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Bird mortality on medium-voltage power lines in the Czech Republic

Mortalita ptáků na elektrických linkách vysokého napětí v České republice

Vlasta ŠKORPÍKOVÁ, Václav HLAVÁČ & Milan KŘÁPEK

Abstract: In 2015–2016, 6,429 km medium-voltage power lines with 76,430 pylons were checked for bird mortality in the Czech Republic. 1,326 bird victims of power lines were found, 156 of which died after collisions, and 1,170 birds were electrocuted. They belonged to 60 species from 12 orders, and birds of prey made up almost half of all victims. Steel pylons bearing several cross-arms including upper and crosswise jumpers were identified as most dangerous from the electrocution point of view. On the other hand, pylons in straight lines with Pařát cross-arms (triangular arrangement of conductors without any horizontal bar) were among the least dangerous, and when they had a simple perch fitted below the cross-arm, no mortality was recorded. But these pylons are new in practice and despite becoming widely used recently, they form less than one tenth of all pylons in the Czech Republic. On other pylons various types of mitigation measures have been installed. Commonly used plastic covers and plastic strips have proved to be especially effective, but only in cases when they are undamaged and correctly installed.

Abstrakt: V letech 2015–2016 bylo v České republice zkontrolováno 6429 km linek vysokého napětí se 76 430 sloupy s cílem podchytit mortalitu ptáků. Bylo nalezeno 1326 mrtvých ptáků, 156 z nich uhynulo následkem kolize s vodičem, 1170 v důsledku výboje na sloupu. Postiženo bylo 60 druhů z 12 řádů, dravci a sovy tvořili téměř polovinu všech obětí. Z hlediska rizika mortality zapříčiněné výbojem se jako nejnebezpečnější ukázaly být ocelové sloupy s více typy konzol a propojením vodičů horními a příčnými spojkami. Na druhé straně sloupy v přímé linii s konzolou typu Pařát (trojúhelníkové uspořádání vodičů bez jakéhokoli vodorovného prvku) patřily k nejméně rizikovým. Pokud byly doplněny ještě o jednoduché bidlo umožňující dosedání ptáků, nebyla na nich zaznamenána vůbec žádná mortalita. Tento typ byl však do praxe zaveden nově, a ačkoli je dnes již široce využívaný, tvoří stále méně než desetinu všech sloupů v České republice. I jiné typy sloupů jsou doplňovány různými prvky, které mají riziko ptačí mortality snížit. Zvláště obecně užívané plastové kryty a límce se ukázaly být efektivními, avšak pouze v případě, že byly nepoškozené a správně instalované.

Key words: electrocution, collisions, mitigation measures

Vlasta Škorpíková, Czech Society for Ornithology, South Moravian Branch, Lidická 27, CZ-602 00 Brno, Czech Republic; Regional Authority of the South Moravian Region, Žerotínovo nám. 3, CZ-601 82 Brno, Czech Republic. E-mail: vlasta_skorpikova@volny.cz.
Václav Hlaváč, Nature Conservation Agency of the Czech Republic, Regional Office of the PLA Žďárské vrchy Administration, Husova 2115, CZ-580 02 Havlíčkův Brod, Czech Republic.
Milan Křápek, College of Regional Development and Banking Institute – AMBIS, a.s., Mezírka 775/1, CZ-602 00 Brno, Czech Republic.

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Introduction

Bird mortality on power lines has been a well-known problem for a long time (APLIC 2006). Birds are affected by collisions with cables or electrocuted on pylons (Lehman et al. 2007). The number of individuals killed annually is high, but the influence of this phenomenon on the population level has been rarely estimated (Bernardino et al. 2018). Since the second half of the 20th century, more attention has been paid to this problem in many countries. The placing of power lines under ground as the most effective solution was completed in the Netherlands and is currently being carried out in Belgium, Denmark, Germany, Norway and the United Kingdom (Prinsen et al. 2011). Otherwise, it has been only implemented in selected regions, e.g. in Austria or Hungary due to protection of the great bustard populations (Raab et al. 2012). More recently efforts have been made by the responsible authorities, bird protection organizations and also power distributors to concentrate on improving the lines and pylon types used.

In the Czech Republic, public attention to the problem of bird mortality on power lines was first widely attracted by an exhibition called "The Light for Prague" in 2001. But up to now, no system of regular monitoring has been developed. Data on electrocutions have been collected from various sources: rescue stations, results of particular projects, studies or assessments focused entirely or partially on this topic, and public databases (www.birds.cz/avif). Nevertheless, thanks to the general pressure of nature protection organizations and especially to the adoption of EU legislation, power distributors are now allowed to use only bird-friendly types of pylons and devices during the construction or reconstruction of medium-voltage power lines, and they have to retrofit all dangerous pylons with approved devices by 2024 (Hlaváč et al. 2013). Three organizations are responsible for electricity distribution, managing and taking care of 73,268 km of medium-voltage power lines. Recently, their attitude to the usage of various pylon types and bird protective equipment has changed somewhat, but all have to cooperate with the Nature Conservation Agency of the Czech Republic. This expert body of the Ministry for the Environment is responsible for assessing which types of used or newly-proposed technical solutions in the distribution of electricity through medium-voltage lines are bird-safe. Due to the lack of appropriate data for specific conditions in the country, a study named "Bird Mortality on Medium-voltage Power Lines" was carried out in 2015–2016 in the framework of the project called "Comprehensive Protection of Fauna in Terrestrial Ecosystems against Landscape Fragmentation in the Czech Republic". The study had several aims: to find out which bird species were most affected by collisions and electrocutions; to obtain precise data on dangerous types of pylons or high-risk devices on them; to evaluate the effectiveness of mitigation measures used; and to estimate the total annual bird mortality on medium-voltage power lines in the Czech Republic (Hlaváč et al. 2017). The most important results are presented in this article.

Material and methods

With the aim of recording as many cases of bird mortality on power lines as possible, attention was focused on open lowland landscapes. Field-work sessions were organized using grid squares created for Kartierung der Flora Mitteleuropas (KFME, 6 latitudinal × 10 longitudinal minutes, i.e. approximately 12.0 × 11.2 km, Ehrendorfer & Hamann 1965). 453 out of 678 squares covering the Czech Republic were deemed suitable, because open landscape below 500 m a.s.l. formed min. 80% their area. Co-workers were found so that the country area was covered equally, if possible, with each of them exclusively working in selected squares to avoid repeating checks of power lines during the project period. In total, 24 field workers checked 6,429 km of medium-voltage power lines with 76,430 pylons of various types in 291 grid squares (Fig. 1). This represents almost one tenth of the total length of medium-voltage power lines in the country (73,268 km).

Field work started on 1st July 2015 and finished on 11th April 2016, but most of it was concentrated in the period from September to March (Fig. 2), when harvest activities were finished and the vegetation in the open landscape was low. Periods with snow cover were avoided.

Bird mortality and parameters of pylons were recorded by means of one-time zig-zag walking below medium-voltage power lines (22 kV and 35 kV) with special attention paid to the surroundings of the pylons. These parameters of pylons were recorded: localization (GPS coordinates); position in a line (straight = in a straight line, corner = in a place where the line direction changed, branch = when a new line started on the pylon or terminal); pole material (wood, concrete or steel); number of cable levels; cross-arm type (horizontal – Fig. 3, Delta – Fig. 4, Pařát – Fig. 5, Delta variant – Fig. 6, untypical, including any combination of several cross-arms – Figs. 16–19, or transformer station); insulators – number (per cable) and type (upright – Fig. 3,

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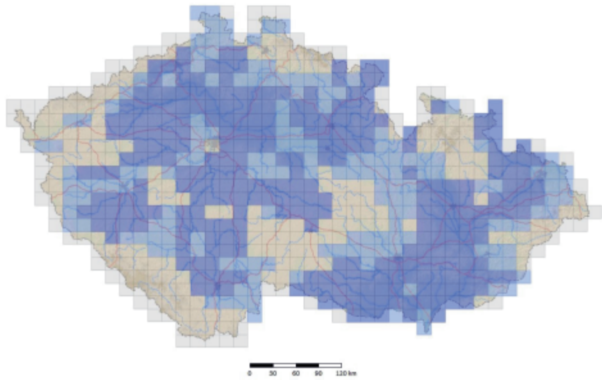

Fig. 1. A map of the Czech Republic with a network of grid squares, where squares suitable, i.e. open landscape below 500 m a.s.l. forming min. 80% of their area are highlighted (blue); and squares chosen for field work are in dark blue.
Obr. 1. Kvadrátová mapa České republiky, kde kvadráty vhodné (otevřená krajina v nadm. výšce pod 500 m tvoří min. 80% plochy) jsou zvýrazněny modrou barvou; kvadráty vybrané mapovateli, kde nakonec probíhaly terénní práce, tmavě modrou.

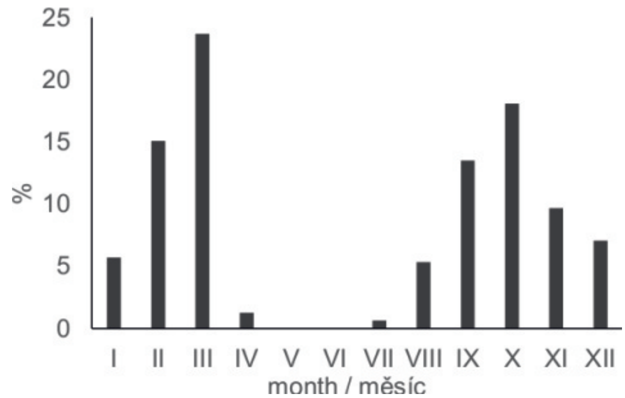

Fig. 2. Percentage of pylons checked monthly in the period from July 2015 to April 2016.
Obr. 2. Množství sloupů (v %) kontrolovaných v jednotlivých měsících od července 2015 do dubna 2016.

suspended – Fig. 19 or strain – Fig. 16); type of present mitigation measures (rack – Fig. 7 or other type of perch discourager – Fig. 18, plastic cover – Fig. 8, plastic strip – Fig. 9, simple perch – Fig 10, bench – Fig. 16 or other type of safe perch – Fig. 18) and its state (satisfactory – Fig. 7–11, damaged or incorrectly fitted – Figs. 12–15). Pictures of each pylon were taken and based on them all parameters were subsequently checked and corrected (if they were incorrectly named by a co-worker), and at the same time information on other components, i.e. jumpers (upper, lower and crosswise), surge arresters and switch disconnectors in upper or lower position (if present), as well as altitude of pylons was added.

The following parameters of bird carcasses were recorded: localization (GPS coordinates), bird species, sex and age (if possible to identify) and cause of death mainly according to the position below a power line (collision, electrocution). Each of them was photographed and recorded data were subsequently checked and corrected, for example piles of feathers found evidently at raptors´ plucking sites were excluded. All found carcasses were divided into four age categories: 1 – less than a week, 2 – from a week to a month, 3 – from one month to two months and 4 – older than two months, and various circumstances were taken into account, among other things damage to the body by field work, traffic or scavengers. For later practical use, a group of target species of all electrocuted birds was assessed separately. Target species, i.e. raptors (Accipitriformes and Falconiformes), owls (Strigiformes) and corvids (Cor-

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Fig. 3–6. Four basic cross-arm types used for medium-voltage electrical lines in the Czech Republic: a horizontal console with upright insulators (“killer pylon”; 3), Delta (4), Pařát (5) and Delta variant (6).
Obr. 3–6. Čtyři základní typy konzol užívaných na elektrických linkách vysokého napětí v České republice: rovinná konzola s podpěrnými izolátory („sloup smrti“; 3), Delta (4), Pařát (5) a Delta variant (6).

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Fig. 7–11. Correctly installed and undamaged components used as mitigation measures on basic cross-arms: racks (7) or plastic covers (on horizontal cross-arms and upright insulators; 8), plastic strips (on Delta cross-arm; 9) or simple perch (used with Pařát, 10, and Delta variant cross-arms, 11).
Obr. 7–11. Správně instalované a nepoškozené ochranné prvky užívané na základních typech konzol: hřebeny (7) nebo plastové kryty (na rovinných konzolách s podpěrnými izolátory; 8), plastové límce (na konzolátch typu Delta; 9) nebo dosedací tyč (užívaná s konzolami typu Pařát, 10, a Delta Variant, 11).

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Fig. 12–15. Incorrectly installed or damaged components used as mitigation measures on/with basic cross-arms: racks with broken teeth or missing parts, plastic covers partly free of cables, a loose plastic strip, a perch installed too high.
Obr. 12–15. Nesprávně instalované nebo poškozené ochranné prvky užívané na základních typech konzol: hřebeny s vylámanými zuby nebo chybějícími částmi, plastové kryty kryjící vodič jen částečně, uvolněný plastový límec, dosedací tyč instalovaná příliš vysoko.

vidae), apart from Eurasian magpies (*Pica pica*) and Eurasian jays (*Garrulus glandarius*), are affected by a similar mechanism due to their comparable size and behaviour, and at the same time their mortality on pylons is important from a nature conservation point of view. Results testing was especially focused on other components, mitigation measures and chosen pylon types. Pylons with a horizontal cross-arm and upright insulators (known as „killer pylons“) deserved that attention due to their widespread use and pylons with a Pařát cross-arm as a recommended solution for medium-voltage power lines in the Czech Republic.

Basic summarization of recorded pylon types and pylons with mortality caused by electrocution is presented in Appendix 1. Bird taxonomy and nomenclature used in this article follows the IOC World Bird List, version 9.2 (Gill & Donsker 2019).

S t a t i s t i c a l   a n a l y s i s
Eighteen variables were used for statistical analysis, 16 of them independent: (i) pylon position – a categorical variable which takes on these values: straight, corner, branch and terminal; (ii) pole material – a categorical variable which takes on these values: wood, concrete, steel; (iii) cross-arm type – a categorical variable which takes on these values: horizontal, Pařát, Delta, Delta variant, transformer station and untypical; (iv) simple perch, other type of safe perch, plastic strip, plastic cover, rack, perch discourager and cable insulation (mitigation measures), surge arrester, crosswise jumper, upper

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Fig. 16–19. A concrete branch pylon with three horizontal cross-arms, upper, lower and crosswise jumpers and two benches (16), a steel branch pylon with two horizontal cross-arms (17), on which extremely high mortality was found. It was replaced with the pylon in Fig. 18; a concrete pylon with Pařát and horizontal cross-arms and more bird-protection measures: a horizontal plastic element as a safe perch, a jumper insulation and perch discouragers on the horizontal cross-arm (18); a steel pylon with two cable levels and suspended insulators (19).

Obr. 16–19. Betonový sloup s odbočkou nese tři rovinné konzoly, horní, spodní a příčné spojky propojující vodiče a dvě lavičky pro dosedání ptáků (16); železný příhradový sloup se dvěma rovinnými konzolami (17), na kterém byla zjištěna extrémní mortalita ptáků. Byl nahrazen sloupem na obr. 18; betonový sloup s rovinnou konzolou a konzolou typu Pařát, s více typy ochranných opatření: rovinný plastový prvek pro bezpečné dosedání ptáků, izolace spojky a zábrana proti dosedání ptáků na rovinné konzole (18); železný příhradový sloup s vodiči ve dvou úrovních a závěsnými izolátory (19).

jumper, lower jumper, upper switch disconnector and lower switch disconnetor (other components) as binary variables.

Two binary variables were dependent: mortality of all birds and mortality of target species. Independent categorical variables were tested with the χ^2 test of independence to dependent variables. The influence of binary variables divided into two groups (mitigation measures and other components) was assessed with the z-test. Relative mortality on pylons with one type of mitigation measure (or other component) and on pylons without any type of mitigation measure (or other component) were compared. Using χ^2 tests and mutual comparisons of pairs of mitigation measures or other compoments, their significance was assessed.

Logistic regression was used for multivariate analysis. Categorical variables were changed into binary variables in the sense that one of them was excluded, because it was functionally dependent on the others (it takes on 0 value in other binary variables). In the end, we had 2 dependent and 23 independent variables, all of them binary. Variables were tested with the Pearson correlation coefficient so that the explanatory variables of the model were not strongly linearly dependent. Predictions found by means of logistic regression were then verified with the χ^2 test. Results with probability $P \leq 0.05$ were considered as statistically significant. To assess the effect of altitude on bird mortality caused by electrocution, the Mann-Whitney U-test was used.

Results

During the survey, 1,326 bird victims of power lines were found, i.e. 1 ind. per 4.85 km (0.21 ind./km). 156 birds (11.76%) died after collisions, 1,170 birds (88.24%) were electrocuted, 54.15% of them were raptors. 26 carcasses found remained unidentified, because only very damaged parts of the skeleton were available or body remnants were inaccesible on a pylon cross-arm. 1,300 identified birds belonged to 60 species from 12 orders, Accipitriformes made up 35.85% and Falconiformes 12.23%.

Time distribution of mortality

The month of death was determined for both collided and electrocuted birds from carcass categories 1–3 (Fig. 20). It is apparent that bird mortality on power lines was highest in the autumn.

Mortality caused by collisions

156 birds were found dead after collisions with cables, i.e. 1 ind. per 41.21 km or 0.02 ind./km.

Affected species: 155 carcasses were identified to species level, belonging to 46 species from 11 orders (Appendix 2). Collision with cables especially threatened perching birds (Passeriformes), which made up half of all collision victims found (78 ind., 50.32%). Particularly *Turdus* sp., e.g. common blackbird (*T. mer-*

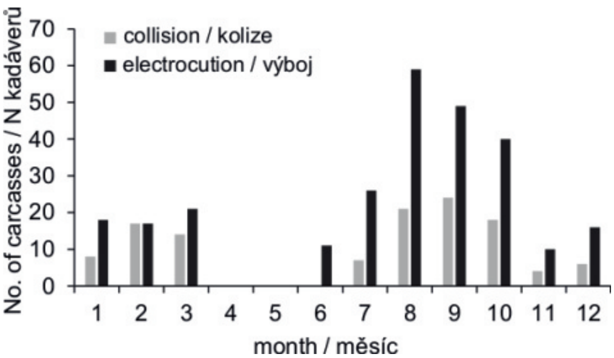

Fig. 20. Bird mortality on medium-voltage electrical lines in months of the year based on carcasses not older than two months (n = 119 collided and 267 electrocuted birds).
Obr. 20. Mortalita ptáků na elektrických vedeních vysokého napětí v jednotlivých měsících roku podle kadáverů ne starších než dva měsíce (n = 119 ptáků uhynulých v důsledku nárazu do vodiče a 267 ptáků uhynulých v důsledku výboje na sloupu).

ula), fieldfare (*T. pilaris*) and song thrush (*T.* philomelos), were afflicted (33 ind., 21.29%). Among other victims, *Columba* sp., e.g. feral pigeon (*C. livia* f. *domestica*), stock dove (*C. oenas*) and common wood pigeon *C. palumbus* (19 ind., 12.26%), and mallard *Anas platyrhynchos* (16 ind., 10.32%) were most numerous.

Influence of the number of cable levels: The number of cable levels in sections (a section is the part of a line between two pylons) was 1–10, single-level sections formed almost two-thirds of them (Tab. 1). 156 birds which had died after collision with a cable were found. They collided on sections with 1–5 cable levels. For statistical testing, bird mortality on single–level and multi-level sections was compared. No statistical difference was found: $\chi^2 = 1.49$, df = 1, P = 0.22.

Mortality caused by electrocution

1,170 birds were found as victims of electrocution after checking 76,430 pylons, i.e. 0.015 ind./pylon. 1–10 carcasses were found below a pylon, bird mortality was recorded at 949 pylons (1.24% all checked pylons). Mostly one dead bird was found below a pylon (829×), 71× two birds and 25× three birds were found, exceptionally up to seven, eight and ten killed birds were recorded. Regarding target species, 826 ind. were electrocuted on 718 pylons (0.94% of all checked pylons).

Affected species: 1,145 out of 1,170 bird victims of electrocution were identified to species level (Appendix 2). They belonged to 31 species from 9 orders. Electrocution threatened mostly birds of prey, i.e. Accipitriformes and Falconiformes (620 ind., 54.15%) and Corvids (385 ind., 33.62%). The common buzzard *Buteo buteo* (452 ind., 39.48%), magpie *Pica pica* (201 ind., 17.55%) and common kestrel *Falco tinnunculus* (159 ind., 13.89%) were the most frequent victims.

Influence of pole material: The relationship between pole material and bird mortality was statistically significant in both all and target species: $\chi^2 = 125.90$, df = 2, $P < 0.05$ and $\chi^2 = 77.72$, df = 2, $P < 0.05$ respectively. The highest mortality was found on steel pylons, and it was approximately double that on concrete pylons (Tab. 2). Mortality on wooden pylons was negligible, with only one bird carcass recorded. It could however result from using steel pylons for more complex cross-arms with other components. Nevertheless, the difference was also confirmed when only pylons with other components (regardless of their type) were tested ($\chi^2 = 28.45$, df = 2, $P < 0.05$ and $\chi^2 = 27.89$, df = 2, $P < 0.05$) and it was most conspicuous on pylons with a horizontal cross-arm and upright insulators (without other components or mitigation measures) ($\chi^2 = 44.45$, df = 2, $P < 0.05$ and $\chi^2 = 36.96$, df = 2, $P < 0.05$), where bird mortality on steel pylons was approximately 9× higher than on concrete pylons.

Influence of pylon position: The relationship between pylon position and bird mortality was statistically significant in both all and target species: $\chi^2 = 208.54$, df = 2, $P < 0.05$ and $\chi^2 = 104.44$, df = 2, $P < 0.05$ respectively. Corner and branch pylons were at least 2× more dangerous for birds than pylons in straight lines (Tab. 3). According to the two-sided z-test of equal proportions it was confirmed that bird mortality was lowest on pylons in ending position, it was higher on pylons in straight lines and the highest on corner and

Tab. 1. Bird mortality caused by collisions on sections of medium-voltage power lines according to the number of cable levels.
Tab. 1. Mortalita ptáků způsobená kolizí na úsecích elektrických linek vysokého napětí podle počtu rovin vodičů.

No. of conductor levels / Počet rovin vodičů	Total no. of sections / Celkový počet úseků	Sections with mortality / Úseky s mortalitou (n / %)
1	48,006	93 / 0.19
> 1	26,659	63 / 0.24

Tab. 2. Bird mortality on pylons depending on pole material. Target species = raptors (Accipitriformes and Falconiformes), owls (Strigiformes) and corvids (Corvidae), apart from Eurasian magpies (*Pica pica*) and Eurasian jays (*Garrulus glandarius*).
Tab. 2. Mortalita ptáků na sloupech linek vysokého napětí v závislosti na materiálu sloupu. Cílové druhy = dravci (Accipitriformes a Falconiformes), sovy (Strigiformes) a krkavcovití (Corvidae) kromě straky (*Pica pica*) a sojky (*Garrulus glandarius*).

	material / materiál	all pylons / všechny sloupy		pylons with horizontal cross-arm and upright insulators / sloupy s vodorovnou konzolou a podpěrnými izolátory		pylons with other components / sloupy s dalšími prvky	
		no. of pylons / n sloupů	p. with mortality / s. s mortalitou (n / %)	no. of pylons / n sloupů	p. with mortality / s. s mortalitou (n / %)	no. of pylons / n sloupů	p. with mortality / s. s mortalitou (n / %)
all species / všechny druhy	concrete / beton	65,858	738 / 1.12	31,131	362 / 1.16	13,112	244 / 1.86
	steel / ocel	8,625	209 / 2.42	57	6 / 10.53	6,243	189 / 3.03
	wood / dřevo	1,896	2 / 0.11	116	0 / 0.00	90	0 / 0.00
	Σ	76,379	949 / 1.24	31,304	367 / 1.17	19,445	433 / 2.23
target species / cílové druhy	concrete / beton	65,858	568 / 0.86	31,131	301 / 0.97	13,112	154 / 1.18
	steel / ocel	8,625	149 / 1.73	57	5 / 8.77	6,243	133 / 2.13
	wood / dřevo	1,896	1 / 0.05	116	0 / 0.00	90	0 / 0.00
	Σ	76,379	718 / 0.94	31,304	306 / 0.98	19,445	287 / 1.48

branch pylons, while the difference between the last two types was not significant. This analysis however produces just information about where the most dangerous pylon types are used; it does not answer the question as to why the bird mortality on them tends to be so high.

Influence of cross-arm type: Pylons were compared according to their cross-arms regardless of other components or mitigation measures (Tab. 4). Cross-arm type had significant influence on bird mortality in both all and target species: $\chi^2 = 95.91$, df = 5, $P < 0.05$ and $\chi^2 = 60.16$, df = 5, $P < 0.05$, respectively. Pylons with one horizontal cross-arm were the most numerous (62.38%) and they were responsible for a substantial proportion of electrocuted birds (58.72% carcasses of all species and 60.54% of target species). Untypical pylons, i. e. with more cross-arm types, were most dangerous; they only made up 18.34% of all pylons, but they were responsible for 31.45% (29.04%) of mortality. According to the two-sided z-test of equal proportions, a statistically significant difference was found between these pylon types (arranged from the least to the most dangerous): Pařát + transformer stations – Delta + Delta variant – horizontal – untypical in all species and Pařát + transformer stations – Delta + Delta variant + horizontal – untypical in target species (the differences between pylon types connected with + were not significant).

Influence of other components: Six other components on pylons were tested: surge arresters, upper, lower and crosswise jumpers, and upper and lower switch disconnectors (Tab. 5). Presence of other components significantly increased mortality in both all and target species: $\chi^2 = 206.37$, df = 1, $P < 0.05$ and $\chi^2 = 80.66$, df = 1, $P < 0.05$ respectively. Influence of other components was confirmed in the case they were used separately ($\chi^2 = 628.48$, df = 5, $P < 0.05$ and $\chi^2 = 317.35$, df = 5, $P < 0.05$), as well as when they were combined ($\chi^2 = 114.90$, df = 5, $P < 0.05$ and $\chi^2 = 46.57$, df = 5, $P < 0.05$). When other components were used separately, the two-sided z-test of equal proportions for all species confirmed that bird mortality on pylons with lower jumpers and lower and upper switch disconnectors was below average; crosswise jumpers increased it approximately 2× and surge arresters and upper jumpers more than 3×. In the case of target species, bird mortality on pylons with upper and lower disconnectors and lower jumpers was lower than on pylons without any other components, whereas crosswise jumpers and surge arresters increased it nearly 2× and upper jumpers 3× (the difference between the last three groups however was not significant).

Tab. 3. Bird mortality on pylons of medium-voltage power lines depending on their position in the line. Target species = see Tab. 2.
Tab. 3. Mortalita ptáků na sloupech linek vysokého napětí v závislosti na jejich pozici v lince. Cílové druhy = viz Tab. 2.

pylon position / pozice sloupu	no. of pylons / n sloupů	all species / všechny druhy pylons with mortality / sloupy s mortalitou (n / %)	target species / cílové druhy pylons with mortality / sloupy s mortalitou (n / %)
in straight line / v přímé linii	62,863	631 / 1.00	501 / 0.80
branch / odbočka	7,529	203 / 2.70	135 / 1.79
corner /rohový	4,816	110 / 2.29	79 / 1.64
terminal / koncový	1,222	5 / 0.41	3 / 0.25
∑	76,430	949 / 1.24	718 / 0.94

Regarding all species and combined components, the two-sided z-test of equal proportions confirmed that the influence on mortality rate was not significant for lower and upper switch disconnectors, but surge arresters, crosswise and lower jumpers increased it approximately 3× and upper jumpers 4×. Differences found for target species were virtually the same; they were just less noticeable.

Influence of bird protection measures: Bird mortality on pylons with any type of bird-protective measures, taking their current state into consideration (suitable versus unsuitable, i.e. damaged or incorrectly installed, regardless of any other parameters and components) was compared with that on unprotected pylons (Tab. 6). The influence on bird mortality was statistically significant in both all and target species ($\chi^2 = 46.93$, df = 2, P < 0.05 and $\chi^2 = 33.62$, df = 2, P < 0.05 respectively). In both groups the mortality on pylons without bird-protection measures was approximately twice higher than on pylons with protection ($\chi^2 = 43.45$, df = 1, P < 0.05 and $\chi^2 = 29.63$, df = 2, P < 0.05). When protective measures were damaged or incorrectly installed, no significant difference in mortality on them and unprotected pylons was found, and mortality was virtually the same.

Eight types of bird protection measures were recorded: simple perches, other types of perches, racks (used on horizontal cross-arms), insulated cables, plastic covers (used on upright insulators), benches (used on horizontal cross-arms), plastic strips (used on Delta cross-arms) and perch discouragers. Their influence on bird mortality was significant for all and target species alike, regardless of whether they were used separately or in combinations, but these tests were not representative due to the low number of pylons equipped with other types of perches, benches, insulation and perch discouragers. The two-sided z-test of equal proportions for other mitigation measures produced the same results for all tested categories (all and target species, measures used separately or in combinations): significant difference was found between these groups (arranged from lowest to highest bird mortality): insulation + plastic strips – plastic covers – simple perches + racks.

Influence of mitigation measures was also tested for selected pylon types. Bird mortality on pylons with a horizontal cross-arm and upright insulators depended on the presence of mitigation measures and their current state in all as well as target species ($\chi^2 = 20.70$, df = 2, P < 0.05 and $\chi^2 = 13.58$, df = 1, P = 0.001, respectively). When protective measures were damaged or incorrectly installed, no significant difference in mortality on them and unprotected pylons was found. Special attention was also paid to pylons with other components, which are generally more dangerous than pylons without them. It was found that the mitigation measures used, regardless of their current state, were not able to decrease bird mortality significantly in all or target species ($\chi^2 = 1.20$, df = 2, P = 0.027 and $\chi^2 = 1.69$, df = 2, P = 0.19). On pylons with a Pařát cross-arm without other components, bird mortality was generally low, and in the case when a simple perch was installed, it was zero. But other components (specifically surge arresters) sharply increased mortality again. These results are not statistically significant due to the low number of variables.

Multivariate analysis: Bird mortality caused by electrocution was evaluated using correlation analysis. Apart from a few exceptions, the final correlation matrix did not confirm linear correlation between the variables. For that reason logistic regression analysis was then used. In the first model, pole material was found to be a significant variable. Significance of variable "concrete" and "wood" was confirmed, so also variable "steel" is significant, because it is in a functional relationship with them. Regarding mitigation measures, significant influence was found for plastic covers and plastic strips. Simple perches rather increased the mortality, but this variable also showed moderately strong dependence on cross-arm type, and collinear depend-

Tab. 4. Bird mortality on pylons of medium-voltage power lines depending on the cross-arm type. Target species = see Tab. 2.
Tab. 4. Mortalita ptáků na sloupech linek vysokého napětí v závislosti na typu konzoly. Cílové druhy = viz Tab. 2.

		all species / všechny druhy		target species / cílové druhy	
cross-arm type / typ konzoly	**no. of pylons / n sloupů**	**pylons with mortality / sloupy s mortalitou (n / %)**	**no. of carcasses / n kadáverů**	**pylons with mortality / sloupy s mortalitou (n / %)**	**no. of carcasses / n kadáverů**
horizontal / vodorovná	47,677	584 / 1.23	687	458 / 1.22	494
delta	6,171	54 / 0.88	60	46 / 0.75	52
pařát	5,677	23 / 0.41	33	13 / 0.23	15
delta variant	1,840	18 / 0.98	18	16 / 0.87	16
transformer station / trafostanice	1,049	4 / 0.38	4	2 / 0.19	2
untypical / netypická	14,016	266 / 1.90	368	183 / 1.90	237
Σ	76,430	683 / 1.24	1,170	718 / 0.94	579

ence could be the reason. So variables for cross-arm types were removed from further analysis, since no significant dependence was found for them.

The following model (Tabs. 7 and 8) did not confirm any significance of simple perches. All models proved that crosswise and upper jumpers increased mortality significantly for both all and target species, and surge arresters just for all species. Vice versa, the probability of mortality on pylons with lower jumpers was significantly reduced for target species.

All models evinced low values of the coefficient of determination. Nevertheless, χ^2 tests confirmed their statistical significance ($P < 0.001$). These results correspond with findings according to other statistical methods, and the coefficients of significant variables found here are in accordance with empirical experience.

In the following step, pylons were divided into three groups according to the probability of bird mortality associated with them (low, medium, high). For each group, estimated and empirically recorded numbers of bird mortality cases were compared (Tabs. 9 and 10). Results were assessed by means of χ^2 test, which confirmed that bird mortality estimated by logistic regression was not statistically different from bird mortality found empirically ($P = 0.272$ for all birds and $P = 0.376$ for target species). Furthermore, χ^2 tests of independence in a contingency table were carried out, which showed if recorded bird mortality on pylons corresponded with their categorization. The tests were positive ($P < 0.001$) for all and target species alike. It was proven that the sorting of pylons into three groups according to their degree of risk for birds estimated by means of models corresponds well to the field data.

Pylon altitude

Median altitude of pylons with recorded mortality (270 m a.s.l.) was significantly lower than that of pylons without recorded bird mortality (315 m a.s.l.; Mann-Whitney U-test, $P < 0.05$).

Discussion

Time distribution of mortality

The highest bird mortality found in autumn can not be a result of intensity of field work in those months, which comparison with Fig. 2 confirms. But this result is logical, because in autumn many freshly flying, inexperienced juveniles are present and the number of local birds is increased by migrating individuals. At the same time we assume that subsequent analyses were not in-

Tab. 5. Bird mortality on pylons of medium-voltage power lines depending on presence and type of other components. Target species = see Tab. 2.
Tab. 5. Mortalita ptáků na sloupech linek vysokého napětí v závislosti na výskytu a typu dalších prvků. Cílové druhy = viz Tab. 2.

other component / další prvek	no. of pylons / n sloupů	all species / všechny druhy pylons with mortality / sloupy s mortalitou (n / %)	target species / cílové druhy pylons with mortality / sloupy s mortalitou (n / %)
present / přítomný	19,445	433 / 2.23	287 / 1.48
absent / nepřítomný	56,985	516 / 0.91	431 / 0.76
∑	76,430	949 / 1.24	718 / 0.94
just pylons with the type of other component / jen sloupy s daným typem dalšího prvku			
surge arrester / omezovač přepětí	784	23 / 2.93	12 / 1.53
upper jumper / horní spojka	636	24 / 3.77	15 / 2.36
lower jumper / dolní spojka	1,902	10 / 0.53	8 / 0.42
crosswise jumper / příčná spojka	3,343	62 / 1.85	45 / 1.35
upper switch disconnector / horní odpínač	4,556	41 / 0.90	27 / 0.59
lower switch disconnector / dolní odpínač	718	6 / 0.83	3 / 0.42
all pylons with the type of other component (alone or in any combination) / všechny sloupy s daným typem dalšího prvku (výlučně nebo v jakékoli kombinaci)			
surge arrester / omezovač přepětí	1,049	32 / 3.05	17 / 1.62
upper jumper / horní spojka	6,554	266 / 4.06	176 / 2.69
lower jumper / dolní spojka	8,324	236 / 2.84	156 / 1.87
crosswise jumper / příčná spojka	7,697	213 / 2.77	146 / 1.90
upper switch disconnector / horní odpínač	4,571	42 / 0.92	28 / 0.61
lower switch disconnector / dolní odpínač	972	10 / 1.03	4 / 0.41

fluenced by preferred checking of specific pylons in the month with the highest bird mortality, because field work sessions were randomly distributed in space and time and the number of checked pylons in each month of the project duration was very high, from 4,074 to 18,099, apart from the months when the project started (July) and finished (April).

Mortality caused by collisions

In our study, 46 species (11 orders) were affected by collisions with electric cables. Passerines (30 species) represented 50.32% of all victims found, almost one fifth of them being common blackbirds. Pigeons and doves (Columbiformes) participated in this type of mortality with 14.19% and geese, mute swans and mallards (Anseriformes) with 13.55%. Bevanger (1998) divided birds susceptible to collisions into poor fliers, water birds, diving birds, marine soarers, aerial predators and thermal soarers. Our results are only partly in accordance with data of his review. Susceptibility to collisions was confirmed in Galliformes (10 ind./3 species), Anseriformes (21/3), Gruiformes (5/3), storks and herons (both 4/1). Low numbers of gulls (2/1) or owls (1/1) could also be expected. On the other hand, the proportion of pigeons, doves and especially passerines found was surprisingly high. This could be related to the time and space extent of our study, when both autumn and spring migration seasons in large areas of the country were included. Birds tend to be present in high numbers in open landscape in these periods, and some can become victims of collisions. The number of affected passerines especially can be generally underestimated in similar studies, because they can be easily overlooked and their carcasses have a higher disappearance rate (Ponce et al. 2010, Costandini et al. 2016). Sometimes they are excluded completely due to problems with their detectability in the field (Janss 2000). It is also possible that focusing on medium-voltage power lines produces a slightly different range of affected species compared with studies focusing on high-voltage lines, which prevail in the countryside.

Few studies give data on relative numbers of birds affected by collisions; many of them concentrate on regions or species attractive from the nature conservation point of view (Costantini et al. 2016 – national parks in Italy, Garrido & Fernández-Cruz 2003 – the white stork *Ciconia ciconia*), while others focus on geographically quite different regions (Loss et al. 2014, 2015 – the USA) or they relate to high-voltage power lines. Recently we could compare our results with the Slovak study from 2014–2016 (Gális et al. 2016): our collision rate of 0.02 birds/km on medium-voltage lines was strikingly lower than the numbers recorded in Slovakia: 0.23–1.4 birds/km. This apparently relates to the studied regions. While the Czech study focused on ordinary

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Tab. 6. Bird mortality on pylons of medium–voltage power lines depending on mitigation measures. Target species = see Tab. 2.
Tab. 6. Mortalita ptáků na sloupech linek vysokého napětí v závislosti na výskytu, stavu a typu ochranných prvků. Cílové druhy = viz Tab. 2.

mitigation measure / ochranný prvek	no. of pylons / n sloupů	all species / všechny druhy pylons with mortality / sloupy s mortalitou (n / %)	target species / cílové druhy pylons with mortality / sloupy s mortalitou (n / %)
present – suitable / přítomný – vyhovující	12,664	81 / 0.64	62 / 0.49
present – unsuitable / přítomný – nevyhovující	2,803	30 / 1.07	25 / 0.89
present all / přítomný vše	15,467	111 / 0.72	87 / 0.56
absent / nepřítomný	60,963	838 / 1.38	631 / 1.04
just pylons with the type of mitigation measure / jen sloupy s daným typem ochranného prvku			
plastic cover / plastový kryt	4,332	30 / 0.69	21 / 0.49
plastic strip / plastový límec	3,680	11 / 0.30	9 / 0.24
simple perch / jednoduché bidlo	1,882	24 / 1.28	20 / 1.06
other type of perch / jiný typ bidla	100	1 / 1.00	1 / 1.00
bench / lavička	983	6 / 0.61	5 / 0.51
rack / hřeben	3,276	31 / 0.95	25 / 0.76
perch discourager / zábrana proti dosedání	487	4 / 0.82	3 / 0.62
conductor insulation / izolace vodiče	340	1 / 0.29	0 / 0.00
all pylons with the type of mitigation measure (alone or in any combination) / všechny sloupy s daným typem ochraného prvku (výlučně nebo v jakékoli kombinaci)			
plastic cover / plastový kryt	4,650	33 / 0.71	24 / 0.52
plastic strip / plastový límec	3,729	11 / 0.30	9 / 0.24
simple perch / jednoduché bidlo	2,130	24 / 1.13	20 / 0.94
other type of perch / jiný typ bidla	150	3 / 0.20	3 / 0.20
bench / lavička	1,011	6 / 0.59	5 / 0.50
rack / hřeben	3,298	31 / 0.94	25 / 0.76
perch discourager / zábrana proti dosedání	570	6 / 1.05	5 / 0.88
conductor insulation / izolace vodiče	346	1 / 0.29	0 / 0.00
pylons with other components / sloupy s dalšími prvky			
present / přítomný	2,159	41 / 1.90	25 / 1.16
absent / nepřítomný	17,287	392 / 2.27	262 / 1.52
pylons with horizontal cross-arm and upright insulators without other components / sloupy s vodorovnou konzolou a podpěrnými izolátory bez dalších prvků			
present – suitable / přítomný – vyhovující	5,615	28 / 0.50	27 / 0.48
present – unsuitable / přítomný – nevyhovující	1,703	17 / 1.00	13 / 0.76
absent / nepřítomný	31,304	368 / 1.18	306 / 0.98
pylons with pařát cross-arm without other components / sloupy s konzolou typu pařát bez dalších prvků			
absent / nepřítomný	4,403	7 / 0.16	5 / 0.10
simple perch / jednoduché bidlo	751	0 / 0.00	0 / 0.00
pylons with pařát cross-arm and other components / sloupy s konzolou typu pařát a dalšími prvky			
absent / nepřítomný	358	8 / 2.23	3 / 0.84
simple perch / jednoduché bidlo	39	7 / 17.95	4 / 10.26

open landscape, the Slovak study concentrated on Special protected areas with high bird numbers.

Similarly as in Infante et al. (2005) in Portugal, no relationship between the number of collided birds and levels of cables was recorded, even if Renssen et al. (1975) found that reducing the number of cable levels in power lines reduced collisions. Maybe this factor is more important on high-voltage power lines.

Mortality caused by electrocution

1,170 birds were found as victims of electrocution below 949 (1.24%) out of 76,430 pylons checked in the course of the study in 2015–2016. According to the similar Slovak survey from 2014–2016, electrocuted birds were recorded on 5% of medium-voltage pylons (Gális et al. 2016). This could mean that power pylons are less dangerous for birds in the Czech Republic than in Slovakia, but also that the bird populations are more numerous in the latter.

Tab. 7. Logistic regression analysis for mortality of all species as dependent variable (* = significance lower than 10%, ** = significance lower than 5%, *** = significance lower than 1%).
Tab. 7. Logistická regresní analýza pro mortalitu všech druhů jako závislou proměnnou (* = významnost nižší než 10 %, ** = významnost nižší než 5 %, *** = významnost nižší než 1 %).

variable / proměnná	coeff. / koef.	SD	z	P	
const.	-4.2864	0.0989	-43.36	<0.001	***
concrete / beton	-0.2939	0.0966	-3.04	0.002	***
wood / dřevo	-2.5488	0.7140	-3.57	<0.001	***
surge arrester / omezovač přepětí	0.7582	0.1876	4.04	<0.001	***
upper switch disconnector / horní odpínač	-0.1049	0.1615	-0.65	0.516	
lower switch disconnector / dolní odpínač	-0.2832	0.3219	-0.88	0.379	
crosswise jumper / příčná spojka	0.3624	0.0926	3.92	<0.001	***
lower jumper / dolní spojka	-0.1664	0.1165	-1.43	0.153	
upper jumper / horní spojka	1.2820	0.1075	11.92	<0.001	***
plastic cover / plastový kryt	-0.7871	0.1844	-4.27	<0.001	***
plastic strip / plastový límec	-1.3714	0.3197	-4.29	<0.001	***
simple perch / jednoduché bidlo	0.0497	0.2099	0.24	0.813	
other type of perch / jiný typ bidla	-0.2986	0.5942	-0.50	0.615	
rack / hřeben	-0.1988	0.1853	-1.07	0.283	
perch discourager / zábrana proti dosedání	-0.3284	0.4172	-0.79	0.431	
conductor insulation / izolace vodiče	-1.5665	1.0034	-1.56	0.119	

Tab. 8. Logistic regression analysis for mortality of target species as dependent variable (* = significance lower than 10%, ** = significance lower than 5%, *** = significance lower than 1%).
Tab. 8. Logistická regresní analýza pro mortalitu cílových druhů jako závislou proměnnou (* = významnost nižší než 10 %, ** = významnost nižší než 5 %, *** = významnost nižší než 1 %).

variable / proměnná	coeff. / koef.	SD	z	P	
const.	-4.6430	0.1236	-37.55	<0.001	***
concrete / beton	-0.1709	0.1221	-1.40	0.161	
wood / dřevo	-2.8632	1.0076	-2.84	0.005	***
surge arrester / omezovač přepětí	0.3712	0.2587	1.44	0.151	
upper switch disconnector / horní odpínač	-0.3128	0.1997	-1.57	0.117	
lower switch disconnector / dolní odpínač	-0.8318	0.5041	-1.65	0.099	*
crosswise jumper / příčná spojka	0.3767	0.1139	3.31	0.001	***
lower jumper / dolní spojka	-0.2713	0.1477	-1.84	0.066	*
upper jumper / horní spojka	1.0812	0.1355	7.98	<0.001	***
plastic cover / plastový kryt	-0.9832	0.2403	-4.09	<0.001	***
plastic strip / plastový límec	-1.3448	0.3574	-3.76	<0.001	***
simple perch / jednoduché bidlo	0.1436	0.2301	0.62	0.533	
other type of perch / jiný typ bidla	0.2272	0.5997	0.38	0.705	
rack / hřeben	-0.3715	0.2294	-1.62	0.105	
perch discourager / zábrana proti dosedání	-0.1966	0.4574	-0.43	0.667	
conductor insulation / izolace vodiče	-12.8558	207.9680	-0.06	0.951	

31 species from 9 orders were affected by electrocution. Accipitriformes and Falconiformes made up more than half of all carcasses found (54.15%), followed by Corvidae species (33.62%), which together made 87.77%. These results perfectly correspond with data published by Haas (1980) for Germany, who found 50.34% raptors and 37.12% Corvidae species among electrocuted birds, together making 87.46%. It is also interesting that a very similar (or same) proportion was recorded for Turdidae species (1.57% in our study vs 1.46% in Haas) and starlings (1.75% in both studies). According to the Slovak study from 2014–2016 (Gális et al. 2016), the common buzzard (34%), magpie (20%) and hooded crow *Corvus cornix* (7%) were the most frequent victims of electrocution. In our survey, the common buzzard (39.48%) and magpie (17.55%) were followed by the common kestrel (13.89%), and crows formed 10.57%. More likely than differences in pylon characteristics, this reflects differences in species composition of bird communities present in the surveyed regions.

Regarding large bird species, solely the white stork was recorded as a victim of electrocution in our study (7 ind., 0.61% electrocuted birds). No eagle was found,

Tab. 9. Mortality of all birds on pylons estimated according to the statistical model and real mortality according to field work.
Tab. 9. Mortalita všech druhů na sloupech odhadovaná podle statistického modelu a reálná podle terénních výsledků.

probability / pravděpodobnost	estimated relative mortality / odhadovaná relativní mortalita (min–max)	real relative mortality / skutečná rel. mortalita	expected no. of cases / očekávaný počet případů	recorded no. of cases / zaznamenaný počet případů	no. of pylons / n sloupů
low / nízká	0.0002–0.0101	0.0055	94.2	100	18,169
medium / střední	0.0101–0.0115	0.0104	460.5	444	42,526
high / vysoká	0.0115–0.1320	0.0248	380.5	391	15,735

Tab. 10. Mortality of target species on pylons estimated according to the statistical model and real mortality according to field work.
Tab. 10. Mortalita cílových druhů na sloupech odhadovaná podle statistického modelu a reálná podle terénních výsledků.

probability / pravděpodobnost	estimated relative mortality / odhadovaná relativní mortalita (min–max)	real relative mortality / skutečná rel. mortalita	expected no. of cases / očekávaný počet případů	recorded no. of cases / zaznamenaný počet případů	no. of pylons / n sloupů
low / nízká	0.0000–0.0080	0.0038	81.4	78	20,357
medium / střední	0.0080–0.0082	0.0083	331.5	341	40,925
high / vysoká	0.0082–0.0566	0.0156	243.1	237	15,148

even if the mortality of large raptors on medium-voltage pylons is known in the Czech Republic. The suggested mitigation measures should therefore generally focus on medium-sized birds, and cases of electrocuted large birds should be still resolved individually and locally.

According to the results of our statistical tests, the most dangerous pylons are situated in places where a line turns or branches, they are made from steel and bear untypical cross-arms consisting of several single cross-arm types, typically including upper and crosswise jumpers. On the other hand, pylons in a straight line consisting of a wooden pole and a Pařát cross-arm rank among the least dangerous. Low mortality was also found on transformer stations in final position in a line, but this is apparently connected with the fact that these pylons are generally situated at the edge of settlements, where the density of susceptible birds is low.

Among these pylon types with extremely high or low influence on bird mortality, there are many other pylons with dozens of possible combinations of components. From the bird protection point of view, it is important to realize the influence of individual components and also their proportion on power lines. The results of our study indicate that individual assessed factors can be arranged from the least to the most dangerous: cross-arm type: Pařát or transformer station – Delta or Delta variant – horizontal – untypical (combination of several single cross-arm types); pole material: wood – concrete – steel; pylon position: terminal – straight line – corner or branch; other components: lower or upper switch disconnectors or lower jumpers – crosswise jumpers – surge arresters or upper jumpers. These results are not surprising; for example pylons consisting of a steel or concrete pole with a steel cross-arm, upright insulators or special devices were already identified as increasing bird mortality by Negro & Ferrer (1995). Similarly as in our study, corner and branch pylons were identified as the most dangerous and transformer stations and pylons with switch disconnectors as the least dangerous in the Slovak survey from 2014–2016 (Gális et al. 2016).

Regarding mitigation measures, usage of several types has already been abandoned in the Czech Republic. Racks as a type of perch disourager proved to be useless, sometimes even dangerous, because they are not durable in outdoor conditions, and their parts break off and fall away early after installation. Birds try to use free space for perching but remnants of the rack push them towards dangerous places from the electrocution point of view. Similarly, benches as elevated perches have not been effective, and they have also been abandoned in other countries, for example in Spain (Negro & Ferrer 1995). Recently, plastic covers and plastic strips have become the most widely-used bird-protective measure in the Czech Republic. But it has been confirmed that their effect depends on their current state: if they are damaged or incorrectly installed, they are useless. A simple perch installed below Pařát and Delta variant cross-arms is one of the new recommended components. It results from experience that electrocution risk increases when birds do not have any possibility for comfortable perching on long spans of power lines, and they are forced to perch in the vicinity of exposed pylon parts (APLIC 2006). The statistical significance of this measure has not been evaluated, because the number of pylons with simple perches is still low.

Low rate of success was found in an effort to make the most dangerous pylons safer, i.e. pylons with other components such as upper and crosswise jumpers or surge arresters. With the aim of decreasing their negative impact, combinations of measures have been used, especially installation of perch discouragers and jumper insulation. It will apparently be necessary to insist during planning procedure on using less dangerous pylon types and components like suspended insulators and lower jumpers. Negro & Ferrer (1995) or Janss & Ferrer (2001) also recommend replacing upright insulators (which are generally associated with high bird mortality) with bird-friendly pylon types fitted with suspended insulators.

In practice, it is important to take into account not only the degree of risk of individual pylon types, but also the proportion of their usage in lines. For example, approx. 82% pylons checked in our survey were situated in straight lines, 62% had a single horizontal cross-arm and 80% did not bear any other component. To protect birds from elecrocution, besides sophisticated solutions for exceptionally dangerous individual pylons it is necessary to search for easy mitigation measures for pylons with lower relative bird mortality rates, which are however very widespread.

In the Czech Republic, pylons with a Pařát cross-arm and a simple perch have been recently recommended as the best solution for pylons in straight lines. No mortality was found on these pylons in our study (but their proportion was low, approx. 1%). In cases simply where surge arresters were present, bird mortality strikingly increased. It is evident that Pařát cross-arms can also be successfully used for more complicated constructions (such as corner or branch pylons), and if appropriate mitigation measures are installed, they prove to be safe. For example, Fig. 17 shows a very dangerous steel pylon with high recorded bird mortality (6 common buzzards, 1 kestrel and 1 starling) during our field survey, which was replaced with a construction based on a Pařát cross–arm with jumper insulation, perch discouragers on the horizontal cross-arm and safe perches in the upper part of the pylon (Fig. 18). No mortality has been recorded on it so far. Preferred use of Pařát cross-arms on power lines is still rather new in the Czech Republic, so the applied statistical tests were not significant, and further research is needed.

References

Avian Power Line Aplication Committee (APLIC) 2006: Suggested practices for avian protection on power lines: The state of the art in 2006. Edison Electric Institute, APLIC and the California Energy Commission. Washington D.C. and Sacramento CA.

Bernardino J, Bevanger K, Barrientos R, Dwyer JF, Marques AT, Martins RC, Shaw JM, Silva JP & Moreira F 2018: Bird collisions with power lines: State of the art and priority for research. Biological Conservation 222: 1–13. DOI: 10.1016/j.biocon.2018.02.029.

Bevanger K 1994: Bird interactions at utility structures: collision and electrocution, causes and mitigation measures. Ibis 136: 412–425. DOI: 10.1111/j.1474-919X.1994.tb01116.x.

Bevanger K 1998: Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biological Conservation 86: 67–76. DOI: 10.1016/S0006–3207(97)00176-6.

Costandini D, Gustin M, Ferrarini A & Dell´Omo G 2016: Estimates of avian collision with power lines and carcass disappearance across differing environments. Animal Conservation 173–181. DOI:10.1111/acv.12303.

Ehrendorfer F & Hamann U 1965: Forschläge zu einer Floristischen Kartierung von Mitteleuropa. Berichte Deutsche Botanische Gesselschaft 78: 35–50.

Gális M, Deutschová L, Šmídt J, Hapl E & Chavko J 2016: Vysoká cena za pohodlie alebo rizikovosť elektrických vedení pre voľne žijúce druhy vtákov [High price for a comfort or risk of power lines for wild bird species], 77–79. In: Krumpálová Z, Zigová M & Tulis F (eds), Zoológia 2016, Zborník príspevkov z vedeckého kongresu, Nitra, 24–26 November 2016. Constantine the Philosopher University in Nitra, Nitra. [In Slovak]

Garrido JR & Fernández-Cruz M 2003: Effects of power lines on a white stork (*Ciconia ciconia*) population in central Spain. Ardeola 50: 191–200.

Gill F & Donsker D (eds) 2019: IOC World Bird List (v9.2). Retrieved July 25, 2019, from https://www.-worldbirdnames.org/ioc–lists/crossref/. DOI: 10.14344/IOC.ML.9.2.

Haas D 1980: Gefährdung unserer Grossvögel durch Stromschlag – eine Dokumentation. Ökologie der Vögel 2, Sonderheft: 7–57.

Hlaváč V, Koubová M & Neuwirthová H 2012: Ochrana ptáků na linkách vysokého napětí. Blýská se na lepší časy? [Protection of birds against high voltage lines.

Is there a sheet lightning?]. Ochrana přírody 67(5): 7–9. [In Czech with English summary]

Hlaváč V, Škorpíková V & Janoška Z 2017: Na sloupech elektrického vedení stále hynou desetitisíce dravců [Tens of thousands of birds of prey have been dying on high-voltage electricity pylons in the Czech Republic]. Ochrana přírody 72(2): 7–9. [In Czech with English summary]

Infante S, Neves J, Ministro J & Brandão R 2005: Estudo sobre o impacto das linhas eléctricas de média e alta tensão na avifauna em Portugal [Impact of distribution and transmission power lines on birds in Portugal]. Quercus Associação Nacional de Conservação da Natureza e SPEA Sociedade Portuguesa para o Estudo das Aves & Sociedade Portuguesa Para o Estudo das Aves, Castelo Branco. [In Portuguese]

Jans GFE 2000: Avian mortality from power lines: a morphologic approach of a species-specific mortality. Biological Conservation 95: 353–359. DOI: 10.1016/S0006-3207(00)00021–5.

Lehman RN, Kennedy PF & Savidge JA 2007: The state of the art in raptor electrocution research: A global review. Biological Conservation 136: 159–174. DOI: 10.1016/j.biocon.2006.09.015.

Loss SR, Will T & Marra PP 2014: Refining estimates of bird collision and electrocution mortality at power lines in the United States. PLoS One 9: e101565. DOI: 10.1371/journal.pone.0101565.

Loss SR, Will T & Marra PP 2015: Direct mortality of birds from anthropogenic causes. Annual Review of Ecology, Evolution and Systematic 46: 99–120. DOI: 10.1146/annurevecolsys-112414-054133.

Negro JJ & Ferrer R 1995: Mitigating measures to reduce electrocution of birds on power lines: a comment on Bevanger's review. Ibis 137: 423–424. DOI: 10.1111/j.1474-919X.1995.tb08045.x.

Paula JJS, Bispo RMB, Leite AH, Pereira PGS, Costa HMRG, Fonseca CMMS, Mascarenhas MRT & Bernardino JLV 2015: Camera-trapping as a methodology to assess the persistence of wildlife carcasses resulting from collisions with human-made structures. Wildlife Research 41(8): 717–725. DOI: 10.1071/WR14063

Ponce C, Alonso JC, Argandoña G, Fernández AG & Carrasco M 2010: Carcass removal by scavengers and search accuracy affect bird mortality estimates at power lines. Animal Conservation 13: 603–612. DOI: 10.1111/j.1469-1795.2010.00387.x

Prinsen HAM, Smallie JJ, Boere GC & Píres N (eds) 2011: Guidelines on how to avoid or mitigate impact of electricity power grids on migratory birds in the African-Eurasian region. AEWA Conservation Guidelines No. 14, CMS Technical Series No. 29, AEWA Technical Series No. 50, CMS Raptors MOU Technical Series No. 3, Bonn.

Raab R, Schütz C, Spakovszky P, Julius E & Schulze CH 2012: Underground cabling and marking of power lines: conservation measures rapidly reduced mortality of West-Pannonian great bustards *Otis tarda*. Bird Conservation International 22(3): 299–306. DOI: 10.1017/S0959270911000463.

Renssen TA, Bruin A de, van Doorn JH, Gerritsen A, Greven NG, van de Kamp J, Linthorst HDM & Smith CJ 1975: Vogelsterfte in Nederland tengevolge van aanvaringen met hoogspannings-lijnen [Bird mortality in the Netherlands as a result of collisions with high-voltage lines]. Rijksinstituut voor Natuurbeheer, Arnhem. [In Dutch]

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Appendix 1. Number of medium-voltage pylon types according to recorded characteristics. Number of pylons with bird mortality is shown in brackets.
Príloha 1. Počet typů sloupů vysokého napětí podle sledovaných znaků. Počet sloupů, na kterých byl zaznamenán úhyn ptáků, je v závorkách.

pylon characteristic / sledovaný znak		cross-arm type / typ konzoly						
		horizontal / vodorovná	Pařát	Delta	Delta variant	transformer / trafostanice	untypical / netypická	∑
position / pozice	in straight line / v přímé linii	44,658 (509)	5,378 (21)	5,978 (52)	1,771 (18)	28	5,050 (31)	62,863 (631)
	corner / rohový	2,854 (75)	291 (2)	193 (2)	69	8	1,401 (31)	4,816 (110)
	branch / odbočka	4	0	0	0	0	7,525 (203)	7,529 (203)
	terminal / koncový	161	8	0	0	1,013 (4)	40 (1)	1,222 (5)
pole material / materiál sloupu	concrete / beton	46,117 (524)	5,545 (23)	6,012 (54)	1,821 (18)	586 (3)	5,777 (116)	65,858 (738)
	steel / ocel	1,396 (60)	0	0	0	412 (1)	6,817 (148)	8,625 (209)
	wood / dřevo	164	132	159	19	0	1,422 (2)	1,896 (2)
	untypical / netypický	0	0	0	0	51	0	51
other component / další prvek	surge arrester / omezovač přepětí	599 (11)	145 (11)	16 (1)	0	0	24	784 (23)
	upper switch disconnector / horní odpínač	269 (37)	17 (2)	0	1	0	431 (2)	718 (41)
	lower switch disconnector / dolní odpínač	4,460 (4)	39	0	0	0	57 (2)	4,556 (6)
	crosswise jumper / příčná spojka	138 (2)	9	23	1	0	3,172 (60)	3,343 (62)
	lower jumper / dolní spojka	393 (3)	3	3	0	0	1,503 (7)	1,902 (10)
	upper jumper / horní spojka	309 (15)	134 (1)	32	28	1	132 (8)	636 (24)
	combinations of more types / kombinace více typů	2,358 (95)	160 (2)	108 (2)	5	0	4,875 (168)	7,506 (267)
	none / žádný	39,151 (417)	5,170 (7)	5,989 (51)	1,805 (18)	1,048 (4)	3,822 (19)	56,985 (516)
mitigation measure / ochranný prvek	plastic cover / plastový kryt	3,283 (15)	16	195 (1)	40	3	795 (14)	4,332 (30)
	plastic strip / plastový límec	0	0	3,353 (7)	0	1	326 (4)	3,680 (11)
	simple perch / jednoduché bidlo	5	790 (7)	6	994 (14)	0	87 (3)	1,882 (24)
	other type of perch / jiný typ bidla	1	81 (1)	0	0	0	18	100 (1)
	bench / lavička	930 (6)	0	0	0	0	53	983 (6)
	rack / hřeben	2,945 (28)	0	12	0	0	319 (3)	3,276 (31)
	perch discourager / zábrana proti dosedání	347 (2)	0	0	0	0	140 (2)	487 (4)
	conductor insulation / izolace vodiče	297	2	0	0	0	41 (1)	340 (1)
	combinations of more types / kombinace více typů	39	20	30	141	0	157 (3)	387 (3)
	none / žádný	39,830 (533)	4,768 (15)	2,575 (46)	665 (4)	1,045 (4)	12,080 (236)	60,963 (838)
	∑	47,677 (584)	5,677 (23)	6,171 (54)	1,840 (18)	1,049 (4)	14,016 (266)	76,430 (949)

Appendix 2. Bird species and orders killed on medium-voltage power lines according to data from a field study in the Czech Republic in 2015–2016.
Príloha 2. Druhy a řády ptáků uhynulých na elektrických linkách vysokého napětí podle studie realizované v České republice v letech 2015–2016.

	collision / kolize		electrocution / výboj		∑	
taxa / taxon	**n**	**%**	**n**	**%**	**n**	**%**
Perdix perdix	5	3.23	0	0.00	5	0.39
Coturnix coturnix	1	0.65	0	0.00	1	0.08
Phasianus colchicus	4	2.58	3	0.26	7	0.54
Anser anser	2	1.29	0	0.00	2	0.15
Anser sp.	1	0.65	0	0.00	1	0.08
Cygnus olor	2	1.29	0	0.00	2	0.15
Anas platyrhynchos	16	10.32	0	0.00	16	1.23
Columba livia f. *domestica*	4	2.58	11	0.96	15	1.15
Columba oenas	3	1.94	4	0.35	7	0.54
Columba palumbus	2	1.29	21	1.83	23	1.77
Columba sp.	11	7.10	26	2.27	37	2.85
Streptopelia turtur	0	0.00	1	0.09	1	0.08
Streptopelia decaocto	2	1.29	4	0.35	6	0.46
Rallus aquaticus	1	0.65	0	0.00	1	0.08
Crex crex	2	1.29	0	0.00	2	0.15
Porzana porzana	2	1.29	0	0.00	2	0.15
Scolopax rusticola	2	1.29	0	0.00	2	0.15
Chroicocephalus ridibundus	2	1.29	0	0.00	2	0.15
Ciconia ciconia	4	2.58	7	0.61	11	0.85
Ardea cinerea	4	2.58	1	0.09	5	0.39
Ardea alba	0	0.00	1	0.09	1	0.08
Accipiter nisus	0	0.00	2	0.18	2	0.15
Accipiter gentilis	0	0.00	5	0.44	5	0.39
Circus aeruginosus	1	0.65	0	0.00	1	0.08
Milvus migrans	0	0.00	1	0.09	1	0.08
Milvus migrans/M. milvus	0	0.00	1	0.09	1	0.08
Buteo buteo	4	2.58	452	39.48	456	35.08
Bubo bubo	0	0.00	7	0.61	7	0.54
Strix aluco	0	0.00	6	0.52	6	0.46
Asio otus	1	0.65	5	0.44	6	0.46
Strix aluco/Asio otus	0	0.00	1	0.09	1	0.08
Dendrocopos major	1	0.65	0	0.00	1	0.08
Picus viridis	0	0.00	1	0.09	1	0.08
Falco tinnunculus	0	0.00	159	13.89	159	12.23
Garrulus glandarius	0	0.00	2	0.18	2	0.15
Pica pica	1	0.65	201	17.55	202	15.54
Coloeus monedula	1	0.65	1	0.09	2	0.15
Corvus frugilegus	0	0.00	5	0.44	5	0.39
Corvus corone/C. cornix	0	0.00	121	10.57	121	9.31
Corvus frugilegus/C. corone/C. cornix	1	0.65	32	2.80	33	2.54
Corvus corax	1	0.65	23	2.01	24	1.85
Alauda arvensis	7	4.52	0	0.00	7	0.54
Hirundo rustica	1	0.65	0	0.00	1	0.08
Delichon urbicum	1	0.65	0	0.00	1	0.08
Phylloscopus trochilus	1	0.65	0	0.00	1	0.08
Phylloscopus collybita	1	0.65	0	0.00	1	0.08
Acrocephalus arundinaceus	1	0.65	0	0.00	1	0.08
Acrocephalus palustris	1	0.65	0	0.00	1	0.08
Sylvia atricapilla	2	1.29	0	0.00	2	0.15
Sylvia curruca	1	0.65	0	0.00	1	0.08
Regulus ignicapilla	2	1.29	0	0.00	2	0.15
Sturnus vulgaris	5	3.23	20	1.75	25	1.92
Turdus merula	15	9.68	9	0.79	24	1.85
Turdus pilaris	6	3.87	0	0.00	6	0.46

Appendix 2. Continuation.
Príloha 2. Pokračovanie.

	collision / kolize		**electrocution / výboj**		**∑**	
taxa / taxon	**n**	**%**	**n**	**%**	**n**	**%**
Turdus philomelos	6	3.87	0	0.00	6	0.46
Turdus philomelos/T. merula	6	3.87	7	0.61	13	1.00
Turdus viscivorus	0	0.00	2	0.18	2	0.15
Erithacus rubecula	4	2.58	0	0.00	4	0.31
Ficedula hypoleuca	1	0.65	0	0.00	1	0.08
Saxicola rubetra	1	0.65	0	0.00	1	0.08
Passer montanus	0	0.00	1	0.09	1	0.08
Motacilla alba	0	0.00	1	0.09	1	0.08
Fringilla coelebs	2	1.29	0	0.00	2	0.15
Linaria cannabina	2	1.29	0	0.00	2	0.15
Carduelis carduelis	1	0.65	0	0.00	1	0.08
Emberiza citrinella	7	4.52	1	0.09	8	0.62
∑	155	100.00	1,145	100.00	1,300	100.00
order / řád						
Galliformes	10	6.45	3	0.26	13	1.00
Anseriformes	21	13.55	0	0.00	21	1.62
Columbiformes	22	14.19	67	5.85	89	6.85
Gruiformes	5	3.23	0	0.00	5	0.39
Charadriiformes	4	2.58	0	0.00	4	0.31
Ciconiiformes	4	2.58	7	0.61	11	0.85
Pelecaniformes	4	2.58	2	0.17	6	0.46
Accipitriformes	5	3.23	461	40.26	466	35.85
Strigiformes	1	0.65	19	1.66	20	1.54
Piciformes	1	0.65	1	0.09	2	0.15
Falconiformes	0	0.00	159	13.89	159	12.23
Passeriformes – Corvidae	4	2.58	385	33.62	389	29.92
Passeriformes without/ bez Corvidae	74	47.74	41	3.58	115	8.85
∑	155	100.00	1,145	100.00	1,300	100.00