eagles and all rabbits during winter was due to a scarcity of alternative food items. The significant relationship between cottontails and eagles throughout the year implies a preference for this prey. This specialization may occur because high local rabbit densities provide an energetically efficient cost/benefit ratio for the predator. Selection for this type of prey would be particularly beneficial to young inexperienced birds. Interaction between rabbits and raptors will be discussed more fully in the section on hunting behavior.

PREY REMAINS

Olendorff (1976), in a review of Golden Eagle food habit studies, indicated that rabbits were the major prey taken (54% of the diet). From visual analysis of prey remains and castings found at the base of powerpoles, it was determined the diet of eagles in the areas studied was composed predominantly of rabbits.

RELATIVE PREY ABUNDANCE

Rabbits at study sites were in several stages of the population cycle described by Gross et al. (1974). Crashes of rabbit populations were noted in several areas while others increased during the same period. Study sites in the Big Horn Basin of Wyoming, where cottontail rabbits were the only species observed, had high densities during the winter of 1977-78. The following winter a population crash occurred. One hundred and fifty miles to the southwest of the Big Horn Basin near Green River, Wyoming, rabbit populations were still at high levels during the spring of 1979. Rabbit numbers along the Gist line west of Roswell, New Mexico, were at a stage in the cycle similar to that of the Green River lines, and showed an increase between the winter of 1978 and the summer of 1979. The sites studied had rabbit populations that appeared to be at the upper end of the cycle or just past the peak. Thurow et al. (1980) observed a similar pattern in Black-tailed Jackrabbits in the Raft River Valley in southern Idaho near one of the sites of this study.

A yearly population fluctuation pattern was determined using observations from all of the sites studied. Although there was no significant difference in rabbit numbers between periods, a yearly population fluctuation was observed. The time categories used were the same as those for raptor abundance. The fledging period correlated with highest numbers of rabbits present; winter the lowest.

Four species of rabbits were observed, the Desert Cottontail Rabbit (*Sylvilagus audubonii*), Nuttall's Cottontail Rabbit (*Sylvilagus nuttallii*), the Black-tailed Jackrabbit (*Lepus californicus*) and the White-tailed Jackrabbit (*Lepus townsendii*). Species were combined within each genus for statistical calculations. Rabbit populations were classified into three categories based on species present: (1) cottontail rabbits only, (2) jackrabbits only and (3) mixed, cottontails and jackrabbits. Four sites had cottontails only, five had jackrabbits only and fifteen had both.

Yearly population fluctuations observed in rabbits were similar to those observed by Woodbury (1955) and Hayden (1966). The lower rabbit numbers in the wintering months require predatory birds to be more efficient in food searching and capture. Rabbit cycle fluctuations are an important factor in the electrocution problem. High prey abundance (e.g., rabbits) attracts raptors to an area (Galushin 1974), potentially creating an electrocution hazard if powerpoles are present that can function as hunting perches.

RAPTOR MORTALITIES AND AVAILABLE PREY SPECIES

An analysis of variance (ANOVAR) of raptor mortalities for both Golden Eagle and non-eagles, between lines having different prey species available was calculated. Three species categories (1) cottontail only, (2) jackrabbit only and (3) combined cottontail and jackrabbit were used in the analyses. Orthogonal contrasts showed eagle mortality rates along lines having only cottontails were significantly higher than those having jackrabbits only or those having both species (Table 6). The ANOVAR calculated for the non-eagle mortalities indicated no significant difference between the different rabbit areas (Table 7).

A significant difference (Chi-square, $P > 0.001$) exists between the number of kill (poles on which raptor mortalities occurred) to non-kill (poles on which no raptor mortalities were observed) poles along the cottontail, jackrabbit and mixed lines. Along the lines with only cottontails present 36.6% of the poles had carcasses under them.

Table 4-6. Golden Eagle mortalities: a comparison, using orthogonal contrasts (ANOVAR), between areas of different leporid species occurrence, cottontail only (C.T.), jackrabbit (J.R.) and both species present.

Contrasts	p-value
C.T. vs. J.R. and Both	0.018
J.R. vs. Both	0.336

Table 4-7. Non-eagle mortalities: a comparison, using orthogonal contrasts (ANOVAR), between areas of different leporid species occurrence, cottontail only (C.T.), jackrabbit (J.R.) and both species present.

Contrasts	p-value
C.T. vs. J.R. and Both	0.711
J.R. vs. Both	0.533

Along jackrabbit only lines 14% of the poles had mortalities occurring on them and 21.9% of the poles where both cottontails and jackrabbits were present had raptor carcasses under them.

White-tailed Prairie Dogs were observed at three Wyoming sites: Cottonwood, Seedskadee and Green River. In the Cottonwood region there were no mortalities in the prairie dog area. In the other locations two raptor mortalities/site were discovered. Poles in the areas where prairie dogs were present represented 1.4% of the total poles while the number of mortalities in these areas were 0.9% of the total.

The data indicate that greater numbers of Golden Eagles are killed on lines where cottontails are present, and more poles electrocute birds in these areas. It appears that either (1) eagles have a preference for cottontails over jackrabbits or (2) there is a differential pattern in use of poles by eagles in cottontail and jackrabbit areas. The behavior of the rabbits and the raptor species hunting them is probably responsible for the differences in mortalities. These differences are a result of divergent hunting techniques used by eagles for cottontails and jackrabbits and involve the use or lack of use of powerpoles as hunting perches. The relationship between rabbits and eagles will be discussed more fully in the section hunting behavior.

The lack of major rodent populations in the study areas implies that there is little, if any, relationship between raptor electrocutions and these animals. The fact that large rodents normally hibernate during the winter, when most electrocutions occur, would substantially reduce the effect they could have on the problem, in most areas.

VEGETATION

When a cluster analysis (Sokal and Rohlf 1962) was calculated based on the proportion of total cover represented by each shrub species present, the dendrogram in Figure 2 resulted. Three major communities were identified from this analysis. The largest group was the sagebrush dominated cluster.

Fourteen of the 24 lines studied were in the big sagebrush dominate group. Big sagebrush represented 45.5 to 100.0 percent of the total shrub cover in these areas. In Figure 2 the points between Vollman-Reynalds and Hamer represent this group.

The two other major groups are dominated by greasewood and shadscale. Green River to Beryl represent the Greasewood sites and Denio to Sevier the shadscale (Fig. 2). The remaining lines, Magdalena I, Magdalena II, Gist and Kimama were dominated respectively by four wing saltbush, pingue, small headed matchweed (Xanthocephalum microcephala) and rubber rabbit brush.

Big sagebrush, present in 19 of the 24 sites, was the most common shrub. Shadscale, greasewood and rubber rabbit brush were next most common, being present at 13, 11 and 10 sites respectively. Table 8 lists the shrubs observed and the sites where each was present. These data were derived from the 9.3 m^2 (100 sq. ft.) circular plots.

The canopy cover data collected using the pole-to-pole and randomly placed 1-m^2 visually estimated plots resulted in different cover values. These estimates were, however, highly correlated (r=0.938) at the 0.001 level. Using correlation analysis, the pole-to-pole and the 1-m^2 estimates were compared with the circular plot measurements. The resulting r-values were 0.846 and 0.892, respectively. Both of these values are significant, at the 0.001 level (Table 9). Average shrub heights for each site are also given in Table 9.

RAPTOR MORTALITIES AND VEGETATION

When three correlation analyses were calculated between the number of raptor mortalities and values from each measurement technique for shrub cover, no significant differences were found. ANOVAR was used to compare areas based on the amount of vegetation present and the number of mortalities. The groups compared were areas that had: less than 10%

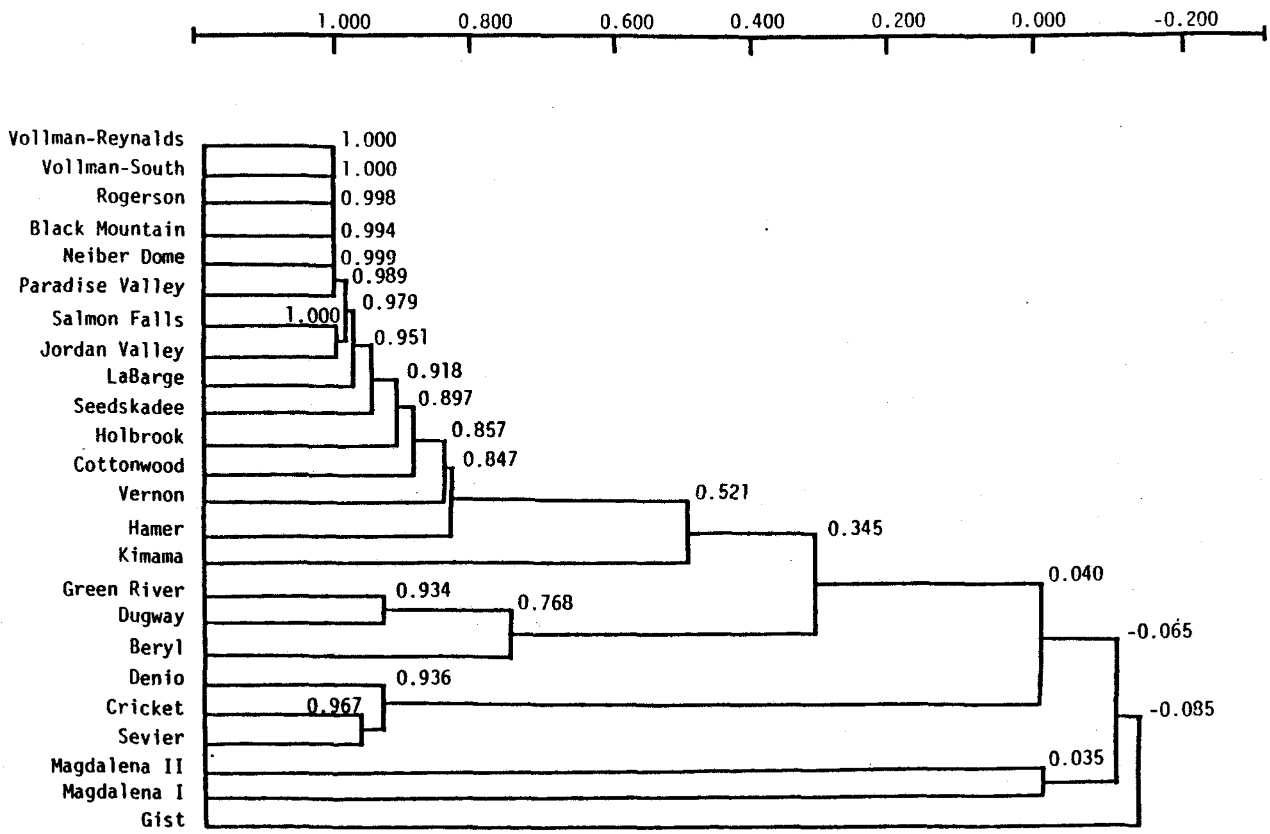

Figure 4-2. Dendrogram of similarity (r) of shrub vegetation at the sites studied.

Table 4-8. Shrub species found at study sites.

Sites	Acacia greggii	Artemisia tridentata	Artemisia spinescens	Atriplex canescens	Atriplex confertifolia	Atriplex gardneri	Ceratoides lanata	Chrysothamnus nauseosus	Chrysothamnus viscidifloris	Ephedra torreyana	Hymenoxys richardsonii	Juniperus oseosperma	Kochia americana	Larrea tridentata	Opuntia acanthocarpa	Purshia tridentata	Sarcobatus vermiculatus	Symphoricarpos longifloris	Tetradymia axillaris	Tetradymia canescens	Tetradymia spinosa	Xanthocephalum microcephala	Xanthocephalum sarothrae
Magdalena I				X				X			X												
Magdalena II				X							X												
Gist	X													X	X							X	
Vollman-Reynalds		X																					
Vollman-South		X																					
Cottonwood		X						X									X						X
Neiber Dome		X			X												X						
Black Mountain		X															X						X
Seedskadee		X			X		X		X								X						
Green River		X						X	X								X				X		
LaBarge		X			X			X	X								X				X		
Holbrook		X						X	X			X				X		X					
Hamer		X						X	X											X			
Kimama		X							X														
Rogerson		X																					
Salmon Falls		X						X															
Jordan Valley		X						X															
Denio		X	X		X																		
Paradise		X			X												X						
Vernon		X	X		X		X	X												X			
Dugway		X			X	X		X	X								X		X	X			
Cricket			X		X		X	X					X				X		X	X			
Sevier			X		X			X	X	X			X				X			X	X		
Beryl		X			X			X									X						

Table 4-9. Percent vegetative cover as determined by circular plot measurement, pole-to-pole visual estimate and 1-m^2 visual estimate and average shrub height (cm).

Location	Circular plot	Pole-to-pole	1-m^2	Mean Shrub height
Magdalena I	3.9	17.5	5.8	24.9
Magdalena II	2.4	13.9	5.9	30.7
Gist	8.6	22.4	10.3	23.8
Vollman-Reynalds	7.3	12.4	7.1	24.1
Vollman-South	7.8(8.6)*	14.8(16.1)*	9.9(10.1)*	21.0
Cottonwood	17.3	12.7	4.1	39.2
Neiber Dome	42.2	27.1	11.9	37.3
Black Mountain	28.0	19.2	10.4	35.5
Seedskadee	19.0	19.2	12.6	26.5
Green River	36.5	27.7	7.8	33.8
La Barge	29.5	20.6	6.8	39.6
Holbrook	68.8	40.4	24.8	55.7
Hamer	17.0(18.8)*	17.9(24.5)*	5.8(8.0)*	48.3
Kimama	2.3(5.7)*	10.3(18.2)*	0.7(1.3)*	27.4
Rogerson	31.4	25.9	9.4	44.6
Salmon Falls	23.9(47.9)*	17.3(29.8)*	4.1(9.7)*	62.4
Jordan Valley	23.0	29.2	11.9	43.0
Denio	40.5	40.6	20.2	38.0
Paradise Valley	46.5	37.4	20.1	48.8
Vernon	48.3	48.5	25.1	29.4
Dugway	70.6	54.0	26.6	48.8
Cricket	26.9	32.0	12.8	27.0
Sevier	22.2	25.2	15.2	22.9
Beryl	55.0	47.5	25.6	28.1

*Calculated minus agricultural land

cover, 10-25%, 25.1-40% and greater than 40%. There was no significant difference between groups. A correlation analysis comparing shrub height and raptor mortalities indicated no significant trend.

The majority of lines (14) were in big sagebrush dominated areas while 19 lines had that species present. The top 25.0% of the lines by mortality, were in sagebrush dominated areas. The various shrub types and numbers of mortalities occurring in each were compared by ANOVAR. Those shrub types with only a single line included in them were grouped together. There was no significant difference between groups.

AGRICULTURAL LAND

Kill and non-kill poles along lines crossing both cultivated and non-cultivated land were compared. There was a significant difference (Chi-square, P 0.001) in the numbers of kill poles between cultivated and non-cultivated areas. Of the poles in the uncultivated portion 31.3% had raptor carcasses under them, while only 8.0% in cultivated areas had killed birds. Twenty-five percent of the poles in the totally non-cultivated areas had killed raptors. Chi-square analysis was used to compare lines in totally non-cultivated areas and the poles in uncultivated areas of lines crossing both types of land. There was no significant difference between areas. There was also no significant difference in the numbers of electrocutions when the totals of both types of lines were compared.

VEGETATION AND RABBITS

An ANOVAR comparing the shrub height and amount of cover present between cottontail, jackrabbit and mixed habitats showed no significant difference. A student's t-test comparing the height and cover of shrubs used as forms by cottontails and jackrabbits showed no significant difference between either shrub height or cover.

Studies of rabbits (Woodbury 1955, McKeever and Hubbard 1960, Hayden 1966, Flinders and Hansen 1972, Chapman and

Willner 1978, Green and Flinders 1980, Fagerstone et al. 1980) show a high association with many of the shrub species observed in this study. The lack of variation in the shrub size used for forms by rabbits appears to be a function of the relative homogeneity of the habitats. The absence of statistical significance between the amounts of vegetation in rabbit areas studied indicates (1) the similarity of the desert regions observed and (2) the wide range of areas that these animals will inhabit.

Statistical tests suggest a highly significant differential use of the agricultural and non-agricultural areas by raptors. A high correlation in raptor and rabbit abundance implies the pattern of use is somehow related to rabbits. Vorhies and Taylor (1933) indicate jackrabbits often move from cover into open areas for foraging during nocturnal periods. Westoby and Wagner (1973) found the greatest use of crested wheatgrass (Agropyron cristatum) plantings by Black-tailed Jackrabbits was in a band 300 m (984 ft.) wide along the edge of the field, close to cover. The higher rate of raptor electrocution in areas with more cover appears to be related to the preference of rabbits to remain near escape cover.

Though there was no statistical difference in the number of kill poles in natural vegetation adjacent to and away from agricultural areas there was a higher percent of poles with kills near cultivated lands. The six percent difference between the two may be due to greater use of agricultural sites by rabbits for grazing, thus attracting raptors. Fagerstone et al. (1980) indicated Black-tailed Jackrabbit densities were significantly higher near cultivated fields. Anderson and Pelton (1976:533) found cottontail concentrations greatest at sites with good cover adjacent to "areas of sparse cover and excellent penetrability". In that study some of the sparse areas used were cultivated fields. The apparent use of cultivated fields by rabbits for feeding probably attracts raptors to these areas. This probably occurs when there is abundant natural vegetation adjacent to fields.

Great variation in the raw cover values obtained using the 1-m^2 plots from the other techniques suggests that that size plot is too small for efficient estimation of shrub cover. The high correlation with values from the measured plots does, however, allow a determination of the amount of cover present when a calibrated estimate similar to that of Tadmor et al. (1975) is used.

POWERPOLES

Some variation of design occurred in the lines studied, but functionally four major types of configurations were observed (Fig. 3). A comparison of the configurations and mortalities that occurred on them was calculated (ANOVAR, Table 10 and 11). When Golden Eagle mortalities were compared, there was no significant differences between configurations. Analysis of the non-eagle mortalities showed a significantly greater number of birds were killed on configuration A (Fig. 3). Tables 10 and 11 show the orthogonal contrasts of these two analyses and the probability values associated with each.

Power output varied between 12,000 and 69,000 volts with most lines being either 12 kV (10) or 34.5 kV (9). One line each was in the 69, 20 and 23.9 kV categories and two were in the 44 kV category. All lines observed are in a potentially hazardous voltage range for raptor electrocutions (Nelson 1979). Raptor mortalities on lower voltage lines (12-23.9 kV) were compared to higher voltage lines (34.5-69 kV) (Student's t-test). No significant difference was found.

To ascertain the effect of pole height on the potential electrocution hazard, the height of each pole was determined. For each line a Student's t-test was calculated comparing the height of poles with mortalities and poles without mortalities. Of the 24 analyses, 23 showed no significant difference between the height of kill and non-kill poles. The remaining test (the Denio line) showed that the kill poles were significantly taller than the non-kill poles. Although there was a significant difference between the height of kill and non-kill poles at the

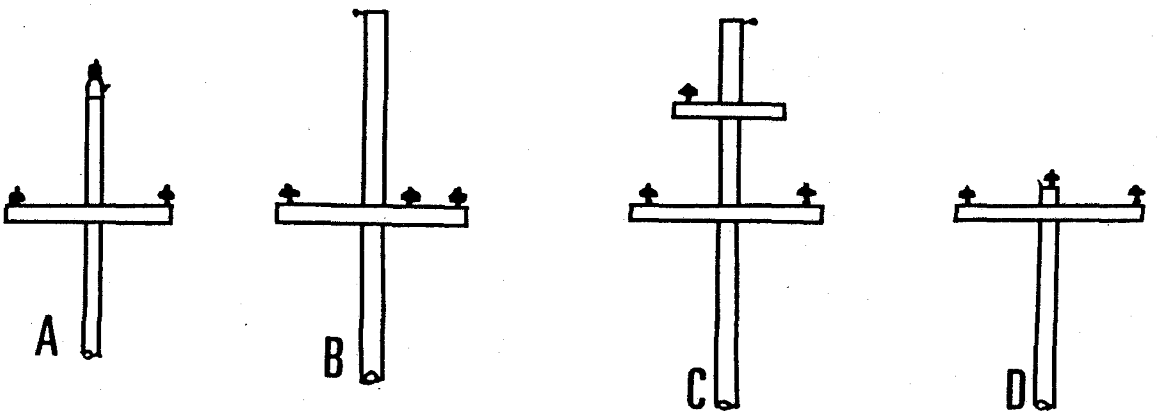

Figure 4-3. Powerpole configurations studied.

Table 4-10. Orthogonal contrasts for ANOVAR of Golden Eagle mortalities by powerline configurations.

Contrasts	p-value
A vs. B C D	0.678
C vs. B D	0.306
B vs. D	0.854

Table 4-11. Orthogonal contrasts for ANOVAR of non-eagle mortalities by powerline configurations.

Contrasts	p-value
A vs. B C D	0.004
C vs. B D	0.801
B vs. D	0.973

Denio site this was probably due to chance since pole height is approximately equal in most areas.

The wingspan of the Golden Eagle (200 cm, 78 in.) (Robbins et al. 1966) easily exceeds the distance between conductors on all four configurations. Significantly more mortalities of smaller raptors did however occur on those poles with configuration A (6-foot crossarm) rather than configuration B-D (8-foot crossarms). The shorter crossarm means the conductor to groundwire distance is less than three feet and short enough for the wings of smaller raptors to complete a connection. It is probable that non-eagle raptor populations have greater mortalities occurring with configuration A than on B-D.

The voltage and amperage of the lines observed were sufficient to electrocute birds, if the proper contact was made (see weather section). In most areas, lines with voltage greater than 69 kV have a large enough separation of conductors to prevent contact by raptors (Nelson and Nelson 1975, Boeker 1975a) unless, as occasionally seems to be the case, there is physical interaction between birds allowing a larger space to be crossed (R. Miller pers. comm.).

Accounts of birds receiving an electrical shock and surviving have been noted (S. Crowe pers. comm., Northern Wyoming Daily News 1978). Information from raptor rehabilitators (S. Ure pers. comm., J. Lee pers. comm.) indicates most of these birds eventually die because of decomposition of the affected tissues. S. Crowe (pers. comm.) observed a Harris Hawk (Parabuteo unicinctus) contact wires on a transformer. The bird was knocked unconscious but recovered after a few minutes and survived. The line voltage was unknown, but because this incident occurred on a transformer, it is possible the voltage was lower than those observed in this study. Personal communication with falconers (J. Stoddart pers. comm., L. Boyd pers. comm., R. Rogers pers. comm., S. Baptiste pers. comm.) and Chingren (1980), indicates that falconry birds are quite vulnerable to electrocution, particularly when coming in contact with transformers. These birds were of the non-eagle size category.

POLE MODIFICATIONS

Some lines in this study had modifications on individual poles before the research was initiated while others were modified afterwards. Modifications were considered either major or minor. Lines having all of the poles modified were considered in the first category. Minor modifications involved only several poles along a line.

Major Modifications

During this study, four of the lines were modified. The Neiber Dome and Black Mountain lines (see B, Fig. 3) had the center insulator moved from on the crossarm to the side of the pole 1.1 m (43 in.) above the level of the other conductors. The groundwire, when present, was insulated from the crossarm to the top. Raising the center phase made it impossible for raptors to touch two conductors simultaneously, and covering the groundwire eliminated the possibility of contact.

The Dugway line, an older construction (see A, Fig. 3), required new crossarms. New 8-foot (2.4 m) arms replaced the older 6-foot (1.8 m) spans, and insulators were moved from above the crossarm to below it. Moving of the insulators provided an unobstructed area on top of the crossarm, eliminating potential contact by raptors.

The Hamer line was very old, and many poles were rotting. Because of new powerline construction and alternate routing, this line was cut down and removed.

These modifications, made in the spring of 1979, were checked after alteration, and no mortalities were found. These subsequent surveys were made spring and summer, times of low raptor use. Additional observations in other seasons should be made to assess their effectiveness.

After this study was concluded, the Vernon line was modified using an 'Inverted V' or 'Eagle Oie' between the two closest conductors. This triangular shaped modification was placed between adjacent insulators to discourage or prevent raptors from landing on crossarm areas that are potentially the most hazardous.

Minor Modifications

Eight lines had modifications on several poles. These modifications included: (1) lowering the crossarm; (2) placement of a pole top extension; (3) placement of conductor skirts; (4) insulation of the center conductor 1.8 m (6 ft.) on either side of the pole; and (5) installation of an elevated perch (Miller et al. 1975).

Modifications 1 and 2 produce a delta shape (formed by the insulators), providing vertical separation of the adjacent conductors. These alterations prevent raptors from contacting two lines. Types 3 and 4 insulate the center phase of the line preventing contact with the bird. The elevated perch of type 5 allows the bird to sit above the crossarm away from the conductors. These modifications are described in Miller et al. (1975).

Two problems were observed with regards to the placement of the elevated perch. Some structures were placed (1) too far above the crossarm or (2) perpendicular to the crossarm. Both situations allow birds to land on the crossarm (as was observed in this study), negating the modification's usefulness. Electrocuted raptors were found beneath some poles after construction of the elevated perch.

HUMAN DISTURBANCE

Data were collected to assess the effects of human disturbance on raptor mortalities along powerlines. These data were of two types: (1) the presence of broken insulators under poles, and (2) the presence of various roads along powerlines.

Broken insulators are usually an indication of shooting (R. Harbicht pers. comm., and R. Seaman pers. comm.). Powerlines were ranked by (1) the percent of poles with broken insulators under them and (2) the number of raptor mortalities along the line. A Spearman's Rank Correlation Coefficient to determine if a relationship existed between the amount of shooting and the number of mortalities along lines showed no significant relationship between these variables.

To determine amount of human activity along a line and the potential for shooting, the type of road in each area was recorded. Roads were adjacent to or near all of the areas studied. Roads ranged from 4-wheel tracks to 4-lane freeways and were classified as paved roads, major dirt roads or patrol roads. An ANOVAR comparing mortalities along lines in each of these types was non-significant.

Of those birds found fresh only two, an immature Golden Eagle at the Black Mountain line in Wyoming, and an adult Ferruginous Hawk at the Cricket line in Utah were determined to be shot. Although there was no significance found in the statistical analyses of the above data, and only raptors were found shot, there is a possibility that birds shot were retrieved by the gunner. If this occurred, it would bias the data. When recommendations are made in specific areas, shooting should be taken into account as a potential problem to both raptors and the lines themselves.

TOPOGRAPHIC RELIEF

Using categorical data analysis, differences in raptor mortalities were calculated according to the topographic placement of powerpoles. Categories of the cross classified data were pole positions and relative amounts of topographic relief along a line. Kill and non-kill poles were the measured response. The amount of topographic relief along a line was calculated as the average vertical difference between adjacent pole bases (low, less than 1.5 m [5 ft.]; medium, 1.5 to 4.6 m [5 to 15 ft.]; high, greater than 4.6 m).

Pole placement categories can be seen in Fig. 4. When the percentage of poles having mortalities was compared, types A and B had 32.6% and 26.6% respectively. Types C and D were subjectively separated because of the direction of their vertical rise and drop. Both types have similar relief measurements, but the directions differ, resulting in varying amounts of area that can be observed. Type C, a saddle, had 21.2% of its poles accounting for mortalities while type D, a side hill, had 23.3%. Considering the two types together, the total is 23.1%. Types E and F have 20.2% and 15.7% respectively.

A significant linear trend was found across the placement categories of poles. This significance occurred whether groups C and D were considered together or separately. Those categories with the greatest height advantage had a higher probability of mortalities occurring on them.

The fact that the greatest numbers of Golden Eagles were electrocuted on poles with higher topographic placement is consistent with predictions of Nelson and Nelson (1975). Craighead and Craighead (1956) indicated buteos frequently select high conspicuous perches from which to hunt. The power structures scattered throughout the West furnish ideal hunting perches. The higher positioned poles provide hunting raptors two advantages, (1) greater view of the surrounding terrain and (2) a greater attack speed. These factors should enhance hunting success. Poles in lower areas will not render the same hunting advantages as poles in higher positions. The fewer numbers of mortalities found when comparing low versus high positioned poles indicates preferential use by raptors.

TOPOGRAPHIC RELIEF AND RABBITS

Variation of the topographic relief in areas with different rabbit populations was significant (ANOVAR, P>0.01). Relief was calculated as previously indicated (i.e., the average

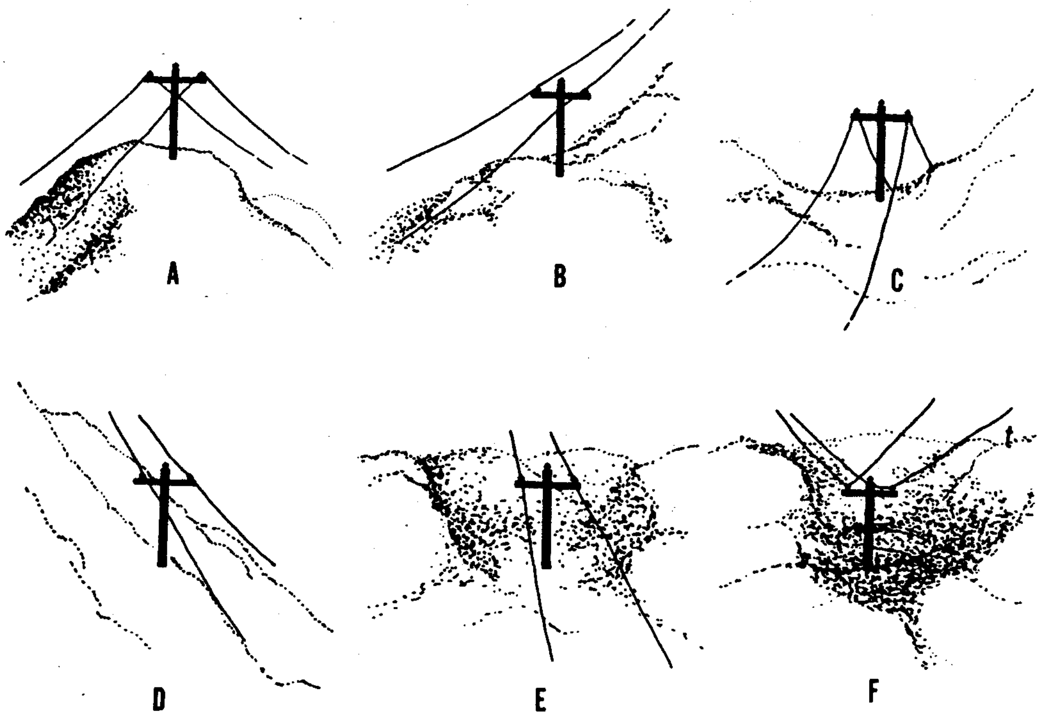

Figure 4-4. Topographic pole placement.

vertical difference between adjacent pole bases along a powerline). The mean vertical difference in cottontail only areas, 5.56 m (18.26 ft.), approaches three times that in the mixed and jackrabbit only areas, 2.05 m (6.74 ft.) and 2.04 m (6.70 ft.) respectively.

The flat topography of jackrabbit only areas is consistent with the 'open plains' habitat Vorhies and Taylor (1933) found these animals to prefer. Open areas are ideal for a fast, wider ranging animal like the jackrabbit. The cottontail, preferring rocky outcrops and thick brush (Chapman 1975, Chapman and Willner 1978), might be expected to inhabit areas of greater topographic relief as was the case in this study. Areas where both species were found were not different topographically from those with only jackrabbits. The occurrence of cottontails in these areas indicates that these animals are more flexible in their habitat requirements than jackrabbits.

SOILS

A cluster analysis (Sokal and Rohlf 1962) using soil characteristics and chemical composition was calculated for the soils at each site. The factors used for the analysis were percent of sand, silt and clay, pH, electroconductivity, percent total nitrogen and parts per million of phosphorus, potassium, zinc, iron, manganese and copper. There was no significant difference in the soils analyzed.

The lack of variation in the soils found in the study areas does not seem unusual when considered ecologically. The soils typical of the study sites are aridisols, which, in the United States, according to Donahue et al. (1977:419), "are located primarily in the Western Mountain and Pacific States in areas of low rainfall where scattered grasses and desert shrubs dominate the vegetation." This description aptly fits the sites studied and generally the whole western United States which has historically had a high electrocution problem.

WEATHER

Precipitation A cluster analysis (Sokal and Rohlf 1962) was calculated to determine similarities between precipitation patterns at study sites (Fig. 5). Lines in the same general area were grouped since they would have complete correlation. The criterion for clustering was monthly average precipitation. The groups combined and their common labels were Magdalena I and Magdalena II, Magdalena; Vollman-Reynalds and Vollman-South, Vollman; Cottonwood, Neiber Dome and Black Mountain, Cottonwood; Seedskadee, Green River and LaBarge, Green River; Rogerson and Salmon Falls, Rogerson; Cricket and Sevier, Cricket. Isolated lines were labeled using the line name.

The data indicate the patterns of precipitation of the New Mexico the Beryl, Utah, lines are negatively correlated with the rest of the areas studied. Wyoming and eastern Idaho lines group together; central Idaho lines and those of Oregon and Nevada are similar. The remaining Utah lines are clustered. The Vernon line was the least like the rest of the Utah group. The total yearly precipitation of these four regions was not significantly different (ANOVAR).

The New Mexico-Beryl group exhibit a pattern of high summer precipitation typical Southwestern hot deserts. The Beryl line is at the northern edge of these deserts.

Wyoming and eastern Idaho lines have a period of high precipitation during the spring while those in western Idaho, eastern Oregon and northern Nevada show two peaks of precipitation, late fall-mid winter and late spring. The remaining Utah lines show no major peaks with March-April and October having the most consistently high precipitation.

There was no significant difference (ANOVAR) between the four groups of lines based on the numbers of raptor mortalities.

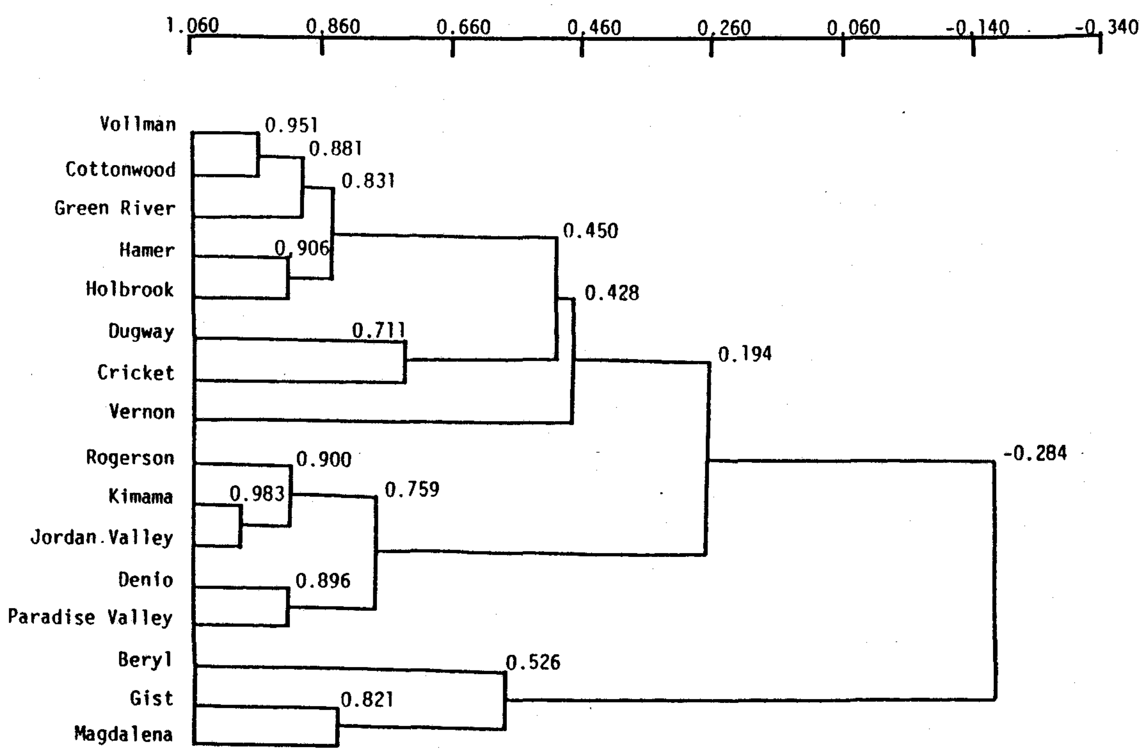

Figure 4-5. Dendrogram of similarity (r) of precipitation at the sites studied.

Although there was no statistically significant difference in the amounts of annual precipitation, this factor must not be overlooked when considering raptor electrocutions. The amount of current (amperage) is the major factor determining electrocution. Nelson (1979) established that raptors react comparably to humans at the same levels of amperage. Eighty volts caused 12 milliamperes of current in an eagle when contact with both conductors was made with the skin. The bird convulsed at this point but was not damaged. Nelson postulated the lethal level of current in raptors is the same as for humans, 17-20 milliamperes. Nelson (1979) also found that wet feathers conduct current much more readily than dry ones. When dry flight feathers of Golden Eagles were attached to electrodes 14, ten and seven inches apart, no current was conducted at 70,000 volts. A wide range of voltages (10 V-70,000 V) were tested. Results indicated that dry feathers were almost as good an insulator as air. In contrast wet feathers burned at 5,000 volts, when the electrodes were ten inches apart. Voltages greater than 5,000 volts arced through saturated feathers, if contact was made. Nelson (1979:7) indicated a wet bird is approximately ten times as vulnerable to electrocution as a dry one and that, "Even when wet there is very little hazard (electrocution) below 5,000 volts..." These data suggest there is little or no potential for electrocution due to contact between wing tips and conductors on many of the rural electrical installations (e.g., irrigation and oil well pumps are usually powered by voltages less than 5,000 volts) and any bird electrocuted when making wingtip contact with higher voltage lines would need to be wet at the time. Birds making contact between conductors and two fleshy parts of the body (e.g., beak-foot, foot-foot, etc.) could be killed by voltages less than 5,000 volts. Nelson (1979) stated that 55,000 volts arcs across five inches of air. The good insulating effects of feathers under dry conditions does not prevent electrocution when contact is made in areas where feather insulation is insufficient to prevent arcing to the skin.

Nelson (1979) felt the chances of a raptor being electrocuted are increased by their habit of spreading the wings to dry after a rain or snow storm. This behavior is common in many species of birds (Lippens 1938, Gush 1951, Smythies 1953, Clark 1969, Kennedy 1969, 1970).

The effect different types of precipitation have on the wetting process of feathers varies. A bird perched for equal periods of time with equal amounts of precipitation falling may not realize the same amount of feather saturation in a snow storm as in a rain storm. Feather structure and the surface tension of a falling raindrop causes much of the rain to roll off a bird. Snow remains on the bird, is melted by body heat and the resulting water percolates into the feathers causing greater wetting. The amount of precipitation at any one time could also have an effect on the probability of electrocution. Prolonged heavy storms like those occurring in winter may create more problems than a brief summer shower. These factors may partially explain why more birds are electrocuted in winter months.

Prevailing Winds

Data collected from (1) National Oceanic and Atmospheric Administration weather records, (2) recorded observations of wind directions during each visit to a study site and (3) predominant direction of defecations surrounding powerpoles helped determine the prevailing wind direction of an area. With the aid of a compass the angle at which the crossarm was placed was determined for each pole. These two types of data were used to determine the predominant angle of contact made by prevailing winds upon each crossarm and thus the most probable direction of approach by a landing raptor.

Three placement categories were used; perpendicular, diagonal and parallel. Imagining a crossarm represents the east and west coordinates of a compass (90° and 270°) the perpendicular directions are from 337.5° to 22.5° and 157.5° to 202.5°, the diagonal are 22.5° to 67.5°, 112.5° to 157.5°, 202.5° to 247.5° and 292.5° to 337.5°. The parallel is 67.5° to 112.5° and 247.5° to 292.5°.

The percentages of poles in the diagonal and parallel categories having raptor mortalities were 33.2% and 36.5%, respectively while the perpendicular crossarm was 16.8%. The difference was significant (Chi-square, $P > 0.001$).

An analysis of differences in the numbers of electrocutions on poles protected and unprotected from the wind was calculated using cross classified data analysis (the categories were non-protected and protected poles and high, medium and low topographic relief). A log-linear model with orthogonal contrasts was used to determine trends across topographic categories and differences between ratios of the cell frequencies at each pole position. There was no significant difference between the categories in the number of mortalities.

The data indicate there was no preference by raptors in use of powerpoles protected from the wind. There did seem, however, to be an effect due to prevailing winds on the ability of eagles to land safely on poles. The difference observed was due to the interference caused by the wires and insulators when landing on a crossarm. About twice the number of birds were killed on poles with crossarms diagonal and parallel to the prevailing winds as poles with crossarms perpendicular to the wind.

A bird landing on a pole usually drops below the pole on its approach, gains speed, then pulls up at the last moment settling on the crossarm. This allows the bird to stall-out at the level of the crossarm and land with its wings partially closed. When approaching a pole with a crossarm diagonal or parallel to the wind the landing bird has to cross the lines and/or insulators at the last moment before landing. A bird approaching diagonally has both the crossarm and wires interfering with its wings upon landing. Because the usual placement of insulators is on the end of a crossarm, birds approaching a pole with the crossarm parallel to the wind first encounters the insulator, which can be slippery and difficult to stand on, particularly when wet. A bird coming from this direction probably jumps or slips from the insulator to the crossarm or rises above the insulator and comes down upon the crossarm. Both of these moves could be potentially fatal.

The bird landing on a crossarm that is perpendicular to the wind usually has to cross the powerline before reaching the pole at a distance where contact is unlikely. Birds approaching this way have more control at the last critical moment of landing and are less likely to make contact with the conductors.

EAGLE BEHAVIOR

Intraspecific Interaction

Golden Eagles were observed hunting on numerous occasions. Along the Neiber Dome and Black Mountain lines eagles were observed in groups of up to six and it was not uncommon to see two or three birds together on the same or adjacent poles at all of the sites. As many as 20 immature and subadult eagles were known to use the area along the aforementioned lines during the winter of 1977-78. Agonistic behavior was observed on numerous occasions between young eagles. One pair of immature eagles was found electrocuted with the talons of each bird imbedded in the breast of the other. On four occasions pairs of freshly electrocuted immature eagles were found together under the same pole.

One group of six subadult and immature eagles was observed along a span of five poles over a wash on the Neiber Dome line, in an area of known cottontail abundance and activity. This behavior was noted during the winter of 1977-78 when rabbit numbers were at the highest level observed at any site. In the winter of 1978-79 the rabbit population in this area crashed after which very few eagles were observed.

Wilson (1975:202) in a discussion of 'monitoring' by animals states: "The presence of food and water, the intrusion of a territorial rival, and the appearance of a predator can all be read from the actions of neighbors". Thorpe (1963:134) speaks of 'local enhancement' as: "an apparent imitation resulting from directing the animal's attention to a particular object or particular part of the environment". Both intra- and interspecific monitoring have been observed and alluded to in studies of avian feeding behavior (Christman 1957, Short 1961, Parks and Bressler 1963, Haverschmidt 1970, Ward and Zahavi 1973).

Individual eagles observing other birds using the same food source as an indicator of prey availability, 'monitoring' or 'local enhancement', may be an explanation for the groups of birds noted in this study, as well as in others. S. Crowe (pers. comm.), in a U.S. Fish and Wildlife Service Golden Eagle translocation project in Texas, personally observed groups as large as 11 birds and had talked to ranchers that had seen groups of 18 and 25. These observations were made in areas of high prey abundance. Niemeyer (1976), in a translocation study in Montana, found large numbers of Golden Eagles also in areas of high prey density. Seventy-five percent of all the birds trapped in his study were immatures and subadults (N=69).

It is important for any species to adapt a foraging strategy that provides the greatest amount of energy gain with the least amount of energy expenditure, particularly when in a cold environment. Any behavior that will maximize this strategy would have a selective advantage.

Hunting Behavior

Daily Pattern. Camping along the powerlines afforded an opportunity to observe if birds were present on poles at dusk and the following dawn. Usually raptors did not roost overnight on poles (although this was known to happen) but were present at first light the following morning. This indicates that some prelight flight activity has occurred.

Most of the observed hunting occurred in the morning prior to and just after sunrise. Once the sun was above the horizon, eagles dispersed from the area. Because rabbits are nocturnal and crepuscular they can be most easily exploited during the pre-dawn and dusk hours when their activity is great (Ingles 1941, Lechleitner 1958). The presence of eagles along lines in the early morning, the hunting behavior observed at this time, their dispersal soon after dawn and the greater rabbit activity during this period appear to support this idea.

Along transects driven on consecutive days, individual Golden Eagles and other raptors were noted using poles. Based on identifying markings on the birds, it appeared the same individuals were using the same areas and often the same poles to hunt from on a daily basis. These birds also dispersed from these areas soon after sunrise. Wakeley (1978) found hunting Ferruginous Hawks had a tendency to return to the same or an adjacent site when successful in capturing prey.

Hunting Techniques. Golden Eagles were observed hunting from poles, and returning to a pole after a miss to make another attempt. One immature Golden Eagle was observed making over 20 of these hunting 'sorties', returning each time to the same pole or moving along the line to a new position. The distance flown on these sorties was estimated to be 100 m (328 ft.) or less. Orde and Harrell (1977) observed Red-tailed Hawks using this hunting technique, which they called the 'strike from perch' and 'strike from direct flight'. They found this hunting technique was the most successful when compared to the 'soar' and 'soar direct flight' hunting methods. Meinertzhagen (1940) and Lowe (1940) observed hunting techniques of raptors in North America, Europe and Africa. In these studies two hunting techniques were observed, 'on the wing search' and 'still' hunting. The 'still' technique was observed in a broad range of raptors including several species of the genus Aquila. The differential use of hunting techniques may account for the different kill rates and percent of kill poles in the various rabbit areas. The type of animal pursued and the terrain affects hunting behavior. Lowe (1940:332) indicated that "If the terrain is a flat plain the birds fly high to find their food..." Lowe observed Martial Eagles (Polemaetus bellicosus) and Verreaux's Eagles (Aquila verreauxi) hunting hyrax (Heterohyrax spp.), a small colonial mammal of Africa, from a perch in trees where they would "drop on an unsuspecting victim". He noted that this technique was a "common trait of other birds of prey". Meinertzhagen (1940) observed four separate flying attacks by Golden Eagles. In three of these instances, pairs of eagles were observed working together to secure their quarry. The species pursued were Chukar (Alectoris chukar), Blue Hare (Lepus timidis), Sand Grouse (Pterocles coronatus) and Ptarmigan (Lagopus mutus). The still technique was also observed by Meinertzhagen in several instances. Meinertzhagen (1940:532) remarked that buzzards, "have two separate techniques: the one 'still' and the other quartering the ground from a height and viewing their prey". He also observed other raptors using these methods.

Collopy (1973:29-30) observed of the two techniques used by the American Kestrel (Falco sparverius) "hunting from a perch was a more efficient means of capturing prey". Tarboton (1978:90) noted the hunting methods used by the Black-shouldered Kite (Elanus caeruleus) finding the hover-hunting technique, "resulted in 2.5 times more strike opportunities and had a 2.2 times higher strike success rate" than perch hunting. Hovering was calculated to be 6.9 times more expensive in energy cost per unit time. Perch-hunting was energetically more efficient than hovering and used almost three times as often. Wakeley (1978) found similar results with Ferruginous Hawks and although the capture rate was greater using an aerial hunting technique the cost/benefit ratio was better when hunting from a perch and this strategy was utilized more often.

The hunting techniques of adult and immature/subadult Golden Eagles varies. Meinertzhagen (1940:535) stated "It seems likely that Golden Eagles hunt in pairs and cooperate in tactics". This type of behavior has been observed in several species by other researchers: Peregrine Falcons (Falco peregrinus), (Cade 1960); Verreaux's Eagle, (Gargett 1971); Bald Eagles, (C. White pers. comm.); Golden Eagles, (M. Nelson pers.

comm., Carnie 1956). If pairs of adult eagles are hunting together experience and cooperation should result in (1) increased capture rate and (2) accessibility to a wider range of prey items. It is likely that the required food sharing is offset by an improved success rate. If cooperation improves the capture rate, then the birds involved could afford to use more energetically taxing hunting methods. It would be to the advantage of an inexperienced, unmated raptor to use an energetically efficient technique of hunting over one less efficient, if his capture rate was the same for both methods.

Hunting Cottontails. The cottontail, a relatively small rabbit (628.5-1250.0 g, 1.4-2.8 lbs.) (Chapman 1975, Chapman and Willner 1978), often uses burrows or rocky areas for cover (Dice 1926, Orr 1940). With a small home range (0.4-6.1 ha, 1-15 acres) (Ingles 1941), this animal is usually close to burrow openings or rock piles that provide protection from avian and mammalian predators. Because of this closeness to protection, the animal does not require an extremely fast escape speed. Grinnell and Storer (1924) estimate the top speed of the cottontail to be approximately 15 miles (24.1 km) per hour.

A large raptor exploiting cottontails should require a more energetically efficient hunting technique to compensate for the relatively small amount of energy acquired in the consumption of this animal. This would be particularly important in the winter when low temperatures cause a greater expenditure of energy due to increased metabolic rates (Hayes and Gessaman 1980). If both techniques are equally successful, hunting from poles in cottontail areas is energetically more advantageous to an eagle than a stoop from high altitude that requires a large energy expenditure in extensive flight time. Wakeley (1978) found Ferruginous Hawks expended energy at about 12.5 times the Standard Metabolic Rate (S.M.R.) (Gessaman 1973) when in "low active flight" and about three to four times the S.M.R. when 'sit and wait' hunting. Wakeley estimated hunting from a soar required an intermediate amount of energy, approximately eight times that of S.M.R.

A prey species with a slow escape speed, such as a cottontail, needs an alternative means of avoiding predation. Having a small home range, the cottontail returns to the protection of its burrow when danger threatens. For a raptor to successfully hunt cottontails, it must make a quick attack before the rabbit reaches safety. If hunting is done from a long distance, the rabbit has a greater escape period and thus more opportunity to avoid capture. In making a short, quick attack, it is advantageous for the raptor to choose a perch close to the burrow of the prey rather than one having more height but at a greater distance. The energetic advantages and the increased success rate of the 'still' hunting technique make this method particularly suitable for catching cottontails.

The greater topographic relief at cottontail sites makes height even less significant for hunting raptors because of the limited viewing range caused by hills in the area. The use of burrows and warrens by cottontails makes the 'still' hunting strategy potentially wasteful energetically for the raptor especially if the bird misses on the first attack and the rabbit reaches safety, remaining there until the danger has passed. If this is true, moving to a new hunting site would be more advantageous for the raptor. Thus, multi-perch hunting behavior would result in greater numbers of poles causing mortalities due to the increased exposure to hazardous conditions. The larger numbers of poles with electrocutions that were observed in cottontail areas is probably due to the multi-perch hunting technique, and interaction between rabbit behavior and the topographic relief of the area.

<u>Hunting Jackrabbits</u>. Jackrabbits can attain speeds in excess of 56.3 km/h (35 mi./h) (Vorhies and Taylor 1933, Lechleitner 1958) and use above ground forms for cover and protection (West et al. 1961). They must rely on fleetness to avoid predators. This escape technique is especially suitable for a fast wide ranging animal that inhabits areas of relatively flat terrain.

Hunting from the air or from a high vantage point will allow the raptor to gain greater speed and view a larger area. This height advantage is helpful in hunting relatively wide ranging animals. In jackrabbit areas where topographic relief is variable it might be expected that poles on high sites receive greater raptor use. However, in most areas in this study, the topography was such that relief seemed to have very little importance in hunting. The wide ranging habits of the jackrabbit and its fast escape speed make it difficult to hunt from a low perch with the 'still' technique. If a raptor was unsuccessful using the 'still' hunting method in a jackrabbit area it would be advantageous to change pursuit tactics and hunt on the wing. The higher expenditure of energy in hunting jackrabbits from the air would be at least partially compensated for in the energy gained from consumption of this relatively large animal (1.4-4.6 kg, 3-10 lbs) (Burt and Grossenheider 1964). If this is the case, fewer poles ,with electrocutions occurring on them would be an indication of less use. The smaller numbers of electrocutions found in jackrabbit areas and the fewer multiple kill poles present seems to indicate that aerial hunting is the principle tactic used in these areas.

<u>Bioenergetics of Hunting and Electrocution</u>. Lasiewski and Dawson (1967) indicated that a 3 kg (6.6 lbs.) Golden Eagle uses 102 kcal/day or 34 kcal/kg. If the 34 kcal/kg/day value is used as the S.M.R. for Golden Eagles, then an eagle of average size, 4.1 kg (9 lbs.) requires 139 kcal/day at existance level.

From the weight values used previously for cottontails and jackrabbits, mean size values are 939.3 g (2.1 lbs.) and 3000.0 g (6.6 lbs.), respectively. Fox (1977) indicated 66.7% of a rabbit was usable as food by the falcons he studied. If this value is used for determining available food, the adjusted weight values of the rabbits are 626.5 g (1.4 lbs.) and 2001.0 g (4.4 lbs.). Dobbs et al. (1980) indicate Black-tailed Jackrabbit muscle contains 1.15 kcal/g. Although no values for Nuttall's or Desert Cottontails were available, Fox (1977) indicated that 151 g (.33 lbs.) of European Rabbit (<u>Oryctolagus cunicularis</u>) muscle equals 100 g (.22 lbs.) of whole House

Mouse (Mus musculus). Using the data of Dobbs et al. (1980) for whole mouse to calculate the caloric content of cottontail muscle the value of 1.11 kcal/g was derived. Because the values of cottontails and jackrabbits are very close, the known value for the jackrabbit was used in calculating caloric content for both animals. Researchers at the Snake River Birds of Prey Natural Area recorded cottontails and jackrabbits as having the same caloric values (U.S. Department of Interior 1979). The caloric values for the adjusted weights of the rabbits when calculated are thus 720.5 kcal, cottontail and 2301.2 kcal, jackrabbit.

Using the values Wakeley (1978) determined for Ferruginous Hawks, the amount of energy expended by the 'sit and wait' and flying hunting techniques for eagles were calculated. The value 3.5 times S.M.R. for 'sit and wait' hunting results in an expenditure of 486.5 kcals of energy while a value intermediate to the soaring and 'low active flight', 10.25 times S.M.R. resulted in 1424.8 kcal expended by the hunting eagle. When the energy expended is subtracted from the available energy, 246.5 kcal and 876.4 kcal result as excess energy from the carcass of a cottontail and jackrabbit, respectively.

Both of the rabbit species meet the energy needs of an eagle. Initially it might seem that catching jackrabbits would be the most advantageous strategy for young eagles. This, however, may not be the case since: (1) the energy expended during 'on the wing' hunting is 2.9 times that of the 'sit and wait' technique, and if an eagle failed to kill an animal while hunting 'on the wing' the energy deficit would rapidly increase, (2) the slower cottontail is probably more easily caught by the inexperienced juvenile eagle, and (3) the gregarious nature of cottontails and their smaller home range make it probable that another rabbit will be readily found by an eagle, if it missed on the first attempted capture.

The above relates directly to the problem of electrocution and is particularly applicable to young eagles that make up the bulk of killed birds. While only requiring one rabbit a day to meet its energetic requirement, the young eagle is most likely to employ the "sit and wait" hunting technique. Although the advantages are greatest for the eagle in terms of an energy budget, the method exposes the eagle to a much greater risk of electrocution by the amount of time spent on poles and by frequency of moving from pole to pole after a hunting foray. As the frequency of movement about on a pole or movement to poles increases, the vulnerability to electrocution increases. Such a scenario seems to explain the higher numbers of young eagles killed and the distribution of kills relative to cottontail rabbit abundance and distribution.