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ELECTROCUTION OF RAPTORS ON POWER LINES IN SOUTHWESTERN SPAIN

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Abstract.—Results of a survey of raptor electrocutions in and around Doñana National Park since 1982 are reported. In 1982–1983 1127 pylons along a sample of 100 km of power lines were monitored and 233 dead individuals of 13 species of birds of prey were found. Allowing for loss to scavengers, it is estimated that about 400 raptors/yr die along this section of electric power system, and perhaps 1200/yr on the 300 km of power lines within and around Doñana National Park. Mortality differed significantly among pylons of different designs and among habitats. The most dangerous pylons possessed exposed insulators above a crossbeam whereas the least dangerous have suspended insulators. Mortality was greater in natural areas within the park than in surrounding human-altered habitats. Electrocution was the cause of death of more than 50% of banded raptors recovered before the study began and the primary known cause of death for the endangered Spanish Imperial Eagle *Aquila adalberti.*

ELECTROCUCIÓN DE RAPACES EN TENDIDOS ELÉCTRICOS DEL SUROESTE DE ESPAÑA

Sinopsis.—Se presentan los resultados del seguimiento de la mortalidad causada por electrocución en el área del Parque Nacional de Doñana desde 1982. En el período 1982–1983 se monitorearon 1127 postes eléctricos a lo largo de una muestra de 100 km de tendidos encontrándose 233 rapaces muertas pertenecientes a 13 especies. Según los resultados de los experimentos de desaparición de cadaveres por carroñeros, estimamos en más de 400 las rapaces muertas/año en estas líneas y en más de 1200/año en el total de 300 km de líneas eléctricas situadas dentro y en los alrededores del Parque. La mortalidad varía significativamente según el diseño del poste y el habitat. Los postes eléctricos más perjudiciales son los que tienen los aisladores por encima del travesaño. El mayor número de muertes se registró en zonas poco alteradas. La electrocución fue la causa de muerte de más del 50% de las rapaces anilladas que se recuperaron en esta área antes de comenzar el estudio, y la primera causa de muerte conocida de la amenazada Águila Imperial, *Aquila adalberti.*

Electric power lines pose a grave danger to raptor populations (Benson 1980, 1982; Haas 1980; Ledger and Annegan 1981; Olendorff 1981; Van Daele 1980). In Doñana National Park, numerous raptor species, including the endangered Spanish Imperial Eagle *Aquila adalberti,* have been electrocuted on power lines which surround and in some cases pass through the park. However, little quantitative information has been available.

The high density of raptors in the park and the profusion of different pylon designs (Haas 1980), offered an opportunity to measure the danger these power lines pose to the raptor populations in the Doñana area. Thus, in July 1982, we began a survey of the power lines, which measured the extent of mortality and the effects of pylon design and habitat on the number of raptors electrocuted. We also estimate the impact of electrocution on raptor population in the Doñana National Park, and present conclusions which would enable effective protective measures to be taken in the Park or in any other area similarly affected.

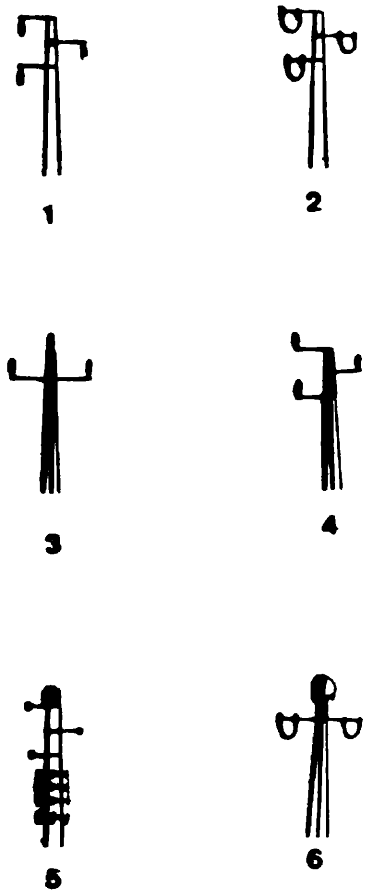

FIGURE 1. Schematic representation of the six pylon designs distinguished in this study. 1) Three crossbeams and suspended insulators. 2) Pylon with three anchoring insulators. 3) Two crossbeams with rigid (pin-type) insulators. 4) Three crossbeams and rigid (pin-type) insulators. 5) Transformer post. 6) Two anchoring insulators and a rigid (pin-type) central one.

METHODS

We chose a sample of 100 km of medium tension power lines (16 kv distribution) with 1127 8–12-m tall metal pylons. We distinguish six different pylon designs based on the location of the insulators and the number of crossbeams (Fig. 1). The power lines studied crossed five distinct habitat types: oak woods, marsh, rice fields, other cultivated fields and roadsides. All six pylon designs were represented in each of the five habitats. From July 1982 through September 1983 most sections of the surveyed power lines were monitored every 2 mo. Some sections with high rates of mortality, however, were censused every month. Since 1983 the lines have been censused twice per year.

Inspections were made on foot. All carcasses and remains were collected at each census to avoid the possibility of double recording. All birds that were found under a pylon and which showed evidence of burns on the primaries, talons or beak, were considered electrocuted. Birds found between pylons were considered to have died from a collision with the wires.

All birds collected in July 1982 were not considered part of the annual study. When remains of birds were found, an attempt was made to determine the minimum number of birds that these remains represented so as not to overestimate mortality.

Age classes were determined by plumage when possible, or according to cranial ossification if the plumage had extensively deteriorated. Sex was very often impossible to determine due to the decomposition of the individual.

Corpses may be carried away by predators and scavengers; consequently a count of carcasses provides only a minimum estimate of annual raptor mortality. To determine the rate at which carcasses were removed by scavengers, we conducted an experiment with the corpses of 25 domestic rabbits (*Oryctolagus cuniculus*) with a mean body mass of 858.6 g. We deposited the rabbits beneath randomly selected pylons in each of the habitats studied and checked the carcasses every 24 h for 60 d, noting when each disappeared. From these data we calculated a logarithmic loss function to estimate how many birds we missed in our monthly and bimonthly censuses. In addition, we left 40 electrocuted birds beneath the pylons at which they were discovered and recorded the proportion remaining at the next census.

We analyzed the effects of pylon design and habitat on the number of electrocuted raptors encountered during the 1982–1983 census year with a two-way analysis of variance without replication. Each combination of pylon design and habitat was represented by the ratio of the total number of raptor carcasses encountered beneath a given pylon type in a given habitat to the total number of pylons of that design monitored in that habitat. A logarithmic transformation greatly improved normality and homogeneity of variances.

RESULTS AND DISCUSSION

Censuses of power lines.—We found 233 electrocuted birds of prey; 142 of these died during the 1982–1983 censuses (Table 1). Ten species of diurnal raptors comprised 93.6% of the individuals encountered in the 1982–1983 censuses. The remaining individuals belonged to three species of owls. Since 1983 we have found two more species: four Bonelli's Eagles (*Hieraaetus fasciatus*), and one Egyptian Vulture (*Neophron percnopterus*), all found in 1986. Deaths from collision with the wires represented only 2.8% of the total mortality; the major cause of mortality along the power lines was electrocution at the pylon. These proportions agree with reports by other authors (Olendorff 1986). Raptors represented only 18.2% of

TABLE 1. Number of raptors found electrocuted along a 100-km section of power line between July 1982 and July 1983.

Species	Number electrocuted		
	Initial count*	During study	Total
Gyps fulvus	9	5	14
Aquila adalberti	2	1	3
Circaetus gallicus	7	1	8
Hieraaetus pennatus	5	4	9
Milvus milvus	3	12	15
Milvus migrans	16	66	82
Buteo buteo	5	30	35
Accipiter gentilis	0	1	1
Falco tinnunculus	1	9	10
Falco peregrinus	0	1	1
Milvus spp.	33	3	36
Falconiforme spp.	7	0	7
Strix aluco	1	2	3
Tyto alba	2	5	7
Athene noctua	0	2	2
Total	91	142	233

* Carcasses present during first census, date of death unknown.

the carcasses collected under the power lines; the total number of dead birds encountered in the 1982–1983 censuses was 778.

Disappearance of corpses.—The disappearance of the rabbit carcasses was a logarithmic function of time (t = days):

$$y = 0.88 - 0.213 \ln t, \qquad n = 25, \qquad r = -0.94$$

Assuming that the probability of death remains constant through the period between two inspections we let:

$$N = \frac{1 + \sum 0.88 - 0.213 \ln t}{t} \times 100,$$

where N is the percentage of the total number of raptors that died between two inspections that were still present at the second inspection; i.e., the percent of carcasses not removed by scavenger. In our case, N = 37% for the 1-mo census intervals and 22% for the 2-mo intervals. Assuming scavenger activity is constant over time and raptor carcasses are found as often as rabbit carcasses, the loss rate of raptor corpses would have averaged about 70% between censuses during the 1982–1983 study.

The disappearance of the 40 monitored bird carcasses supports the validity of this model. The model predicted that we would find 14 of the original birds. In reality we found 15, a value that is indistinguishable from the predicted ($\chi^2 = 0.054$, df = 1, $P > 0.75$).

The loss rate of all the remains of a bird was influenced by carcass size. This is demonstrated by comparing the percentage of large birds found during the preliminary "cleaning inspection" to the percentage found during subsequent censuses. In the first cleaning census the proportion of total raptors greater than 1200 g was 10.7%, whereas during the 1982–1983 study these larger birds made only 4.0% of the total.

Including estimated losses to scavengers, we estimate that more than 400 raptors were electrocuted per year along the 100-km stretch of power lines. Black Kite (*Milvus migrans*) alone is estimated to have suffered about 200 deaths. The more than 300 km of power lines, with the same pylon designs, present in and along the bordering areas of the Doñana National Park, may electrocute more than 1200 birds of prey annually.

Effects of pylon design and habitat on mortality.—Both pylon design and habitat had highly significant effects on raptor mortality (pylons: $F = 11.75$, df $= 4$, $P < 0.001$; habitat: $F = 8.08$, df $= 5$, $P < 0.001$), explaining 82% of the variance in death rates (Sum of squares: two factors = 51.67, error = 11.34; Sokal and Rohlf 1979). A great difference in the number of dead birds existed among pylon types. Mortality on the most dangerous pylons (0.652 raptors per pylon, backtransformed mean) was 24.1 times greater than mortality on the least dangerous pylons (0.027 raptors per pylon). The greatest numbers of deaths were found on those pylons which possess two anchoring insula tors and a rigid central one located above the crossbeam with the wire passing through it (number 6, Fig. 1). The safest pylons were those possessing three crossbeams and suspended insulators (number 1, Fig. 1). A post-hoc comparison (Wilkinson 1986) demonstrated that the two pylon designs with suspended insulators (numbers 1 and 2, Fig. 1) as a group caused significantly less mortality than the four designs with erect insulators as a group ($F = 47.54$, df $= 1$, $P < 0.001$).

Although all pylons with erect insulators are dangerous to raptors, they are not equally deadly. Among pylons with erect insulators, design six (Fig. 1), with an exposed loop of wire above the insulator, killed significantly more raptors per pylon than the other three as a group (post-hoc comparison, $F = 9.01$, df $= 1$, $P < 0.005$). In general, any design that encourages raptors to perch near the wires is dangerous.

Other authors have noted that pylon design can affect raptor mortality rates. Haas (1980) warned that the greatest frequency of deaths was on metal pylons with rigid insulators, though he did not evaluate differences among designs. Olendorff (1981) pointed out the danger of wooden power posts that have the power cable running very near the ground wire. More similar to our final result, Benson (1982) found significant differences among varying pylon designs that used rigid insulators. No study, however, has found such large differences among designs as we found in this study. The use of metal in constructing power pylons of all sizes in Spain means that electrocution occurs not only through contact between cables, but also when a bird merely touches one wire and the post. Our work has demonstrated that on metal pylons the position of insulators is an extremely critical factor affecting raptor mortality rates.

Whereas differences in mortality among pylon types can be directly

TABLE 2. The total number of electrocuted raptors (1982–1983) found beneath a given pylon design in a given habitat, divided by the number of pylons of that design studied in that habitat. Means were calculated with log-transformed values, then backtransformed for presentation.

Habitats	Pylon design (see Fig. 1) 1	2	3	4	5	6	Back-trans-formed means
Roadsides	0.009	0.002	0.037	0.053	0.166	0.400	0.036
Rice fields	0.017	0.070	0.183	0.153	0.133	0.200	0.098
Marsh	0.039	0.166	0.102	0.182	0.500	0.500	0.176
Cultivated fields	0.038	0.100	0.330	0.370	0.100	0.980	0.250
Oak woods	0.063	0.121	0.585	0.612	0.153	3.000	0.328
Backtransformed means	0.027	0.049	0.168	0.202	0.246	0.652	

related to design of the pylon, the ultimate causes of differences in mortality among habitats are uncertain. With the present data we cannot distinguish among differences such as density of raptors, availability of alternative perching sites and distribution of prey. Nonetheless, it is clear that electrocution causes substantially more mortality in the park than in the extensively human-altered habitats bordering it (Table 2). The post-hoc contrast between the park habitats, woodland and marsh, as a group, and the four human-altered habitats as a group, revealed a highly significant difference ($F = 10.64$, df $= 1$, $P < 0.005$). The use of "safe" pylons may be especially important when power lines must cross natural habitats.

Impact on the populations.—Determining with any degree of accuracy the effect of electrocution deaths on the Doñana raptor populations is very difficult because for most raptor species, data on population dynamics and status are sparse. Nevertheless, the data that exist strongly suggest a significant impact.

Between 1974 and 1982, before we began this study, 52.23% of all raptor ring-recoveries ($n = 62$) in the Doñana area and the surroundings were from electrocuted birds, suggesting that electrocution could be an important source of mortality.

Other data also suggest that electrocution is having a serious impact on raptor populations. Table 3 shows the estimated number of breeding pairs of some representative raptor species nesting in Doñana National Park, and the number of adult birds electrocuted that we found during the 1982–1983 breeding season within Doñana, only in our sample of 100 km and without considering the effect of scavengers. For some species, a significant number of pairs are losing a member during this critical period. Losses during the remainder of the year (Table 1) make the situation even more serious.

The case of the Spanish Imperial Eagle is especially disturbing because it is considered a species in danger of extinction (Collar and Andrew

TABLE 3. Estimates of the reproductive populations of some diurnal raptor species in Doñana National Park, and number of adults of these species found electrocuted in Doñana during 1982–1983 breeding season, only in the 100 km of power lines monitored.

Species	No. of breeding pairs	No. of adults electrocuted during the breeding season
Aquila adalberti	15	1
Circaetus gallicus	10	1
Hieraaetus pennatus	60	3
Buteo buteo	25	5
Milvus milvus	60	3
Milvus migrans	300	36
Falco tinnunculus	50	2

1988, Mountfort and Arlott 1988). In Doñana, 69.2% of all known eagle deaths are attributable to electrocution. Since 1974, at least 30 individuals have died on power lines. Considering that only 15 pairs of the Spanish Imperial Eagle exist in Doñana, the impact is especially severe. It is possible that cases of a 1-yr delay in the replacement of a missing member of a pair and, on many occasions, the formation of a pair with a juvenile member (Ferrer and Calderón 1990), are the first symptoms of a notable decline in the population. Since 1986, deaths of 8 of 19 radio-tagged immatures in Doñana have been caused by electrocution (Ferrer unpubl. data).

Considering the distribution of deaths by age classes within a species reveals two patterns: (1) a majority of the electrocuted individuals were adults of summering raptor species (70% of all found), while (2) a minority were adults of non-migratory species (30%). The winter increase of immature population of some non-migratory species in Doñana could explain this pattern. As an example, Figure 2 shows variation through the year in the proportion of immature and adult deaths in one summering species (Black Kite) compared with those of a non-migratory species (Common Buzzard, *Buteo buteo*).

Protective measures.—The measures that must be adopted to alleviate the electrocution problem should be started even before the construction of the power lines. We have demonstrated that both the selection of pylon design and of habitat crossed can ameliorate the impact of power lines on raptor populations. We recommend that : (1) only power pylons with suspended insulators be considered, (2) pylons with an exposed loop of wire above the insulator should never be used, and (3) more power lines should be routed along roadsides, a habitat with low raptor mortality. In the case of areas such as Doñana, where power lines already exist, we recommend that all exposed rigid insulators be replaced by suspended ones, that certain unnecessary stretches of power lines be disconnected

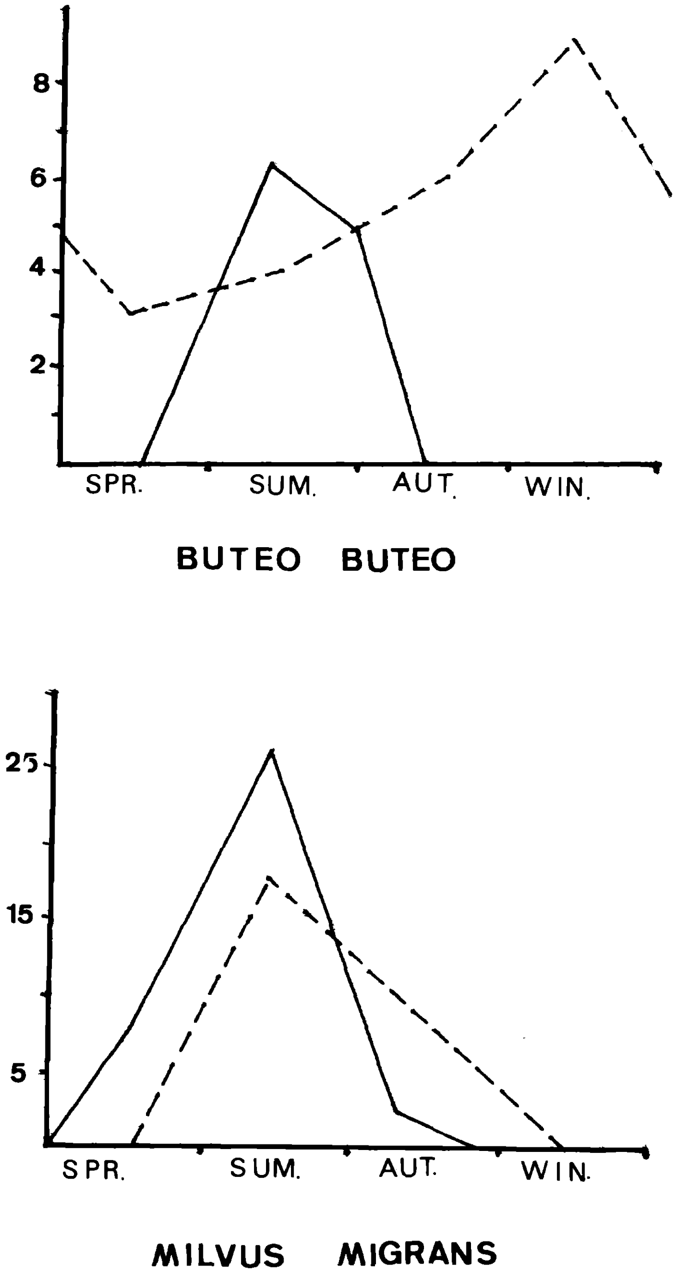

FIGURE 2. Annual variation in electrocutions of immatures (broken line) and adults (continuous line) of two species of raptors in (Doñana, a summering species (Black Kite, *Milvus migrans*) and a resident species that has a winter population increase (Common Buzzard, *Buteo buteo*).

and that protective systems be installed on the pylons themselves to prevent birds from coming into contact with wires.

Many protective systems have been developed (Ansell and Smith 1980, Hass 1980, Negro et al. 1989, Olendorff 1981, Regidor et al. 1988). For the metal pylons and posts used in Spain we suggest that which insulates a small portion of the wires (1.20 m on each side of an insulator). Alternative perching sites, such as those designed and placed by ICONA (Institute for Nature Conservation), do not appear to be effective on metal pylons. There is no evidence that they have decreased the number of electrocutions in Doñana (Ferrer et al. 1986, Negro et al. 1989); since the use of these perches began in 1986, six Spanish Imperial Eagles have died on pylons supposedly protected with this system.

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QUAIL UNLIMITED OFFERS NEW FIELD POSITIONS

Augusta, Georgia—Continued growth in Quail Unlimited's fundraising and habitat programs nationwide has created two new Quail Unlimited field staff positions.

"We are accepting applications for regional director positions in North Carolina and Texas," said Rocky Evans, Quail Unlimited Executive Vice-President. "Highly motivated individuals with proven wildlife management credentials and experience in working with the public will receive the highest consideration," Evans explained. The successful candidates will be responsible for developing chapter fundraising activities and coordinating habitat programs with chapter volunteers, private landowners and state wildlife officials throughout their respective regions.

"Texas and North Carolina are key quail states that offer tremendous challenge and career opportunity to the right individuals," Evans stated. Evans went on to say that the ten-year-old organization plans to fill the regional director positions within the next 60 days. Resumes can be forwarded to The Director of Chapter Development, Quail Unlimited National Headquarters, P. O. Box 10041, Augusta, Georgia 30903.

Quail Unlimited is a private, non-profit conservation organization dedicated to the perpetuation of wild quail, their habitat and America's hunting heritage.