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Biological and conservation aspects of bird mortality caused by electricity power lines: a review

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Abstract

Empirical data and theoretical considerations indicate that species with high wing loading and low aspect run a high risk of colliding with power lines. These birds are characterised by rapid flight, and the combination of heavy body and small wings restricts swift reactions to unexpected obstacles. When the number of reported collision victims is considered relative to the abundance and population size of the species concerned, some Galliformes, Gruiformes, Pelecaniformes and Ciconiiformes species seem to appear in disproportionately high numbers. In contrast, species frequently affected by electrocution particularly seems to involve Ciconiiformes, Falconiformes, Strigiformes and Passeriformes. An alarmingly large number of species with endangered and vulnerable status are identified among the victims, but there are insufficient data at present for judging the significance of mortality caused by power lines at the population level.

Keywords: Bird; Electrocution; Endangered species; Collision; Power line

1. Introduction

Steadily increasing environmental stress has made mortality factors important that were once considered insignificant. Healthy populations can normally compensate for additional mortality deriving from unusual causes but may be seriously affected when these act on a reduced population. Ecologists (e.g. Temple, 1986) have emphasised that the circumstances that ultimately cause a species to perish may be entirely unlike the incidents that first caused the population to become endangered. The annual death of birds world-wide through electrocution and collision with power lines and other types of overhead wires (Braaksma, 1966; Renssen et al., 1975; Gylstorff, 1979; Hoerschelman et al., 1988; Bevanger, 1994a, 1995a) is an example of a poorly understood mortality, although it was observed and commented on for more than one hundred years (Coues, 1876; Emerson, 1904). Reports mainly derive from South Africa, North America and Europe, where they were highlighted because of the economic impact of interruptions in energy supply, and the scientific and conservation concern for endangered, vulnerable and harvestable species (Brown and Lawson, 1989; Bevanger, 1994a,b, 1995a,b; Negro and Ferrer, 1995). Information from the rest of Africa, South America, Asia and Australia is scarce (for a literature review, see Avery et al., 1980; Herbert and Reese, 1995). As a majority of power lines are located in remote areas far away from public awareness of the bird collision or electrocution problems, reported losses must be considered a superficial measure of its occurrence (Thompson, 1978; Longridge, 1986; Faanes, 1987).

Much is known about how topographical, meteorological and technical factors can alter collision or electrocution hazards for birds (Bevanger, 1994a; Alonso et al., 1994; Brown and Drewien, 1995; APLIC, 1996). Less attention was paid to the biological and ecological characteristics of the victims, i.e. behaviour, physiology and morphology. No investigations seem to have been designed to test the influence of, for instance, biomechanics on collisions. A main question addressed in the present paper is whether existing data can reveal qualities of morphology and biomechanics that predict a species' susceptibility to collisions with power lines or electrocution accidents. The implications of this mortality for conservation are discussed in the light of principles of population dynamics.

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2. Predicting bird collisions with power lines

The causes of birds colliding with power lines is a complex problem (Bevanger, 1994a,b). Statistical testing of pooled data is inappropriate because the records are biased by several factors: the geographical location of the research, the abundance of the species, their behavioural patterns (e.g. the time different species spend in the air) and their nocturnal and/or crepuscular habits. It is, for instance, impractical to obtain relative figures, i.e. the number of collisions compared to the number of birds crossing overhead wires, for rare species or species with a ground-dwelling life style. Resident and migratory species have frequently been pooled and treated together. Investigations addressing this type of information (e.g. Meyer, 1978; James and Haak, 1979; Willdan Associates, 1982; Faanes, 1987; Hartman et al., 1992) have partly been designed as 'worst case studies' connected with key functional areas for birds and major flyways of migratory species.

Rayner (1988) applied principal component analysis to wing morphology and derived statistically independent measures of size and wing proportions. Of particular interest were the 'loading' and 'aspect' components, and a scatterplot of these for flying birds is informative (Fig. 1). The major bird groups fall into six main categories, determined by differences in aerodynamic performance: 'poor' flyers, water birds, diving birds, marine soarers, aerial predators and thermal soarers.

As Rayner (1988) emphasised, the species in the lower right-hand quadrant (the 'poor' flyers) are interesting as they have probably never experienced strong pressure to enhance their flight efficiency. Most of them belong to Gruiformes, Galliformes and Tinamiformes. It is interesting to relate Rayner's categories to the data derived from the literature on 'collision species' (Table 1).

Indeed, rails, coots and cranes are among the species most commonly and numerously recorded as collision victims in America and Europe (e.g. McKenna and Allard, 1976; Heijnis, 1980; Zerda and Rosselli, 1997). Moreover, 14 species of the Gruidae and Rallidae families world-wide were classified as endangered (Temple, 1986). Most of the 15 crane species are known to have dwindling populations with endangered status (Bylin, 1983) mainly as a result of destruction of wetland habitats.

Several gallinaceous species were known to suffer losses because of flying into overhead wires (Leopold, 1931; Borell, 1939; Paludan, 1963; Krapu, 1974; Rose and Baillie, 1992). Recent research in Norway has revealed that tetraonids are particularly exposed to collision hazards (Bevanger, 1988, 1995a,b), which is all the more striking considering their ground-dwelling behaviour.

The 47 species of Tinamiformes are endemic to the Neotropical Region (del Hoyo et al., 1992). Most of them look like gallinaceous birds, although their morphology reflects convergent evolution. Unfortunately, almost no research addressing the problem of bird collisions with power lines was carried out in Latin America, but these birds are known to 'fly into obstacles—branches, posts, wires and even houses' (del Hoyo et al., 1992, p. 113). If the theoretical considerations about high collision probability for the 'poor' flyer group are correct, Tinamiformes species should be particularly vulnerable to colliding with power lines. Several Tinamiformes species are ranked as vulnerable and endangered (del Hoyo et al., 1992).

'Water birds' and 'diving birds' (Fig. 1) also have high wing loading, and many species of Anseriformes are recorded as frequent collision victims (Table 1). The Charadriformes vary somewhat. Species belonging to the Scolopacidae family are found as collision victims in nearly every investigation related to birds and power lines. This is not surprising considering that most of the species are Neotropical and Palaeotropical migrants crossing vast distances—and many power lines—in huge numbers. The snipe *Gallinago gallinago*, however, figures in the high wing loading group and accounts for 21% ($n=602$) among the 2833 Scolopacidae victims recorded (Table 1).

In the 'low loading' group, gulls are frequent collision victims, and are therefore an exception to the prediction based on wing morphology (Table 1). Studies in Washington and Oregon (Meyer, 1978; James and Haak, 1979; Beaulaurier, 1981) showed a significantly higher probability that Anatidae species would collide than Laridae species, ducks being 50–100 times more likely to collide than gulls. However, Laridae species spend much of their time in the air and are numerous; moreover, the investigations incorporated in Tables 1 and 2 mainly derive from wetland and coastal habitats where they are particularly common. It has also been suggested that birds such as gulls, with high aspect ratio and low loading, are susceptible to being blown into wires in strong winds, and also that birds in flocks, like gulls, may be in greater danger of colliding, particularly those that are far behind, as their view is obstructed by the birds in front (Scott et al., 1972; Renssen et al., 1975; Henderson et al., 1996).

As Rayner (1988) emphasised, there are significant variations within some groups (e.g. Anatidae) regarding wing load and aspect ratio, underlining the importance of making accurate analyses among species in the same family to predict the species-specific collision hazard. Moreover, reaction studies (James and Haak, 1979) have revealed significant variations in the reaction of ducks when approaching a power line, indicating differences in perceptional and reactional abilities as well as behaviour (e.g. descending or elevating flight course,

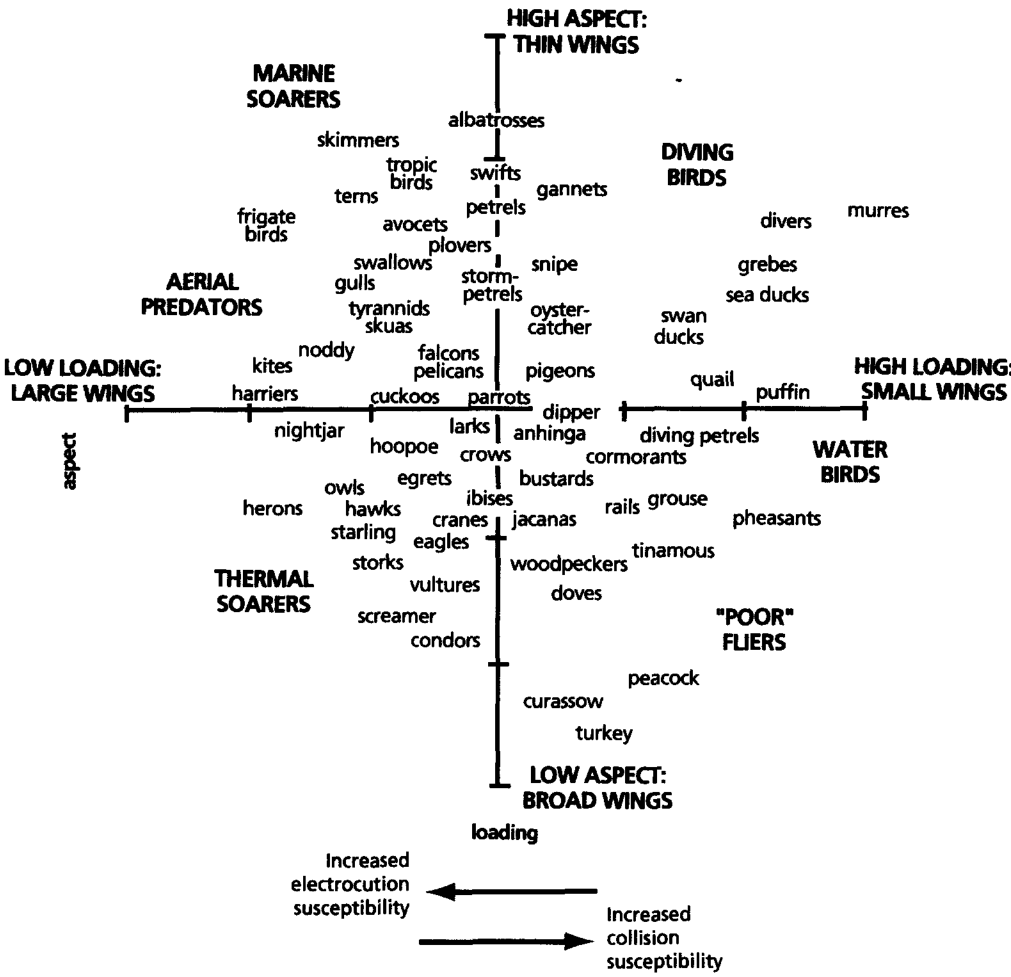

Fig. 1. Major bird groups arranged according to wing morphology expressed in principal-components form where statistically independent measures of size and wing proportions are derived. The figure is based on a scatterplot of the size-independent components of flying birds (after Rayner, 1988).

or flight interruption when attempting to cross the wires).

Aerial hunters like the European swift *Apus apus* and several raptor species possess excellent flying abilities (and binocular vision). However, they spend a major part of their life in the air and the probability of crossing power lines (and colliding) is higher compared to ground-dwelling species, which may explain why aerial predators are regularly recorded as collision victims, although in seemingly small numbers (Bevanger and Overskaug, in press).

It is difficult to predict the danger to 'thermal soarers' (Fig. 1), i.e. birds with large and broad wings and a decreased wing loading. Some species seem to be susceptible both to electrocution and collision. Herons and several other Ciconiiformes species and Gruiformes and Pelecaniformes species, suffer an alarmingly high mortality from power lines, but available data do not allow clear distinctions to be made between electrocution and collision accidents. However, electrocution accidents seem to be increasingly important among these groups, apparently being dependent on body size, hunting, perching or roosting behaviour.

Empirical evidence is amassing that species with high wing loading and low aspect, i.e. the 'poor' flyers, deserve to be classified in a high risk group as regards collisions with power lines. The 'poor' flyers are characterised by rapid flight, and the combination of heavy body and small wings obviously restricts swift reactions to unexpected obstacles.

An interrelationship between biomechanical factors and vision should certainly be considered. Unfortunately, there is a lack of detailed information about the sensory capacities of birds, although research into bird vision has revealed a great variety of adaptations among various groups (Sillman, 1973; Martin, 1985; Schmidt-Morand, 1992).

3. Characteristics of bird electrocution

Electrocution of birds is a simpler problem than collision. It may take place when a bird touches two phase conductors or one conductor and an earthed device simultaneously, especially when the feathers are wet.

Table 1
Birds recorded as victims of collisions with power lines in 16 investigations

Order	Family	Genera	Species	Individuals
Gaviformes	Gavidae (divers)	1	2	3
Podicipediformes	Podicipedidae (grebes)	4	7	303
Procellariiformes	Procellaridiidae (fulmars, petrels, shearwaters)	1	1	4
Pelecaniformes	Pelecanidae (pelicans)	1	2	4
	Sulidae (boobies, gannets)	1	1	1
	Phalacrocoracidae (cormorants, shags)	1	2	62
Ciconiiformes	Ardeidae (bitterns, herons)	4	6	79
	Ciconiidae (storks)	1	1	5
	Threskiornithidae (ibises, spoonbills)	2	3	13
	Phoenicopteridae (flamingoes)	1	1	8
Anseriformes	Anatidae (wildfowl)	14	37	2983
Falconiformes	Accipitridae (hawks, vultures, eagles)	3	4	7
	Falconidae (falcons and allies)	1	4	7
Galliformes	Phasianidae (partridges, quails, pheasants and allies)	7	9	321
Gruiformes	Rallidae/Gruidae (rails, coots, cranes)	6	9	1653
Charadriformes	Haematopodidae (oystercatchers)	1	1	54
	Recurvirostridae (stilts, avocets)	2	3	12
	Burhinidae (stone-curlews, stone-plovers)	1	1	1
	Charadriidae (plovers, lapwings)	3	7	520
	Scolopacidae (snipes, sandpipers and allies)	19	48	2833
	Laridae (gulls)	5	16	1447
Apodiformes	Apodidae (swifts)	1	1	6
Columbiformes	Columbidae (pigeons)	3	7	374
Cuculiformes	Cuculidae (cuckoos)	1	1	2
Strigiformes	Tytonidae (barn owls and allies)	1	1	1
	Strigidae (typical owls)	2	3	4
Passeriformes	Tyrannidae (tyrant flycatchers)	2	2	6
	Alaudidae (larks)	1	1	68
	Hirundinidae (swallows)	1	1	9
	Motacillidae (pipits, wagtails)	2	3	34
	Troglodytidae (wrens)	2	3	3
	Turdidae (chats, thrushes)	6	12	420
	Sylviidae (warblers and allies)	5	12	117
	Muscicapidae (flycatchers)	1	2	3
	Emberizidae (buntings and allies)	7	11	86
	Parulidae (wood-warblers)	3	4	7
	Icteridae (blackbirds, orioles and allies)	3	3	87
	Fringillidae (finches)	2	4	25
	Ploceidae (weavers and allies)	1	1	46
	Sturnidae (starlings)	4	6	590
	Corvidae (crows and allies)	2	2	18

References: Scott et al. (1972); McKenna and Allard (1976); Anderson (1978); Gylstorff (1979); Meyer (1978); Christensen (1980); Grosse et al., (1980); Heijnis (1980); Willdan Associates (1982); Longridge (1986); Rusz et al. (1986); Bevanger (1988); Thingstad (1989); Hartman et al. (1992); Bevanger (1993); Bevanger and Sandaker (1993).

Hence, body size and behaviour, such as perching and roosting on poles or wires, are the keys to understanding why and how birds become electrocuted.

Birds below the size of a jackdaw *Corvus monedula* have a reduced chance of becoming electrocuted because the conductors and earth wire or earthed devices are generally too far apart. However, irregular and unexpected electrocution accidents do take place because of the huge diversity in electrical installations and equipment (Kroodsma and Van Dyke, 1985; Negro and Ferrer, 1995). In Norway, pole-mounted transformers, pin insulators and a triangular conductor configuration were reported as the most dangerous electrocuting devices by the energy companies as a response to a questionnaire (Bevanger and Thingstad, 1988). Flocks of small birds (house sparrow *Passer domesticus*, starling *Sturnus vulgaris* and thrushes *Turdus* spp.) crossing a high tension power line (and when several roosting birds take off simultaneously) have also been observed to result in short circuits, as the current can pass through several individuals (reported by four energy companies in Norway; cf. Bevanger and Thingstad, 1988).

Species frequently affected by electrocution belong to Ciconiiformes, Falconiformes, Strigiformes and Passeriformes (Tables 2 and 3) (Bevanger, 1994b). Data on electrocution from Germany, Switzerland and Spain (Haas, 1980) show a majority of medium sized raptors

Table 2
Birds recorded as collision or electrocution victims. The data have been separated into studies dealing with: (i) bird collisions with power lines; (ii) bird electrocution; and (iii) ringing recoveries reporting 'killed by electricity'. Category (iii) cannot be separated into collision or electrocution as recoveries of ringed birds are not normally specific regarding collision or electrocution mortality

Order	Number of birds		
	Collision	Electrocution	Ringing recoveries
Gaviformes	3	—	—
Podicipediformes	303	—	2
Procellariiformes	4	—	18
Pelecaniformes	67	—	45
Ciconiiformes	105	14	193
Anseriformes	2983	—	3091
Falconiformes	14	739	648
Galliformes	321	—	17
Gruiformes	1653	—	37
Charadriformes	4867	1	1150
Apodiformes	6	—	74
Columbiformes	374	12	20
Cuculiformes	2	—	3
Strigiformes	5	68	263
Caprimulgiformes	—	—	1
Coraciiformes	—	—	4
Piciformes	—	—	13
Passeriformes	1519	416	1258

References collision data: Scott et al. (1972); McKenna and Allard (1976); Anderson (1978); Meyer (1978); Gylstorff (1979); Christensen (1980); Grosse et al. (1980); Heijnis (1980); Willdan Associates (1982); Longridge (1986); Rusz et al. (1986); Bevanger (1988); Thingstad (1989); Hartman et al. (1992); Bevanger (1993); Bevanger and Sandaker (1993).

References electrocution data: Haas (1980); Ferrer et al. (1991).

References ringing recoveries: Stolt et al. (1986); Bevanger and Thingstad (1988); Rose and Baillie (1992).

and owls (and also corvids) figuring among the casualties. Unfortunately, few reports addressing electrocution mortality have included complete lists of the victim species and the numbers of casualties. Several species among the 'thermal soarers' (e.g. hawks, eagles, vultures, condors) are obviously susceptible to electrocution using utility structures for perching. However, records, even from biologists, frequently fail to distinguish between death caused by collision or electrocution.

Adult white storks *Ciconia ciconia* and eagle owls *Bubo bubo* seem to be surprisingly common among electrocution (and collision) victims of these species (Fiedler and Wissner, 1980; Stolt et al., 1986; Larsen and Stensrud, 1988; Grischtschenko and Gaber, 1990). These data seem to be among the most convincing indication of a population-regulating effect of mortality caused by utility structures. In their analyses of 1185 recoveries of 'Helgoland ringed' white storks, Riegel and Winkel (1971) found that, of 294 birds recovered in Germany with known causes of death, 226 were killed because of 'overhead wires'. Of these, 62.8% were 1-year-old subadults, 2.2% were 2- and 3-year-old birds and 35% were 4-year-old or older adults.

Benson (1980, 1982) concluded that subadult age classes of large raptors suffer higher losses because of electrocution than adults, as a result of inexperience in flight and different hunting methods. Young and juvenile birds are inexperienced flyers less adept at manoeuvring than adults, e.g. when landing and taking off (Nelson and Nelson, 1976, 1977) and may even overbalance while perching on a high-tension wire and become electrocuted (Leshem, 1985). Several authors have stressed that there is a high percentage of juveniles and subadults among collision victims because subadults normally constitute the majority of a population, particularly in autumn; subadults often have a more gregarious behaviour, and several investigations were carried out in periods when the proportion of young birds in the population is high and exposed. It was claimed that birds learn to avoid air obstacles through experience (Lee, 1978; Thompson, 1978). However, no hard data seem to exist. Birds injured in collisions and electrocution may recover (Benson, 1982), but most individuals only gain experience once, and habituation seems particularly irrelevant in the case of electrocution.

In South Africa, several hundred individuals of the vulnerable, endemic Cape vulture *Gyps coprotheres* were found electrocuted (Markus, 1972; Ledger and Annegarn, 1981; Mundy et al., 1992; Ledger et al., 1993), and numerous Egyptian vultures *Neophron percnopterus*—

Table 3
Birds recorded as electrocution victims (based on Haas, 1980)

Order	Family	No. of genera	No. of species	No. of individuals
Ciconiiformes	Ciconiidae (storks)	1	2	14
Falconiformes	Accipitridae (hawks, vultures, eagles)	9	13	430
	Falconidae (falcons and allies)	1	1	88
Charadriformes	Laridae (gulls)	1	1	1
Columbiformes	Columbidae (pigeons)	1	3	12
Strigiformes	Tytonidae (barn owls and allies)	1	1	14
	Strigidae (typical owls)	3	3	54
Passeriformes	Turdidae (chats, thrushes)	2	4	15
	Sturnidae (starlings)	1	1	18
	Lanidae (shrikes)	1	1	1
	Corvidae (crows and allies)	2	4	382

considered as endangered in South Africa—were found electrocuted in the Sudan (Nikolaus, 1984). During the last few years, numerous reports of electrocuted raptors have come from Spain and other parts of southern Europe, particular concern being expressed for the Spanish imperial eagle *Aquila adalberti* (Ferrer et al., 1991; Negro and Ferrer, 1995). In Norway, most of the owl and raptor species were recorded as either collision or electrocution victims (Bevanger and Overskaug, in press).

It is now hoped to save the California condor *Gymnogyps californianus* from becoming extinct through breeding in captivity (Wallace, 1992; Caughley, 1994). In 1992, three of eight released birds in the former distribution area of the species were found electrocuted (Mestel, 1993). While the initial population decline was supposed to have been caused by habitat loss, shooting, etc., it was stressed that toxic organochlorines were the main factor during the 1970s and 1980s. It is imperative to clearly determine the causes of decline in the population of a critically endangered species to enable appropriate management actions to be implemented. Particular attention should be paid to local populations and areas with a high density of overhead wires.

4. Conservation impacts of collision and electrocution mortality

No investigation was found that was specifically designed to judge effects of power lines on bird mortality at the population level, and the problem has mainly been addressed as one co-objective among empirical questions connected with collision extent, behavioural effects and mitigating measures (Meyer, 1978; Beaulaurier, 1981; Willdan Associates, 1982; Faanes, 1987; Hartman et al., 1992).

The impact of seemingly density-independent mortality factors, like hunting, predation and utility structures, is generally thought to be compensated for among the survivors. Although numerous birds and mammals generally show a type II survivorship curve (e.g. Begon et al., 1996), indicating that few individuals reach their physiological life span and that survival is highly age-dependent, it is well known that heavy hunting may change survivorship curves within a population, for example from a type I survivorship (i.e. mortality is massive towards the end of the greatest life span) towards a type II survivorship curve (Lowe, 1969). If a dwindling population is unable to respond with compensatory actions to the mortality caused by utility structures, this mortality is population regulatory and must be considered a significant problem for nature management authorities.

Species with dwindling populations are listed in Red Data Books (RDB) and it is reasonable that RDB species are a main target of concern regarding anthropogenically-induced mortality factors (e.g. Willard, 1978. There are numerous collision and electrocution victims among bird species recorded as vulnerable and endangered (Appendix A). It is not surprising that there are no good data for most rare species. Even in abundant species, like waders and gulls, observed collisions occur in only between 0.07 and 0.003% of total flights (Meyer, 1978). However, recoveries of rare species, ringed in small numbers, were made. For example only two ringed individuals of both corn crake *Crex crex* and water rail *Rallus aquaticus* were recovered in Norway during the period 1914–1981 (Bevanger and Thingstad, 1988), which constitute 3.3 and 6.1% of the total number of ringed birds, respectively. In both these species, one of the recoveries was a collision victim.

There are contrasting views regarding threat categories for birds and animals (e.g. Collar and Andrew, 1988; Mace and Lande, 1991; Bibby et al., 1992). Species recorded in a world-wide RDB list do not necessarily reflect local or regional (in some instances not national) situations. When the significance of collision and electrocution-induced mortality is being addressed particular attention should be paid to local populations. Unfortunately, some countries are still ignorant about the population status of potentially vulnerable and endangered species, and lack a conservation management action plan.

The indirect effects of utility structures are rarely focused upon. Clear-felled transmission-line corridors in forest areas vary in breadth from 30 m up to 60 m or more depending on the voltage, and may have far-reaching fragmenting and habitat-changing effects that might affect the fauna (e.g. Bevanger and Henriksen, 1996). Habitat fragmentation is identified as a main threat to biodiversity and is a focal point among conservation biologists, especially in tropical and neotropical areas (Bierregaard et al., 1992; Fiedler, 1993). There is no question that many more power lines will be built in the future, particularly in vulnerable, tropical and subtropical areas (Bevanger, 1994a). It was stressed that power-line corridors may be particularly damaging and create barriers to some groups of species (e.g. antbirds (Formicariidae), ovenbirds (Furnariidae), hummingbirds (Trochilidae) and tapaculos (Rhinocryptidae)) that are restricted to the understorey of mature forests (Zerda and Rosselli, 1997). Specialised mammals in the tropics, including primates, bats and rodents, are vulnerable to habitat fragmentation, as are amphibians and reptiles. Several of these creatures are also prone to electrocution (e.g. Quincy, 1993; Lawson and Wyndham, 1993; Zerda and Rosselli, 1997), although few studies have focused on this.

Conservation management authorities should not only focus on the lack of hard data rooted in population dynamics but use available documentation and indices to carry out an early warning policy, like those deriving from analyses of morphology and biomechanics. Hopefully this can also convince energy companies to seriously consider financially adverse alternative routing, earth cabling and technical solutions for the construction of utility structures to reduce the adverse wildlife effects.

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Appendix

Species regarded as rare, vulnerable or endangered (nationally or internationally) reported as collision and/or electrocution victims. The taxonomy follows Howard and Moore (1991)

Order	Family	Genus	Species	Source
Pelecaniformes	Pelecanidae	*Pelecanus*	Dalmatian pelican *P. crispus*	Crivelli et al., 1988
			White pelican *P. erythrorhynchos*	Ryder, 1981
			Brown pelican *P. occidentalis*	McNeil et al., 1985
Ciconiiformes	Ardeidae	*Botaurus*	Eurasian bittern *B. stellaris*	Andersen-Harild and Bloch, 1973; Gylstorff, 1979; Rose and Baillie, 1992
	Ciconiidae	*Ciconia*	White stork *C. ciconia*	Fiedler and Wissner, 1980; Haas, 1980; Oatley and Rammesmayer, 1988
	Phoenicopteridae	*Phoenicopterus*	Lesser flamingo *P. ruber*	Longridge, 1986
			Greater flamingo *P. minor*	Longridge, 1986
Anseriformes	Anatidae	*Cygnus*	Mute swan *C. olor*	Perrins and Sears, 1991; Rose and Baillie, 1992; Mathiasson, 1993
			Whooper swan *C. cygnus*	Folkestad, 1980; Rose and Baillie, 1992; Bevanger, unpubl.
			Tundra swan *C. columbianus bewickii*	Rose and Baillie, 1992
		Anser	Greylag goose *A. anser*	Rose and Baillie, 1992
Falconiformes	Cathartidae	*Gymnogyps*	California condor *G. californianus*	Snyder, 1986; Anon., 1993
	Pandionidae	*Pandion*	Osprey *P. haliaëtus*	Stolt et al., 1986; Bevanger and Thingstad, 1988; Muñoz-Pulido, 1990
	Accipitridae	*Pernis*	Western honey buzzard *P. apivorus*	Stolt et al., 1986
		Milvus	Red kite *M. milvus*	Haas, 1980; Ferrer et al., 1991; Rose and Baillie, 1992
		Haliaëtus	American bald eagle *H. leucocephalus*	Smith and Murphy, 1972; Meyer, 1980; Olendorff and Lehman, 1986
			White-tailed sea eagle *H. albicilla*	Bevanger and Thingstad, 1988
		Aegypius	Cinereous vulture *A. monachus*	Garzon, 1977
		Gyps	Griffon vulture *G. fulvus*	Mundy, 1983; Leshem, 1985; Ferrer et al., 1991
			Cape vulture *G. coprotheres*	Markus, 1972; Ledger, 1984; Ledger and Annegarn, 1981
			African white-backed vulture *G. africanus*	Drake and Mundy, 1981
		Neophron	Egyptian vulture *N. percnopterus*	Nikolaus, 1984
		Gypaetus	Lammergeier *G. barbatus*	Wuethrich, 1993
		Hieraaetus	Martial eagle *H. bellicosus*	Brooke, 1984; Maclean, 1985; Ledger, 1990
		Circus	Hen harrier *C. cyaneus*	Scott et al., 1972; Rose and Baillie, 1992
			Montague's harrier *C. pygargus*	Rose and Baillie, 1992
			Western marsh harrier *C. aeruginosus*	Rose and Baillie, 1992
		Accipiter	Northern goshawk *A. gentilis*	Stolt et al., 1986; Bevanger and Thingstad, 1988; Rose and Baillie, 1992
		Aquila	Spanish imperial eagle *A. heliaca adalberti*	Garzon, 1977; Haas, 1980; Ferrer and Court, 1988; Meyburg, 1989; Ferrer et al., 1991
			Golden eagle *A. chrysaëtos*	Olendorff et al., 1981; Bevanger and Thingstad, 1988; Rose and Baillie, 1992
	Falconidae	*Falco*	Gyr falcon *F. rusticolus*	Gudmundsson and Clausen, 1974
			Peregrine falcon *F. peregrinus*	Olsen and Olsen, 1980; Stolt et al., 1986; Rose and Baillie, 1992
Gruiformes	Gruidae	*Grus*	Common crane *G. grus*	Stolt et al., 1986
			Sandhill crane *G. canadensis*	Walkinshaw, 1956; Drewien, 1973; Brown et al., 1987; Windingstad, 1988
			Manchurian crane *G. japonensis*	Brown et al., 1987
			Whooping crane *G. americana*	Brown et al., 1987; Doughty, 1989; Howe, 1989
		Bugeranus	Wattled crane *B. carunculatus*	Johnson and Sinclair, 1984
	Rallidae	*Rallus*	Water rail *R. aquaticus*	Scott et al., 1972; Grosse et al., 1980; Bevanger and Thingstad, 1988
		Crex	Corn crake *C. crex*	Stolt et al., 1986; Bevanger and Thingstad, 1988
		Porzana	Spotted crake *P. porzana*	Grosse et al., 1980; Heijnis, 1980
	Otidae	*Ardeotis*	Kori bustard *A. kori*	Longridge, 1986
		Otis	Great bustard *O. tarda*	Cramp and Simmons, 1980; Cardoso, 1985
Strigiformes	Tytonidae	*Tyto*	Barn owl *T. alba*	Rose and Baillie, 1992
	Strigidae	*Bubo*	Northern eagle owl *B. bubo*	Glutz and Bauer, 1980; Förstel, 1983; Larsen and Stensrud, 1988
		Strix	Ural owl *S. uralensis*	Stolt et al., 1986
			Great grey owl *S. nebulosa*	Stolt et al., 1986