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Factors Influencing Bird Mortality Caused by Power Lines within Special Protected Areas and undertaken Conservation Efforts

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Abstract: Electrocution and wire collision have various degrees of negative impact on different groups of birds. In this study, 25 power supply lines with a length of 204.1 km were inspected in the Special Protected Areas (SPAs). The total number of the inspected power poles of various types was 2116. A total of 297 victims of 46 different taxa, including 11 orders were identified. The victims of electrocution accounted for 69.02 % of all registered deaths. The species that died most often from electrocution belonged to the order Ciconiiformes (27%) and the family Corvidae (29%). The species of highest mortality rate due to electrocution were: White Stork (24.39%), Common Buzzard (12.68%), Hooded Crow (9.76%), and Magpie (8.29%). The species that most often fell victims to collisions with wires were: White Stork (21.7%), Common Buzzard, and Starling with 7.6% each. The highest number of victims was found in flat relief, an average of 3.33 ± 6.34, followed by the elevated (slanted) relief, 2.05 ± 4.43. The highest electrocution killing rate was recorded in open grassland habitats, including pastures and abandoned land (KR = 0.11). The highest number of victims, an average of 3.29 ± 8.75, was established during migration.

Key words: Electrocution, collision, power lines, bird mortality, conservation

Introduction

The usual way to provide power to end consumers in Bulgaria is through overhead power lines. These lines are located in various natural habitats, and, combined with the dangerous construction of power poles with different types of insulation, may sometimes pose considerable threat to birds' life. Contemporary studies carried out in different countries show that mortality of birds caused by risky power supply networks is among the global problems leading to biological diversity loss (Markus 1972, Haas 1980, Ledger, Annegarn 1981, Ferrer, Hiraldo 1991, Ferrer *et al.* 1991, Bayle 1999, Guyonne *et al.* 1999a, 2001, Arhipov 2000, Janss 2000, Kruger, Van Rooyen 2000, Van Rooyen 2000, Adamec 2004, Karyakin *et al.* 2005, Karyakin, Barabashin 2005, Mastina 2005, Medzhidov *et al.* 2005, Pestov 2005, Rubolini *et al.* 2005, Kariakin, Novikova 2006, Cartron *et al.* 2006, Lehman *et al.* 2007, Harness 1998, 2000, Harness *et al.* 2008).

There are two main aspects of the negative impact of power supply lines on birds:

1) electrocution – upon perching or flying off a pole, a bird can cause short circuit as its body might bridge the wires and the earthing section of the pole. The risk of such short circuits increases in humid and rainy weather. Birds have semi-liquid faeces and when defecating while perched on a pole they can cause a voltaic arc;

2) collision with wires – birds in flight might collide with wires as they are difficult to notice, especially in poor weather conditions of low visibility.

Various studies show the negative impact at population level on some species, *e.g.* the Spanish

Imperial Eagle (*Aquila adalberti* Brehm, 1861*)* (Ferrer *et al.* 1991), the Eagle Owl (*Bubo bubo* Linnaeus, 1771) (Sergio *et al*. 2004) and some of Galliformes (Bevanger 1995). There are certain data indicating that the increased mortality and reduced abundance of Steppe Eagle (*Aquila nipalensis* Hodgson, 1833) in Kazakhstan are due to the risky power supply network (Moseikin 2003). Electrocution is considered to be the main cause of the decline in the population of Bonelli's Eagle (*Aquila fasciata* Vieillot, 1822) in Spain and France (Real *et al.* 1996, Real, Manõsa 1997), and of Eurasian Eagle Owl in France (Bayle 1999) and Italy (Rubolini *et al.* 2001). The European Union's action plan for the Bonelli's Eagle identified the reduction of electrocution mortality as a critical measure, being crucial for the survival of the species (Arroyo *et al*. 1998). In the Russian Federation, the annual bird mortality caused by electrocution was estimated at 10 million birds belonging to 100 species (Matsyna, Matsyna 2011).

The studies carried out so far have made it clear that the better part of the power supply network in Bulgaria is a threat to birds. The 20 kV long-distance power lines proved to be the most risky (Stoychev, Karafeizov 2004, Demerdzhiev *et al*. 2009), being at the same time the most widely used (over 45 000 km). The first systematic study on the mortality in birds as a result of the risky 20 kV power supply network was carried out in 2004 (Demerdzhiev *et al*. 2009). The results showed that a great number of birds of various groups are killed every year because of the risky power supply network and the highest mortality rate is among the orders Ciconiiformes, Accipitriformes, Falconiformes, Passeriformes and the family Corvidae that was studied separately from the rest of the species of the Passeriformes order.

The present study aims at studying the impact of the 20 kV power supply network as a factor related to the increased mortality of birds at sites within Special Protected Areas (SPAs), including Sakar (BG0002021), Zapadna Strandzha (BG0002066), Kamensky Bair (BG0002059), Sinite Kamany-Grebenetz (BG0002058), Derventski Heights (BG0002026) and adjacent areas. In addition, the effect of the insulated electric poles on bird mortality has been evaluated.

Material and Methods

Study areas

The Sakar SPA is a low-mountain area of Sakar Mountains with rounded hilltops and comparatively open river valleys of the Maritsa and Tundzha River tributaries, close to the state border with Turkey (Fig. 1). The terrain altitude ranges between 50 and 856 m. The lower parts of the Sakar territory are occupied by farmland that has replaced forests of Downy Oak (*Quercus pubescens* Willd.) and Virgilian oak (*Quercus virgiliana* Ten.). Dispersed xerothermal grass associations, dominated by Dichantium (*Dichantium ischaemum* L.), Bulbous bluegrass (*Poa bulbosa* L.), etc., and more rarely, meso-xerothermal vegetation (Bondev 1991), occupy about 15% of the area. The neighbouring Derventski Heights SPA is a low-mountain hilly area with a mosaic of different habitats, located to the east of the Tundzha River. The state border between Bulgaria and Turkey passes along the main ridge of the area. The altitude of the hills is between 120 and 550 m. a.s.l. About 20% of the territory of the Derventski Heights is covered by mixed deciduous forests of oak, most often Turkey oak (*Quercus cerris* L.) and Hungarian oak (*Quercus frainetto* Ten.), at some places mixed with Oriental hornbeam (*Carpinus orientalis* L.) and Mediterranean elements. The Zapadna Strandzha SPA is located in southeastern Bulgaria. It covers the western parts of the Strandzha Mountains. Its territory includes several types of habitats, the biggest area being occupied by farmland, pastures and shrubs. The area of Sinite kamani-Grebentz SPA is located in the Sliven Mountain, which is part of the main Balkan Mountain chain. Kamenski Bair SPA is located in southern Bulgaria, southwest of the town of Sliven, in the grounds of the village bearing the same name. The main habitats are open areas of farmland (arable and abandoned), pastures and shrub associations.

Ornithological significance of the studied SPAs

The area of Sakar currently supports 220 bird species (Stoychev *et al*. 2008), 91 of which are listed in the Red Data Book of Bulgaria (Golemanski 2011). Of the birds occurring there, 96 species are of European conservation concern (SPEC) (BirdLife International 2004), 11 of them being listed in category SPEC 1 as globally threatened, 23 in SPEC 2, and 62 in SPEC 3 as species threatened in Europe. The Sakar supports the biggest parts of the Bulgarian populations of Imperial Eagle (*Aquila heliaca* Savigny, 1809*)*, Lesser Spotted Eagle (*Aquila pomarina* Brehm, 1831), Booted Eagle *(Aquila pennata* Gmelin, 1788), Black Kite (*Milvus migrans* Boddaert, 1783), and Long-legged Buzzard (*Buteo rufinus* Cretzschmar, 1829). Sakar is one of the most important sites in Europe for the Imperial Eagle with the ten nests of the species there (Demerdzhiev 2011).

The Zapadna Strandzha supports 112 bird

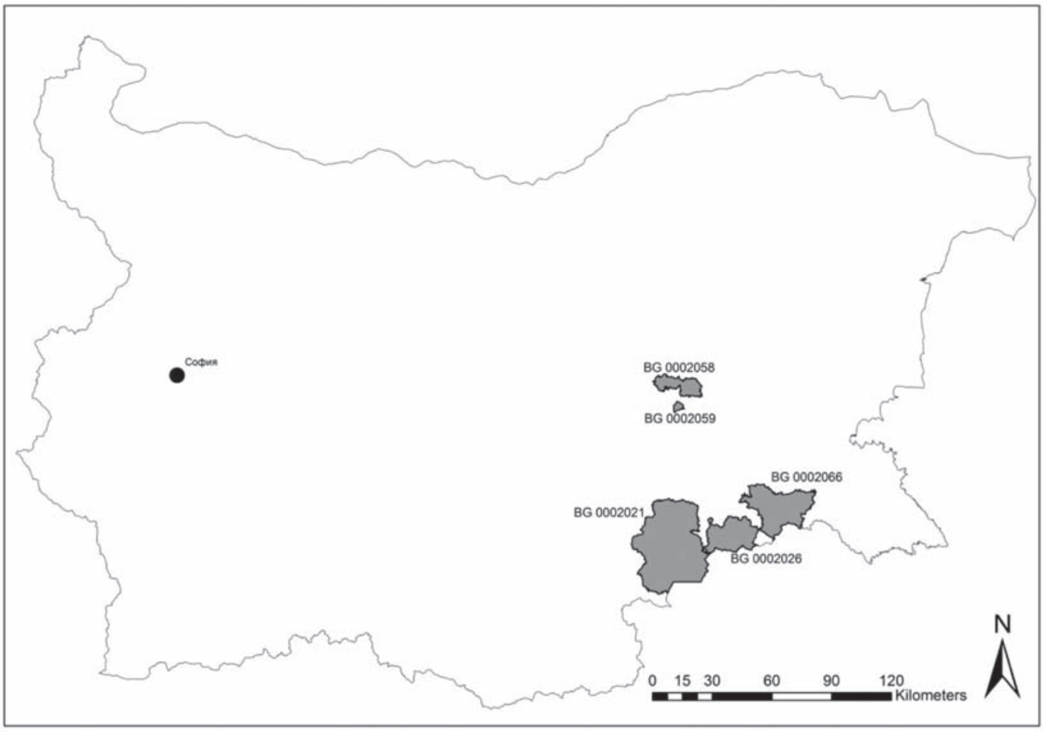

Fig. 1. Studied Special Protected Areas

species, 34 of which are listed in the Red Data Book of Bulgaria (Golemanski 2011). Of the birds occurring there, 53 species are of European conservation concern (SPEC) (BirdLife International 2004), 4 of them being listed in category SPEC 1 as globally threatened, 16 in SPEC 2 and 33 in SPEC 3 as species threatened in Europe. Zapadna Strandzha is an area of global importance for the globally threatened Imperial Eagle that breeds in this SPA (Demerdzhiev 2011).

The region of Derventski Heights supports 120 bird species (Kostadinova, Gramatikov 2007). Of the birds occurring there, 59 species are of European conservation concern (SPEC) (BirdLife International 2004), 2 of them being listed in category SPEC 1 as globally threatened, 17 in SPEC 2, and 40 in SPEC 3 as species threatened in Europe. The globally threatened Imperial Eagle breeds in the Derventski Heights as well.

The area of Sinite Kamani, Stidovska Mountain and Grebenets Ridge supports 170 bird species. The area includes some very valuable breeding and foraging habitats for certain threatened diurnal birds of prey, such as the Imperial Eagle, Saker Falcon (*Falco cherrug* Gray, 1834), and Long-legged Buzzard. Sinite Kamani-Grebenets is of global importance for the Imperial Eagle both as breeding and temporary settlement area for concentration of young and immature birds (Demerdzhiev 2011). This is also one of Bulgaria's most important areas for the Saker Falcon.

Kamenski Bair, despite its small territory, supports 142 bird species. Kamenski Bair is of global importance as one of the most significant temporary settlement areas in the country, which is used as a hunting ground by the globally threatened Imperial Eagle. One Imperial Eagle pair has been breeding in the area since 2007 (Demerdzhiev 2011).

General information

Several types of power supply facilities (hereinafter referred to as 'poles'), defined on the basis of various combinations of the support structure (pole) and the number of insulators located on them, can be found in the studied SPAs. The main types of poles include (Fig. 2):

1. Type 1 – metal poles of 3 side-fixed insulators, parallel to wires;
2. Type 2 – concrete poles of 3 upward fixed insulators;
3. Type 3 – metal poles of 3-6 insulators mounted on 2 support beams, insulators are downward fixed;
4. Type 4 – concrete poles of 3 downward fixed insulators;
5. Type 5 – metal poles of 3 upward fixed insulators;
6. Type 6 – metal poles of 9 upward-pointing insulators (shifting towers)

For the purpose of this study, 25 representative inter-village power lines with a total length of 204.1 km were selected, which crossed all main types of habitats and consisted of various pole configurations. The surveyed powerlines within the studied SPAs were distributed as follows: Sakar SPA – 7 powerlines (75.4 km); Derventski Heights SPA – 3 powerlines (33.4 km); Zapadna Strandzha SPA – 7 powerlines (71 km); Sinite Kamani-Grebenets SPA – 6 powerlines (13 km); and Kamenski Bair SPA – 2 powerlines (11.3 km).

The main habitat types in the studied areas are:

1. Arable lands (AL) – agricultural lands, sown with various cultures (wheat, oats, sunflower, maize, and others). These lands are actively used by people for various crops and birds use them as foraging grounds, especially during the migration period;

2. Grasslands (G) – these include all abandoned farm lands that are no longer cultivated, all pastures, meadows and areas of single trees or tufts and bushes, and of varying coverage area. Those areas are used by birds round the year as feeding, resting, nesting and winter grounds.

3. Vineyards (V) – traditional extensive vineyards. These are specific habitats convenient for meeting all the needs of birds almost throughout the year.

4. Forests (F) – territories of various types of forest vegetation. This habitat is used by birds throughout the year as a place for nesting and chicks rearing, overwintering, feeding, etc.

The relief is assessed by sight using two categories: flat and elevated (slanted).

Data on the victims found are categorised in three seasons: reproductive (May through August), migration (September, October, November, March, April) and winter (December through February).

The birds, according to their size, were divided in five groups: group A (body length of 14-25 cm; includes various Passeriformes), group B (body length of 27-35 cm and wing-span of 46-75 cm; includes small raptors, Coraciiformes, Columbiformes), group C (body length of 46-64 cm and wing span of 120-150 cm; includes medium diurnal raptors and species of the Corvidae family), group D (body length of 65-110 cm and wing span of 160-200 cm; includes medium to large eagles and storks), and group E (body length of 120-150 cm and wing span of 220 cm; includes swans).

Field study

The study was carried out in two periods. The first period lasted from September 2004 to December 2004 (Demerdzhiev *et al*. 2009), and the second from February 2008 to January 2010. To evaluate the efficiency of the insulators, 535 insulated poles were inspected again once a month during the period September – November 2012. Inspections were carried out once a month by walking along the power lines. The period between the inspections was no less than 20 days and no more than 30 days. The inspections were performed by the transect method (Bibby *et al*. 1999) counting the remains of victims within an area of 20 m on either side of each power supply line. The following specifics of each power pole were considered: GPS coordinates (GPSMAP 60Cx), type of pole, individual pole code (every pole has a digit number on it), habitats within a radius of 50 m around the pole, and relief. On finding a victim, the following data were entered in a standard field form: name of the line, individual pole number, species, age, gender of the bird (when determined), the number of the victims, condition of the victims (fresh carcass, mummified carcass, feathers and bones, only feathers or only bones bearing traces of singes or burns), distance and position of the victim to the pole and wires, type of habitat and relief. The victims were recognised by using comparative material (feathers, bones). Following the entry in the form, the victim was taken away from the line in order to avoid re-counting during the next inspection. All victims within a radius of 5 m around the pole were considered electrocuted, while birds found under the wires were considered victims of collision (Demerdzhiev *et al*. 2009).

Data analysis

The data were processed using Microsoft Office 2007, Statistica 7.0. The calculation of the number of electrocuted birds was performed by introducing a Killing Rate index (KR) calculated by dividing the number of all victims of a certain type of power pole by the total number of power poles of the relevant type.

$$KR_{(pole)} = \frac{\text{number of victims (n)}}{\text{number of poles (n)}}$$

The value obtained (KR) is per pole and varies from 0 to 1 and the higher it is, the higher the danger of this type of pole is for the birds.

Calculation of the number of birds dead owing to collision was also performed by introducing a Killing Rate index calculated by dividing the number of all collision victims by the length of the power lines (km). The value obtained (KR) is per kilometer of power line.

$$KR_{(km\ powerline)} = \frac{\text{number of victims (n)}}{\text{Km powerlines}}$$

Initially, the data were analysed for normality of distribution through the Shapiro-Wilk test (Shapiro *et al*. 1968). Where the data were not normally distributed, they were transformed through logarithm of the function log (x + 1) to achieve a distribution close to the normal one (Fowler, Cohen 1992). The results were considered significant at $p < 0.05$ [a = 5%]. In order to establish the impact of various factors on the killing rate, a one-way ANOVA analysis was used, where the group variable was the order to which the victim belonged. In order significant correlation between testing variables and different groups of birds was used. The analysis did not include power poles of Type 4 as they were non-representative in this study. The species of the family Corvidae were separated from the Passeriformes due to their specific ecology and ethology.

Results

Species and mortality causes (electrocution, collision with power lines)

The survey established 297 victims of 46 different taxa, including 11 orders (Table 1), (Fig. 3).

The number of the victims taken by scavengers was neglected. Supposedly, a significant number of victims was not registered during the study as their carcasses had been carried off by jackals (*Canis aureus* Linnaeus, 1758) and foxes (*Vulpes vulpes* Linnaeus, 1758), which are of great abundance and density in the studied areas. Probably, the actual mortality rate was significantly underestimated, being, in fact, manifold higher (Ferrer *et al*. 1991, Guyonne *et al*. 1999a, b, 2001). Due to their small size, Passeriformes birds are often eaten by carnivores and usually only body parts, beaks, flight feathers of raptors, storks and corvids are found (Demerdzhiev *et al.* 2009). Thus, the number of registered songbirds was probably underestimated.

The electrocution victims accounted for 69.02 % of all registered deaths (n = 297) along the

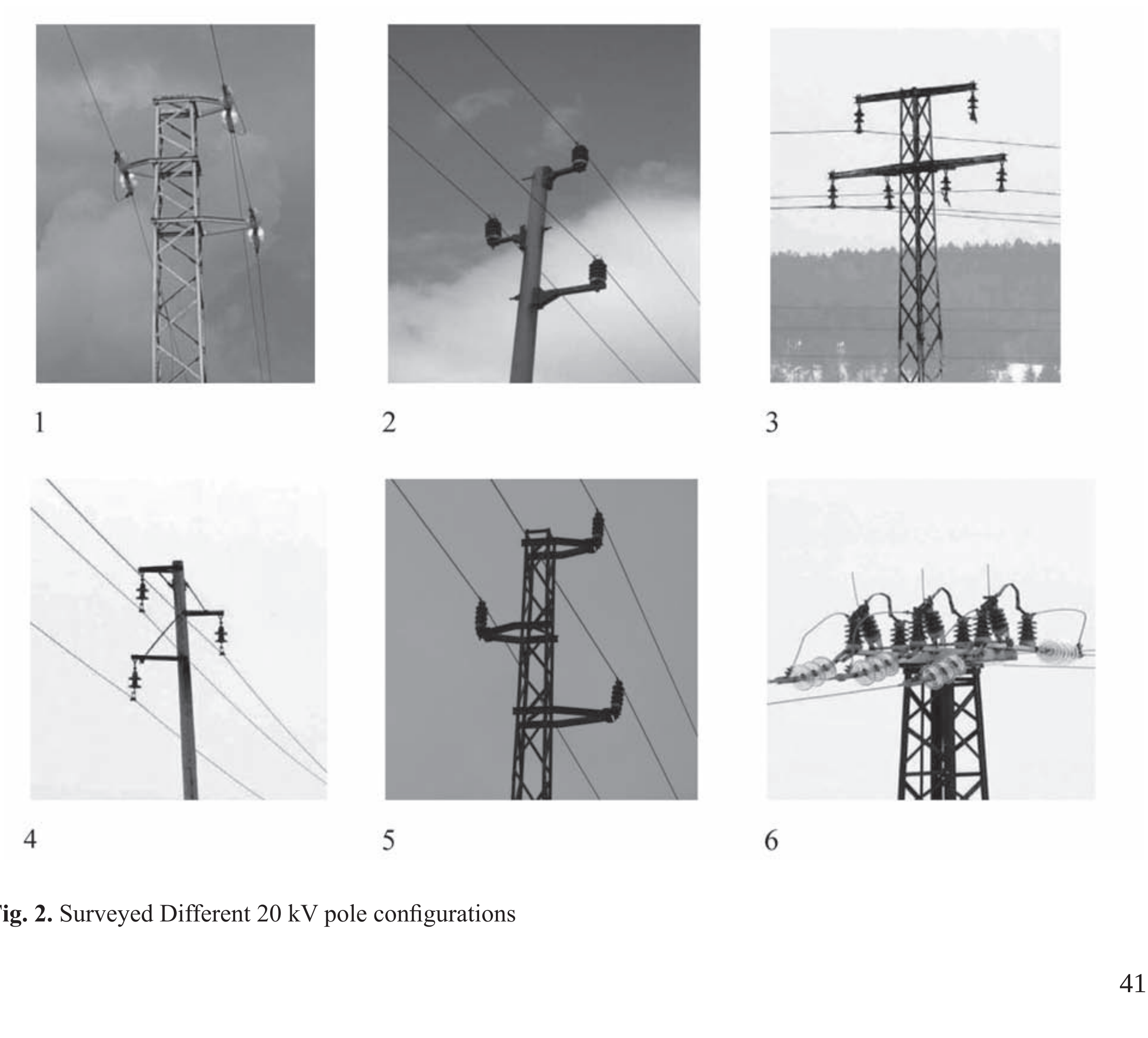

Fig. 2. Surveyed Different 20 kV pole configurations

Table 1. Species of victims of the studied powerlines

N	Species	Electrocution	Collission
1	Greylag Goose (*Anser anser* Linnaeus, 1758)	1	-
2	Mute Swan (*Cygnus olor* Gmelin, 1789)	1	1
3	White Stork (*Ciconia ciconia* Linnaeus, 1758)	50	20
4	Black Stork (*Ciconia nigra* Linnaeus, 1758)	4	5
5	Great White Heron (*Egretta alba* Linnaeus, 1758)	1	-
6	Northern Goshawk (*Accipiter gentilis* Linnaeus, 1758)	3	1
7	Sparrowhawk (*Accipiter nisus* Linnaeus, 1758)	1	1
8	Common Buzzard (*Buteo buteo* Linnaeus, 1758)	26	7
9	Long-legged Buzzard (*Buteo rufinus* Cretzchmar, 1827)	1	1
10	Short-toed Snake Eagle (*Circaetus gallicus* Gmelin, 1788)	2	-
11	Imperial Eagle (*Aquila heliaca* Savigny, 1809)	5	-
12	Golden Eagle (*Aquila chrysaetos* Gmelin, 1788)	1	-
13	Common Kestrel (*Falco tinnunculus* Linnaeus, 1758)	8	-
14	Roller (*Coracias garrulus* Linnaeus, 1758)	7	-
15	Hoopoe (*Upupa epops* Linnaeus, 1758)	1	-
16	European Bee-eater (*Merops apiaster* Linnaeus, 1758)	1	1
17	Common Wood Pigeon (*Columba palumbus* Linnaeus, 1758)	1	-
18	Turtle Dove (*Streptopelia turtur* Linnaeus, 1758)	1	1
19	Common Moorhen (*Gallinula chloropus* Linnaeus, 1758)	-	2
20	Spotted Crake (*Porzana porzana* Linnaeus, 1766)	-	1
21	Grey Partridge (*Perdix perdix* Linnaeus, 1758)	-	1
22	Common Pheasant (*Phasianus colchicus* Linnaeus, 1758)	-	1
23	Chukar (*Alectoris chukar* Gray, 1830)	-	1
24	Long-eared Owl (*Asio otus* Linnaeus, 1758)	-	1
25	Syrian Woodpecker *Dendrocopos syriacus* (Hemprich,Ehrenberg, 1833)	-	1
26	Common Raven (*Corvus corax* Linnaeus, 1758)	11	6
27	Hooded Crow (*Corvus cornix* Linnaeus, 1758)	20	5
28	Rook (*Corvus frugilegus* Linnaeus, 1758)	4	-
29	Western Jackdaw (*Corvus monedula* Linnaeus, 1758)	2	1
30	Eurasian Magpie (*Pica pica* Linnaeus, 1758)	17	2
31	Eurasian Jay (*Garrulus glandarius* Linnaeus, 1758)	1	1
32	Famile (*Corvidae* Vigors, 1825)	2	-
33	Common Starling (*Sturnus vulgaris* Linnaeus, 1758)	21	7
34	Great Reed Warbler (*Acrocephalus arundinaceus* Linnaeus, 1758)	-	3
35	Crested Lark (*Galerida cristata* Linnaeus, 1758)	-	1
36	Calandra Lark (*Melanocorypha calandra* Linnaeus, 1766)	2	4
37	Eurasian Skylark (*Alauda arvensis* Linnaeus, 1758)	-	2
38	Meadow Pipit (*Anthus pratensis* Linnaeus, 1758)	-	1
39	Common Linnet (*Carduelis cannabina* Linnaeus, 1758)	-	1
40	Goldfinch (*Carduelis carduelis* Linnaeus, 1758)	-	1
41	Corn Bunting (*Miliaria calandra* Linnaeus, 1758)	-	1
42	Red-backed Shrike (*Lanius collurio* Linnaeus, 1758)	-	1
43	Blackbird (*Turdus merula* Linnaeus, 1758)	3	1
44	Barn Swallow (*Hirundo rustica* Linnaeus, 1758)	-	2
45	Spanish Sparrow (*Passer hispaniolensis* Temminck, 1820)	1	1
46	Songbird (Passeri iden. Linnaeus, 1758)	6	5
	TOTAL	205	92

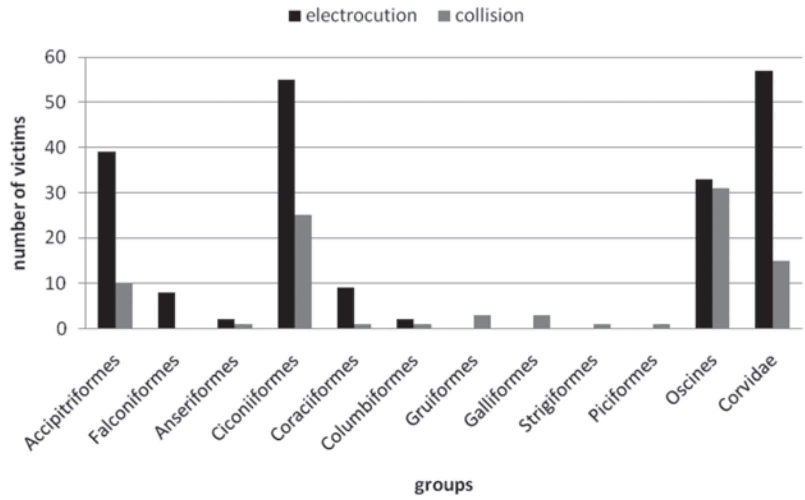

Fig. 3. Mortality caused by the hazardous power supply network with different bird groups

Table 2. Killing rate established with the various types of power poles

Power Pole Type	Number of Poles	Number of Victims	KR
Type 1	341	65	0.19
Type 2	1447	116	0.08
Type 3	130	5	0.04
Type 4	31	1	0.03
Type 5	135	12	0.09
Type 6	32	6	0.19

studied power lines. The species that died most often from electrocution belong to the order Ciconiiformes (27%) and Corvidae family (29%). Both systematic groups accounted for 56% of the electrocuted birds. There was a considerable share of loss among diurnal raptors (Accipitriformes, Falconiformes) – 23%. A significant percentage of the electrocuted songbirds consisted of starlings which accounted for 10.24% of the deaths. The species of highest mortality rate due to electrocution were: White Stork (24.39%), Common Buzzard (12.68%), Hooded Crow (9.76%), and Magpie (8.29%).

Collision with wires accounted for 30.98% of the registered death cases (n = 92) along the 20 kV power supply network. The victims most often belonged to the suborder of the songbirds, which accounted for 34% of the collision death cases. They were followed by Ciconiiformes (27%) and corvids (17%). A relatively high percentage was shown in diurnal raptors (11%). This aspect of the problem related to the risky power supply network shows that collision affects a wider variety of birds. The species that most often fell victim to collisions with wires were White Stork (21.7%), Common Buzzard and Starling (with 7.6% each).

The comparison of bird mortality caused by electrocution or collision showed statistically significant differences in the following groups: diurnal raptors ($\chi^2 = 13.09$, $p < 0.001$), Ciconiiformes ($\chi^2 = 11.25$, $p < 0.001$), Coraciiformes ($\chi^2 = 6.4$, $p < 0.01$), and Corvidae ($\chi^2 = 24.5$, $p < 0.001$). Comparison by species revealed that considerably more birds died from electrocution than from collision with wires, namely: White Stork ($\chi^2 = 12.9$, $p < 0.001$), Common Buzzard ($\chi^2 = 10.9$, $p < 0.001$), Common Kestrel ($\chi^2 = 8$, $p < 0.01$), Imperial Eagle ($\chi^2 = 5$, p □ 0.05), Roller ($\chi^2 = 7$, $p < 0.01$), Hooded Crow ($\chi^2 = 9$, $p < 0.01$), Rook ($\chi^2 = 4$, $p < 0.05$), Magpie ($\chi^2 = 11.8$, $p < 0.001$), and Common Starling ($\chi^2 = 7$, $p < 0.01$).

Killing rate of power poles

The study considered six different types of power poles. It proved that the highest threat was posed by poles of Type 1 and Type 6 (Table 2).

The power poles of Type 2 and Type 5 also caused high bird mortality. Poles of Type 3 and Type 4 were relatively safe for birds and rarely caused electrocution. All victims were gathered under 144 of all 2116 studied poles. These 144 power poles, called ‘killer poles’, accounted for 6.8% of all power poles included in the study. The highest victim concentration was found under single poles (n = 111), 23 of the poles had 2 victims per pole, 4 poles had 3 victims per pole, and 2 poles had 5 victims per pole. In four instances, 4, 6, 7, and 9, the victims were found under a single pole.

Impact of different factors on bird mortality

The results of the analysis show statistically significant difference between different birds groups with the following factors: electrocution (F = 2.52, p =

Table 3. Impact of different factors on bird mortality (ANOVA analysis. Values of p □ 0.05 are significant)

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Electrocution	**3.806**	**9**	**0.423**	**5.723**	**36**	**0.159**	**2.660**	**0.018**
Collision	1.011	9	0.112	2.992	36	0.083	1.351	0.246
Type 1	1.275	9	0.142	3.715	36	0.103	1.373	0.237
Type 2	**3.163**	**9**	**0.351**	**3.825**	**36**	**0.106**	**3.308**	**0.005**
Type 3	0.077	9	0.009	0.435	36	0.012	0.707	0.699
Type 5	0.297	9	0.033	0.833	36	0.023	1.425	0.214
Type 6	0.112	9	0.012	0.417	36	0.012	1.074	0.405
Flat relief	0.918	9	0.102	4.478	34	0.132	0.775	0.640
Elevated relief	3.257	9	0.362	7.478	34	0.220	1.645	0.142
Arable lands	0.455	9	0.051	5.125	36	0.142	0.355	0.949
Vineyards	0.137	9	0.015	1.095	36	0.030	0.501	0.864
Grasslands	**2.759**	**9**	**0.307**	**3.800**	**36**	**0.106**	**2.904**	**0.011**
Forests	0.052	9	0.006	0.505	36	0.014	0.414	0.919
Breeding season	1.454	9	0.162	4.574	36	0.127	1.272	0.285
Migratory season	2.570	9	0.286	4.977	36	0.138	2.066	0.060
Wintering season	0.831	9	0.092	1.996	36	0.055	1.665	0.134

0.02), pole Type 2 (F = 3.13, p = 0.007), and open grasslands (F = 2.78, p = 0.01) (Table 3).

Impact of pole type

There is considerable correlation between mortality of diurnal raptors caused by electrocution and power pole Type 1 (p □ 0.01), Type 2 (p □ 0.01) and Type 3 (p □ 0.001). In songbirds, considerable correlation is shown with power pole Type 1 (p □0.001) and Type 2 (p □ 0.001). Mortality in Ciconiiformes correlates considerably with Type 1 and Type 2 (p □ 0.05). Species from the Corvidae family also show significant correlation in Type 1 (p □ 0.001) and Type 2 (p □ 0.001) electrocution.

Impact of rielef

The relief, within which the victims of the power supply network were found, was divided into two categories: elevated and flat. The highest number of victims was found in flat relief (an average of 3.33 ± 6.34), followed by the elevated relief (2.05 ± 4.43). The victims of electrocution among the diurnal raptors show considerable correlation with regard to relief and it is most significantly demonstrated in the elevated relief (p □0.001). In raptors, there is considerable correlation between the collision with wires and the flat relief (p □ 0.01). The songbirds have a high electrocution killing rate, as well as collision killing rate (p □ 0.001), in flat relief (p □ 0.001). A significant correlation in killing rate caused by electrocution (p □ 0.001) and collision (p □ 0.01) is shown in the cases of elevated terrains. In corvids, there is a significant correlation between electrocution and elevated terrain (p □ 0.001) and flat terrain (p □ 0.01). With regard to the collision with electric wires, the same species are most often killed both on elevated (p □ 0.01) and flat (p □ 0.05) relief. Coraciiformes show significant correlation between electrocution and elevated relief (p □ 0.001). Storks also have significant correlation between electrocution and elevated relief (p □ 0.05).

Impact of habitat

The highest electrocution killing rate was recorded in open grassland habitats, including pastures and abandoned land (KR = 0.11). These were followed by vineyards (KR = 0.09), arable land (KR = 0.07) and forests (KR = 0.02). Wire collision kill birds most often in vineyards (KR = 0.49) and open grasslands (KR = 0.46), followed by arable land (KR = 0.33) and forests (KR = 0.15). In diurnal raptors a considerable correlation is shown between the electrocuted species and open grassland habitats (p □ 0.01), forest (p □ 0.05) and arable land (p □ 0.05). The electrocution killing rate in songbirds correlates strongly with the following habitats: arable land (p □ 0.001), open grassland (p □ 0.001), and vineyards (p □0.001). The correlation between wire collision and arable land and open grasslands is high in songbirds (p □ 0.001). In Ciconiiformes, there is a significant correlation between the killing rate and habitat similar to electrocution and arable land (p □ 0.05). The corvids died from electrocution mostly in open grassland habitats (p □ 0.001), arable land ($p < 0.001$), and vineyards ($p < 0.05$). A considerable correlation was found between the wire collision of those species and their habitats in arable land ($p < 0.01$).

Impact of seasons

There is no statistically significant difference between the numbers of victims of the power supply network found during the various seasons. The highest number of victims was established during migration – an average of 3.29 ± 8.75 for the period of this study. The second highest number of victims occured during the breeding season (2.13 ± 3.61) and in winter (1.11 ± 1.80). The diurnal raptors died from electrocution considerably more often during their breeding and migration period ($p < 0.01$) than in winter. There is a significant correlation between wire collision and the migration period ($p < 0.05$). A very considerable statistical correlation is demonstrated between the number of the victims of electrocution/ collision among the songbirds throughout all seasons ($p < 0.001$). No statistically relevant correlation is established between the killing rate of Storks and the seasons. A correlation of very high significance is found between the electrocuted specimens and the breeding season of the family Corvidae ($p < 0.001$). A highly significant in this group is also the correlation between the electrocuted birds and migration period ($p < 0.01$). There is a considerable correlation between the number of the collision victims and the breeding and migration period ($p < 0.05$).

Impact of the bird size

The size of birds was found to be among the important mortality factors related to the contacts with the power supply network. The results after analysing the five studied groups according to the bird size show that bird size has no significant overall impact on electrocution probability ($F = 1.33$, $p = 0.3$) or wire collision ($F = 1.67$, $p = 0.2$). Nonetheless, in the collision victims there is a statistically significant difference between the birds from group B and those from group D ($p = 0.02$). The density of victims belonging to group B is 0.06/km while group D shows 0.12/km.

Discussion

The large number of victims established in this study shows that the mortality of birds on contacting with the hazardous power supply network is a problem of considerable negative impact on the populations in a variety of species. The results obtained reveal that along the Bulgarian 20 kV power supply network a vast number of bird species get killed, with the better part of those species being protected by the Biological Diversity Act and some being considered threatened with extinction in Europe and/or worldwide by BirdLife International and the IUCN, as well as listed in Appendix I of the Birds Directive of the EU (Council Directive 79/409/EEC, dated 02 April 1979 on the conservation of wild birds). Both aspects of the problem: electrocution and wire collision have various degrees of negative impact on different groups of birds. This study confirms the findings of the initial studies carried out in Bulgaria (Demerdzhiev *et al*. 2009, Gerdzhikov, Demerdzhiev 2009), showing that 2/3 of the victims of the hazardous power supply network die of electrocution. Among the most seriously affected groups are the species of the family Corvidae, Ciconiiformes and diurnal raptors, which account for 77% of all victims. A number of studies reveal that the birds most affected by electrocution are corvids and diurnal raptors. In some parts of Spain, these systematic groups account for 80% – 96% of the electrocution victims (Guyonne *et al*. 2001, Manosa 2001). Similar results were obtained in southeastern France where diurnal raptors and corvids account for 85% of the electrocution victims (Bayle 1999). The most numerous victims to electrocution in Europe include: Common Buzzard, Black Kite, Red Kite (*Milvus milvus* Linnaeus, 1758), and Common Kestrel (Lehman *et al.* 2007). In Mongolia, raptors account for more than 60% of all victims of electrocution, found under a total of 1427 inspected power poles (Harness *et al.* 2008). The Spanish Imperial Eagle and the Bonelli's Eagle are particularly affected by electrocution. Within a 16-year period (1989-2004), the transmission of electricity caused more than half (50.2%) of the non-natural deaths of Spanish Imperial Eagles (González *et al.* 2007). In Bulgaria, the main factor related to the mortality of Imperial Eagles is electrocution. The data gathered during a twenty years' study period show that 35% of immature eagles' deaths resulted from electrocution (Author's unpubl. data). The high mortality rate with the eagles' species is related to their ecology. They often use power poles for rest or as perches for hunting (Demerdzhiev *et al*. 2009). When perching on poles, birds sometimes touch the power pole and wire with parts of their bodies and get electrocuted (Stoychev, Karafeizov 2004, Demerdzhiev *et al*. 2009). A considerable number of White Storks migrate through Sakar SPA and Zapadna Strandzha SPA. In these sites, throughout the breeding period, there are also flocks of hundreds of floaters (Author's unpubl. data). The great number of dead storks is a result of their behavior, namely using power poles as a resting perch to avoid terrestrial predators at night. While perching on the poles to roost, especially when there are not enough poles and the flock is big, the birds often fight. This increases the risk of electrocution. Storks and big diurnal raptors sometimes get electrocuted while defecating since their semi-liquid feces provoke a voltaic arc. Electrocution with starlings occurs when their large flocks perch on wires near the power pole. When all birds in the flock simultaneously fly off, the wires sway and come in contact, thus killing the birds. Collision with wires is the most often reason for songbirds to get killed as they fly in flocks and cross the wire-span. When crossing the power lines, the flocks of songbirds are considered a single object and when it comes in contact with the wires, a voltaic arc can be formed. Thus, not all birds get killed but just some of them. The high number of storks killed by collision with wires is recorded mainly during the migration period when flocks of hundreds of storks cross the power supply lines. Strong wind and poor weather increase considerably the risk of collision (Demerdzhiev *et al*. 2009). Victims of collision are also some poor fliers, such as moorhens, spotted crakes, partridges, pheasants, chukars.

The pylon design is one of the main factors related to bird mortality caused by electrocution. A number of studies (Ferrer *et al*. 1991, Harness 2000, Manosa 2001, Guyonne *et al*. 2001, Demerdzhiev *et al*. 2009) show the interdependence between the electrocution of birds and the type of construction of the power poles. With Type 1 poles, proven to be of highest hazard, although the external adaptors are ducted under the horizontal beams of the pole, the upper adaptor-wire is mounted in such a way that a perching bird can easily come in contact with it. In the works of Demerdzhiev *et al*. (2009), this type of power poles is also identified as the most hazardous as it concentrates 54.3% of all electrocution victims. The power poles of Type 6 (circuit breakers), because of the location of their insulators, upward and parallel to the wires, are very convenient for perching, which increases the risk of contact between the bird and the wire. However, circuit breakers are rarely used on the power supply lines; otherwise their killing rate would have been even higher. The concrete power poles of Type 2 and the steel poles of Type 5, identified as dangerous for birds by Stoychev, Karafeizov (2004) and Demerdzhiev *et al*. (2009), were confirmed as such in this study. In Spain, the power poles of similar types were also noted as dangerous to birds (Ferrer *et al*. 1991, Jans, Ferrer 1999, Guyonne *et al*. 2001). The results obtained on power poles of Type 3 and 4 confirmed the findings of the initial studies, which shows they are less dangerous to birds (Demerdzhiev *et al*. 2009).

The analysis of the environmental factors' impact on mortality of birds shows that various factors have different impact. Relief impacts the mortality rate of the various groups of birds in different ways. Raptors and storks are often electrocuted in elevated relief, as they prefer perching on poles located in uneven sites. Songbirds are killed by electrocution or collision with wires mostly on flat relief as they prefer open areas.

Habitat also has a considerable impact on mortality of birds. The victims of electrocution are mainly birds in open grasslands, vineyards, and orchards. In pastures and deserted lands, the mortality rate is high in diurnal raptors, songbirds and corvids that feed in these habitats. Storks, corvids and songbirds get killed mostly in arable lands. Birds get killed by collision mostly in vineyards, open grasslands and arable lands. Those victims are mainly songbirds and corvids. The power supply lines rarely cross forested areas where, owing to the availability of suitable perching substrate, these lines are rarely used by birds; hence the killing rate is lower in such habitat. Also, the presence of raptors or bird concentrations in the vicinity of the power lines may be a result of the landscape peculiarities (Hunting 2002), including vegetation structure and composition, prey density, and perch availability. The risk of mortality caused by electrocution is considerably higher for species breeding in open habitats (*e.g.* wetlands, grasslands), since they provide less nesting places and natural perches (Haas *et al.* 2005, Lehman *et al.* 2007).

Seasons have impact on the mortality of birds when the latter get in contact with the hazardous power supply network. Mortality rate peaks during migration because of the increased number of birds in the studied areas. Similar results were obtained in central Kazakhstan on comparing the number of victims in the migration and breeding period (Lasch *et al.* 2010). High mortality rate is also registered in the breeding period as most of the birds use the power supply facilities to perch and hunt, copulate, etc. In the migration and breeding periods, it is mainly raptors, corvids and storks that get electrocuted. During these periods, raptors and birds of Corvidae family show a high killing rate due to collision with wires. Songbirds have a high mortality rate due to both electrocution and collision with wires throughout the seasons studied. In the other studies most bird deaths are recorded in late summer, in the period of fledging or post-fledging (Bevanger 1998, Bayle 1999, Manville 2005, Lehman *et al.* 2007, Lasch *et al.* 2010). However, migrating birds are exposed to a greater risk of collision in poor weather conditions that force them to fly at lower altitudes (especially at night). This is also valid for migrating birds that stop over near a power line. Unlike local birds, migratory birds are not aware of the landscape and the related obstacles.

Although an insignificant factor, the size of birds impacts their mortality along the power supply network. In general, the large birds are more affected by electrocution, because the conductors are too far apart and smaller birds cannot touch them simultaneously (Janss, Ferrer 1999). Birds of the size of a crow, big and medium sized raptors and storks are often electrocuted. Storks and small songbirds often die from collision with wires. Birds of the size of a pigeon get rarely killed.

Conservation implementation

A total of 535 poles of Type 2 were insulated within „Conservation of Imperial Eagle and Saker Falcon in key Natura 2000 sites in Bulgaria" LIFE07 NAT/BG/000068. The insulators were fitted on the hazardous poles in the territories of six Imperial Eagle pairs in the Sakar, Zapadna Strandzha, and Kamenski Bair SPAs. The examinations of the insulated poles confirmed the efficiency of the insulators, since no victims were found under the poles. In different countries the problem related to the hazardous power supply network is solved at different levels and through different approaches. In Germany, there is a prohibition on the construction of new "killer poles", and all existing power poles were agreed to be safeguarded by 2012. In the Netherlands, all low utility and medium voltage distribution lines are installed underground. Similar measures have been undertaken in other countries as well (Belgium, the United Kingdom, Norway, Denmark, and Germany). This has resulted in the complete elimination or a considerable reduction of the risk of electrocution in those countries. The biggest power supply company in the Czech Republic agreed to retrofit the power lines in the Special Protected Areas of the Natura 2000 network and other hotspots (Schürenberg *et al.* 2010). More than 50 000 medium voltage power poles were modified and safeguarded in Hungary (Demeter 2004, Horvath *et al.* 2011). In Spain, electrocutions decreased considerably since 1990, following the adoption of a mandatory regulation, which resulted in the substitution of 6560 dangerous pylons (López-López *et al.* 2011).

Collision prevention measures applied in different countries include: route planning, underground cabling, replacement of overhead wires with underground lines, and line modification. These modifications reduce the risk of collision, keep birds away from the power line, and make the conductors more visible. Underground cabling is the best solution to electrocution and collision. However, since this is also the most expensive mitigation measure, it is applied mainly in the countries of Western Europe (Jenkins *et al.* 2010). Another possible method preventing bird collision is fitting coloured bird diverters on the power lines.

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