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Comprehensive analysis of bird mortality along power distribution lines in Slovakia

Komplexná analýza mortality vtákov na distribučných vedeniach na Slovensku

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Abstract: Collisions and electrocutions on power lines are known to kill large numbers of birds annually on a global scale. We conducted comprehensive research focused on bird mortality caused by 22 kV and 110 kV distribution power lines in 13 Special Protection Areas in Slovakia. In the period between December 2014 and February 2016, 6,235 km of power lines were inspected twice during two periods (12/2014–03/2015 and 04/2015–02/2016) of field survey. In addition an intensive study was conducted during the second field survey at one-month intervals on power lines identified as the most dangerous for birds to collide with. As a result, 4,353 bird carcasses and bird remains representing 84 bird species and 14 orders were identified. Electrocution was suspected for 76.72% and collision for 23.28% of fatalities. Raptors were associated with 40% of all identified victims of electrocution. Two peaks of incidence were recorded, the first in March with a high rate of electrocutions as well as collisions of swans, pheasants, common blackbirds, ducks and herons, and the second in September predominantly featuring electrocution of raptors, magpies and corvids. We were unable to quantify seasonal patterns of mortality due to the limited sample of repeated mortality surveys resulting from the large grid of inspected power lines. We conducted comprehensive statistical analysis of more than 100 configurations of pylons and calculated their potential risk towards birds. Strong spatial correlation was revealed in the data set. Metal branch pylons and corner pylons with exposed jumper wires passing over the supporting insulators above the cross arms were the most dangerous configuration, accounting for 34.72% of total recorded electrocution fatalities (0.13 carcass/pylon). Cases of electrocution were also recorded for two bird species of major conservation concern in Slovakia: saker falcon (*Falco cherrug*) and eastern imperial eagle (*Aquila heliaca*). The results of this study may substantially improve conservation management and policies needed to reduce bird mortality.

Abstrakt: Nárazy vtákov a zásahy elektrickým prúdom zabíjajú v celosvetovom meradle každoročne veľké množstvo vtákov. Komplexný výskum, zameraný na mortalitu vtákov na 22 kV a 110 kV elektrických vedeniach, bol realizovaný v 13 chránených vtáčích územiach na Slovensku. V období od decembra 2014 do februára 2016, počas dvoch etáp (12/2014 – 03/2015 a 04/2015 – 02/2016) terénneho monitoringu, bolo dvakrát skontrolovaných 6235 km elektrických vedení. Okrem toho, prebiehal v mesačných intervaloch počas druhej etapy terénneho výskumu, intenzívny monitoring elektrických vedení, označených ako najrizikovejšie z pohľadu možných nárazov. Identifikovali sme 4353 uhynutých jedincov, resp. zvyškov, zastúpených 84 druhmi vtákov zo 14 radov. Zásahy prúdom boli zodpovedné za 76,72 % úmrtí, nárazy za 23,28 % úmrtí. Dravce tvorili až 40 % všetkých identifikovaných obetí v dôsledku zásahu prúdom. Zaznamenali sa dva sezónne vrcholy výskytu úhynov, vždy v období migrácií. Prvý v marci, s vysokým počtom úhynov v dôsledku zásahov, ale aj nárazov, najmä u labutí, bažantov, drozdov, kačíc a volaviek. Druhý vrchol pripadal na september, spojený s úmrtiami v dôsledku zásahov u dravcov a krkavcovitých druhov. Kvôli obmedzenej vzorke opakovaných prieskumov mortality vyplývajúcich z veľkého rozsahu monitorovaných elektrických vedení, sme nedokázali kvantifikovať sezónne vzorce úmrtnosti. Vykonali sme komplexnú štatistickú analýzu viac ako 100 konfigurácií stožiarov a vypočítali sme ich potenciálne riziko pre vtáky. V súbore údajov bola odhalená silná priestorová korelácia. Najnebezpečnejšiu konfiguráciu z hľadiska zásahov prúdom, predstavovali tzv. odbočné oceľové stožiare s neizolovanými preponkami a rohové stĺpy s preponkami vedenými ponad konzolu, zodpovedné za 34,72 % všetkých určených úmrtí (0,13 úhynov/stĺp). Zaznamenané boli aj prípady úhynov v dôsledku zásahov prúdom u dvoch druhov vtákov, ktoré sú na Slovensku významné z hľadiska ich ochrany: sokola rároha (*Falco cherrug*) a orla kráľovského (*Aquila heliaca*). Výsledky tejto štúdie môžu významne zlepšiť manažment ochrany a postupov potrebných na zníženie úmrtnosti vtákov.

Key words: electrocution, collisions, raptors, waterbirds, mitigation measures

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Introduction

Depending on the type of construction, power lines may cause fatal injuries and death to birds due to electrocution and collision. Electrocution is a worldwide problem identified especially on medium–voltage types of power line (1–52 kV). It has been documented in a number of earlier and more recent reports from the USA (APLIC 2006, Lehman et al. 2010, Dwyer et al. 2015). The problem has also been described in various countries in Asia, e.g. Mongolia, Saudi Arabia, India, Dagestan (Gombobaatar et al. 2004, Harness et al. 2008, Karyakin et al. 2009, Shobrak 2012, Harness et al. 2013, Gadziev 2013) and in Europe (Ferrer et al. 1991; Janss & Ferrer 2001, Haas et al. 2005, Demerdziev et al. 2009, Samushenko et al. 2012, Demerdziev 2014, Demeter et al. 2018). Several of the available studies include quantified avian electrocution rates. The highest risk is associated primarily with medium-voltage power lines representing very attractive perches to many birds in open rural areas without tree growth (APLIC 2006). The group most threatened with electrocution are defined as the diurnal bird species, specifically eagles, hawks, vultures, kites, falcons, owls, storks and corvids (Haas et al. 2005, Guil et al. 2011, Prinsen et al. 2011, Ferrer 2012, Gadziev 2013, Fransson et al. 2019, Škorpíková et al. 2019). The highest mortality rate due to electrocution is registered mainly for medium-sized and large birds. In certain cases it can have significant negative effect on the species, either on the local scale or even at the population level, such as has been documented for the saker falcon (Harness et al. 2008, Kovács et al. 2014) or imperial eagle (Bagyura et al. 2002, Karyakin et al. 2009, Demeter et al. 2018).

Collisions of birds with electrical lines represent a significant mortality factor for several species. They have been noted as an important cause of mortality and they vary with habitat, local avian populations, line design (Ward & Anderson 1992, Koops 1994, Roig & Navazo 1997, Hunting 2002, Bevanger & Brøseth 2004, Wright et al. 2008, APLIC 2012, Shobrak 2012, Sporer et al. 2013) and line orientation (Brown 1993). Power lines crossing the birds' daily movement corridors can be particularly problematic (Bevanger & Brøseth 2004, Frost 2008, Stehn & Wassenich 2008). There are great differences between habitats: on grassland there are 113 collisions/km/year; on agricultural land 58 collisions/km/year, and near river crossings 489 collisions/km/year (Erikson et al. 2005). Collision risks also are exacerbated during low light, fog, or inclement weather conditions (Savereno et al. 1996, APLIC 2012).

Bird casualties due to collision with above-ground power lines can happen on any electricity grids (distribution or transmission) (Bahat 2008, Jenkins et al. 2010). Larger, heavy-bodied birds with short wing spans and poorer vision (Kelly & Kelly 2009) are more susceptible to collisions than smaller, light-weight birds with relatively large wing spans, agility and good vision (Bevanger 1998, Shaw et al. 2010, APLIC 2012). Understanding the nature of bird collisions is essential for minimizing them. Problems of collisions with power lines can be divided into four main categories generally based on factors of origin, namely from the biological, topographical, meteorological and technical perspective (APLIC 2012).

Electrocution and collisions are still an important, continuing mortality factor for several bird species, despite the number of mitigation measures implemented worldwide. They represent a biologically significant risk, since for species which are rare or endangered, the loss of a few or even one individual may impact a local population or the overall population's viability (Crowder 2000).

In Slovakia the problem of electrocution has been the focus for mitigation measures since 1991. The first insulation device was designed by the NGO named

SVODAS (since 2004 Raptor Protection of Slovakia) in cooperation with the State Nature Conservancy of the Slovak Republic, in the form of plastic combs preventing birds from perching on poles, and was installed in 1993 in Mala Fatra mountains. Since then many other solutions have been designed and tested. Deaths from collisions were identified sporadically by local experts, rescue stations or in field surveys carried out under small projects until 2009. The first field research focusing exclusively on collision mortality was held in 2010 in Ondavská rovina Special Protection Area (hereafter SPA). The results proved the need for a systematic approach and further study of the topic. Especially for this reason, the LIFE Energy project was designed and started being implemented in 2014.

In this study we present the results of field monitoring of bird mortality on 22 kV and 110 kV lines in 13 Special Protection Areas (SPAs) and their adjacent areas in Slovakia. The main objectives were to analyse the risk of distribution power lines for different bird species and compare electrocution and collision mortality rates on different pole types/designs, power line constructions, and then to propose protection measures against electrocution. It was the largest scope of systematic survey and evaluation conducted on this topic so far in Slovakia. In our study we also aimed to investigate which bird species were affected by collisions and electrocutions, how different pole designs could influence the rate of electrocution mortality, which bird protection measures were effective, and whether power line design could influence the risk of possible collision. Preliminary results from our findings have been published in studies by Gális et al. (2016, 2017a, 2017b, 2018a, 2018b & 2019).

Material and methods

Study area

The field survey was carried out in 13 SPAs and their adjacent areas: Záhorské Pomoravie, Dunajské Luhy, Lehnice, Kráľová, Ostrovné lúky, Dolné Považie, Parížske močiare, Poiplie, Slovenský kras, Košická kotlina, Ondavská rovina, Medzibodrožie, Senianske rybníky, taking in an area of approximately 8,685 km^2, including 2,250 km^2 within SPAs. All SPAs are located in the southern part of Slovakia (Fig. 1), mainly in lowland agricultural landscapes (except for the Slovenský kras karst area). The selected surveyed area is of high avifaunic importance for birds using the area for breeding, roosting, during migration and/or foraging habitats (Karaska et al. 2015). Intensive agricultural use has led to a decrease in tree growth resulting in increasing preference of birds of prey for electricity pylons (APLIC 2006), especially in rural areas.

A considerable part of the national population of imperial eagle (60% of all pairs) and saker falcon (80% of all pairs) together with many other raptors, water and

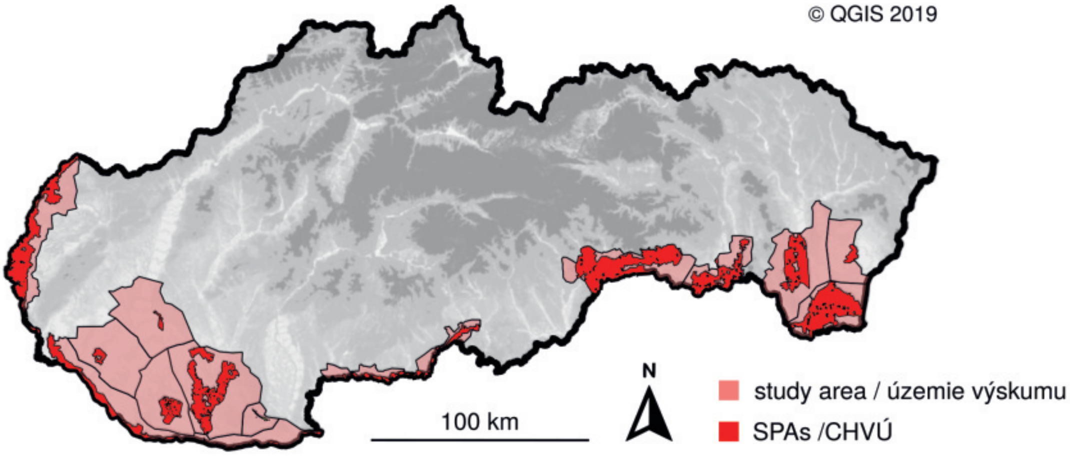

Fig. 1. Location of study area covering 13 Special Protection areas (SPA) and their adjacent areas.
Obr. 1. Poloha skúmaného územia, zahŕňajúceho 13 Chránených vtáčích území (CHVÚ) a ich priľahlé okolie.

wetland species are concentrated within this area. The project area is also an important human settlement area, which has led to electrification with the potential for causing significant bird mortality. The occurrence of many wetlands, marshes, rivers, lakes and ponds separated by these power lines represents great exposure to collision, especially for wetland bird species.

Power line characteristics

Electric power is delivered within Slovakia via two main groups of power supply operators. One national transmission company, the Slovak electricity transmission system (SEPS) operates a grid of app. 2,300 km of high and extra-high voltage lines (220 kV and 400 kV). Three regional 22 kV and 110 kV distribution service providers (Západoslovenská distribučná, a. s., Stredoslovenská distribučná, a. s. and Východoslovenská distribučná, a. s.) operate 30,970 km of medium and high-voltage lines. Two types of distribution power lines with a total length of 6,235 km cross the project area; a single/double circuit 22 kV line and single/double circuit 110 kV line (with one earth wire above the phase conductors).

Mortality surveys

Two periods of field survey were carried out between the years 2014 and 2016). During the first field study period (12/2014–03/2015) 6,235 km of 22 kV (5,211 km) and 110 kV (1,024 km) power lines were surveyed once in the project area for bird carcasses and for technical data about pole and pylon construction. The data collected in this period were used to assess mortality rates comparing different species and poles construction. The buffer for the survey was defined as a distance of 10 m from the edge conductor in the case of 22 kV and 25 m in the case of 110 kV lines. The survey was conducted by one trained field assistant for 22 kV and two assistants for 110 kV walking in parallel with the electricity line. Walking in zig-zag pattern was carried out only in high and dense vegetation or crops. The slow, regular pace used during the survey optimized the results and decreased the searcher bias. Trained field assistants were also paid for each carcass found, to be motivated to survey the area properly.

The location of each bird carcasses or remains found was recorded by GPS device and described with eight parameters [identification by species or in the most precise taxonomic category possible, sex and age (if possible), cause of death (electrocution, collision, other or unknown cause of death), distance and direction to the pole and conductors, description of visible injury, stage of carcass decomposition, effect of scavengers]. Data were accompanied by a photo of the whole carcass, injuries and location with regard to the closest pole/pylon. For bird collision victims, the location and distance from the wires were recorded to identify the possible effect of power line orientation on collision mortality. For each electricity pole and pylon, special technical data were collected together with other abiotic and biotic factors about the surrounding land use, landscape structure and habitat important for birds. The information recorded for every single pole included: GPS coordinates, type (position in the line), number of circuits, material of pole/pylon (concrete, metal or wood), number of poles, number of vertical separation of wires, number of cross arms, type of cross-arm, number of insulators per conductor, position of insulators, presence and type of insulators and their current quality state (O.K., damaged or wrong application). The presence and position of jumpers were also noticed. All poles/pylons were photographed for verification of the data collected in the field. All detected bird carcasses were removed from the area during the first period of field survey to prevent double counts in the second (detailed) survey. All gathered data were processed and used as inputs for special collision-risk methodology (Šmídt et al. 2019) to select the power lines for intensive survey within the second field period.

In the second field period (04/2015–02/2016) a survey was conducted once on the same length of power lines investigated in first period (6,235 km). In addition, intensive surveys were conducted at one-month intervals on power lines identified as the most dangerous for birds to collide with, based on the results from the first period of field survey and collision-risk methodology. During these surveys, an area with a buffer zone of 20 m + the base of each pole (for 22 kV) and 50 m (for 110 kV) from the edge of the power lines was surveyed for bird carcasses. All identified bird carcasses were removed from the area to prevent double counts. All birds found within a radius of 3 m from the poles with or without evidence of burn marks on feathers, feet or bill were considered as electrocuted. Birds found under or close to the phase conductors were considered to be victims of collisions. The body condition of bird carcasses was also taken into account, to estimate the possible date of death.

Altogether 81 field assistants were trained by ornithologists and GIS experts during two theoretical and practical training sessions, and several field meetings were held to ensure proper survey data collection together for both reporting periods. The experts (in the role of supervisors) joined the field assistants during the initial field surveys to decrease searcher bias and ensure proper data collection and transcription. A survey monitoring protocol was designed and used. If relevant, nearby tree and shrub growth was inspected up to 100 m from the border of the surveyed buffer zone, because injured birds often move themselves or are moved by predators. All gathered data were verified, revised by experts in ornithology and recorded in an offline database. Additionally, the size category of the species: small (wingspan 20–50 cm), medium (51–120), large 121–230 cm) was identified, and it was assigned to one of the orders (waders, anglers, birds of prey/owls, pigeons, ravens, ducks/geese/swans, short–winged birds, cuckoos/swifts, songbirds and mercenaries). Monitoring was carried out only in suitable weather and site conditions, to avoid searcher bias in some crops or in unfavourable weather. The majority of the field visits was concentrated in the period when most crops were already harvested and the vegetation in the open landscape was low (the field survey was stopped if the vegetation was higher than the ankle, to reduce observer error mainly regarding small birds). Only records of carcasses showing confirmed interaction with a power line (death or injury) were selected for post-processing and subsequent statistical analyses. Individuals in an advanced stage of decomposition were excluded from further data analysis (it was not possible to determine the cause of death). Data from this survey were used to calculate the relative mortality rate for electrocution and collision, the effects of different types of pole construction, and the efficacy of already-installed protective measures against electrocution.

Data analysis

The main objective of the statistical analysis was to determine the risk of individual types of electricity poles and pylons to birds, namely: (i) the risk of electrocution caused by direct contact; and (ii) the risk of collision. The parameters of the power line are given by the poles or pylons holding the wires along it. For the purposes of evaluation, therefore, each record of interaction was assigned to a particular pole or pylon, both in the case of electrocution as well as collision. The dataset analysed consisted of 64,649 utility poles and pylons (60,925 of 22kV and 3,724 of 110kV), under 3,156 of which at least one dead bird was recorded. In total, 4,363 animal carcasses were found during the first and second field study periods together, almost all of which (> 99% of cases) were birds. 110 kV lines killed birds exclusively by collision (carcasses assigned to 186 pylons). For each type of pole/pylon a mean risk value was calculated using Blaker's exact confidence intervals (95%) for binomial distribution (Blaker 2000). These confidence intervals are symmetrical around the mean value and provide information on mean variability, which in our case allowed us to identify statistically significant differences in risk between different types of poles and pylons. The calculation could only be carried out under the condition: (i) that at least one record of incident was assigned to the specific type of pole/pylon; (ii) the sample size was above 10 poles/pylons in the dataset. Blaker's confidence intervals were then visualized using barplots, where the top of the bar corresponds to the mean risk value and the vertical line represents the 95% confidence interval for that mean value. By comparing the overlap of confidence intervals, statistically significant differences in risk rates can be determined. Subsequently we used the sorting algorithm "k-means", which divided the utility poles into five groups according to the level of risk for birds (low, $p_{kill} = 0.04 \pm 0.02$; low-medium, $p_{kill} = 0.12 \pm 0.03$; medium, $p_{kill} = 0.21 \pm 0.03$; medium-high, $p_{kill} = 0.37 \pm 0.05$; high, $p_{kill} = 0.57 \pm 0.09$). The same approach (but without the use of "k-means") was followed in further analyses taking into account the differences in risk for birds with regard to the type of pole, presence of jumper wire, size and ecological group of the killed bird and type of protection). All statistical calculations were performed in the R language 3.6.1 environment (R Core Team 2019) using the "MASS" (Venables & Ripley 2002) and "PropCIs" libraries version 0.3-0 (Scherer 2018). In the second part of the statistical evaluation, the aim was to allocate zones with a high incidence of bird mortality due to electrocution for individual geographical areas (so-called "death zones"). For this purpose, we applied 2D-Kernel density estimation to the geographic coordinates of the recorded mortality incidents, and then projected the results onto a map ("kernels for individual areas").

Results

In total 4,353 victims were identified under all surveyed power lines. For 3,900 individuals belonging to 84 species it was possible to determine the cause of death (Tab. 1). Descriptive analysis showed that 22 kV lines killed birds in both ways, i.e. by electrocution (2,096 poles) and by collision (588 poles/pylons, whereby electrocu-

Tab. 1. Distribution of identified carcasses by taxa (12/2014-02/2016).
Tab. 1. Rozdelenie identifikovaných kadáverov podľa taxónov (12/2014-02/2016).

species / druh	**electrocution / zásah prúdom**	**collision / náraz**	∑	**species / druh**	**electrocution / zásah prúdom**	**collision / náraz**	∑
Accipiter gentilis	29	-	29	*Erithacus rubecula*	-	4	4
Accipiter nisus	11	2	13	*Falco cherrug*	7	-	7
Acrocephalus scirpaceus	-	1	1	*Falco tinnunculus*	95	3	98
Alauda arvensis	-	8	8	*Falco* sp.	10	-	10
Anas crecca	1	3	4	*Ficedula hypoleuca*	-	1	1
Anas platyrhynchos	-	47	47	*Fringilla coelebs*	-	3	3
Anas sp.	2	11	13	*Fulica atra*	-	2	2
Anser anser	-	2	2	*Gallinago gallinago*	-	1	1
Anser sp.	-	2	2	*Gallinula chloropus*	-	2	2
Aquila heliaca	6	-	6	*Garrulus glandarius*	6	2	8
Aquila pomarina	1	-	1	*Grus grus*	-	3	3
Aquila sp.	1	-	1	*Ixobrychus minutus*	-	1	1
Ardea cinerea	-	14	14	*Lanius collurio*	-	1	1
Ardea purpurea	-	2	2	*Larus cachinnans*	-	2	2
Ardea sp.	-	1	1	*Chroicocephalus ridibundus*	-	3	3
Asio flammeus	-	1	1	*Larus* sp.	-	11	11
Asio otus	24	11	35	*Locustella* sp.	-	1	1
Aves	145	40	185	*Motacilla alba*	-	1	1
Aythya ferina	-	1	1	*Muscicapa striata*	-	1	1
Bubo bubo	5	-	5	*Oenanthe oenanthe*	-	1	1
Buteo buteo	1025	3	1028	*Pandion haliaetus*	1	-	1
Buteo rufinus	1	-	1	*Parus major*	4	4	8
Carduelis carduelis	-	3	3	*Passer domesticus*	1	-	1
Carduelis chloris	-	3	3	*Passer montanus*	2	7	9
Ciconia ciconia	80	12	92	*Passer* sp.	34	25	59
Ciconia nigra	2	-	2	*Phalacrocorax carbo*	-	2	2
Circus aeruginosus	1	1	2	*Phasianus colchicus*	-	120	120
Circus cyaneus	-	1	1	*Phylloscopus collybita*	-	1	1
Circus sp.	-	1	1	*Pica pica*	601	5	606
Cocc. coccothraustes	-	5	5	*Porzana parva*	-	2	2
Columba livia	34	27	61	*Rallus aquaticus*	-	3	3
Columba oenas	1	1	2	*Regulus regulus*	-	1	1
Columba palumbus	15	2	17	*Saxicola rubetra*	-	1	1
Columba sp.	61	70	131	*Streptopelia decaocto*	20	7	27
Corvus corax	102	3	105	*Streptopelia turtur*	-	2	2
Corvus cornix	212	6	218	*Strix aluco*	13	-	13
Corvus frugilegus	129	3	132	*Sturnus vulgaris*	20	14	34
Corvus monedula	22	-	22	*Sylvia atricapilla*	-	9	9
Corvus sp.	253	5	258	*Sylvia borin*	-	2	2
Coturnix coturnix	-	6	6	*Sylvia communis*	-	2	2
Crex crex	-	4	4	*Sylvia curruca*	-	3	3
Cuculus canorus	1	2	3	*Turdus iliacus*	-	2	2
Cygnus olor	-	189	189	*Turdus merula*	2	58	60
Delichon urbicum	-	2	2	*Turdus philomelos*	1	32	33
Dendrocopos major	-	1	1	*Turdus pilaris*	2	30	32
Dendrcopos sp.	1	1	2	*Turdus viscivorus*	-	2	2
Ardea alba	-	10	10	*Turdus* sp.	7	5	12
Emberiza citrinella	-	6	6	*Tyto alba*	1	-	1
Emberiza schoeniclus	-	4	4	*Vanellus vanellus*	-	9	9

tion was much more common ($\chi^2 = 847.24$, df = 1, $P < 0.001$). 110 kV lines killed birds exclusively by collision (carcasses assigned to 186 pylons). The majority (76.72% 2,992 ind.) was killed by electrocution, and 23.28% (908 ind.) solely due collision with wires. In the case of 451 carcasses it was not possible to determine the cause of death due to their advanced stage of decomposition. Two instances of beech marten (*Martes foina*)

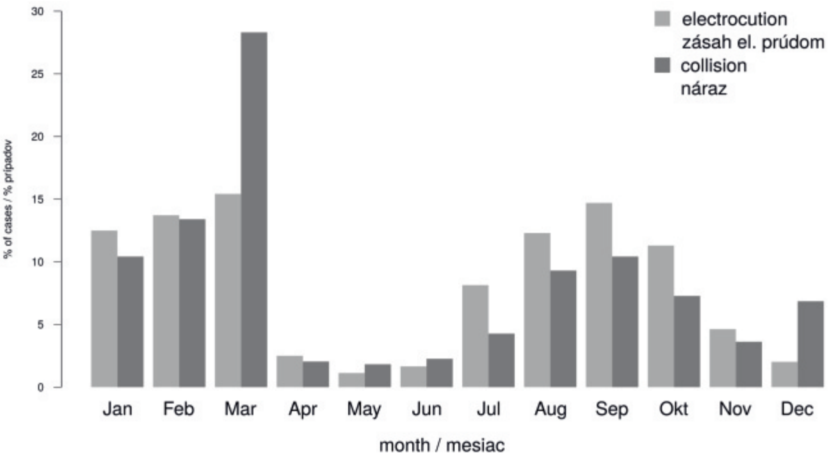

Fig. 2. Seasonal distribution of bird mortality due to electrocution and collision during both survey periods.
Obr. 2. Sezónna dynamika úhynov vtákov s rozlíšením podľa príčiny úmrtia za obe etapy monitoring.

and eight other *Martes* sp. individuals were also recorded as electrocuted.

The social value of the individuals found either electrocuted or dead after collision was calculated based on Law No. 543/2002 Coll., and amounted to 2.2 million euro in total. Based on the same law the amount can be increased by 300% if the incident is recorded within an SPA. In that case the total amount of social value/ damage caused to nature would be 3.6 million euro.

The frequency of bird mortality from electrocution and collisions had two main peaks (Fig. 2). During spring the peak was in March and during autumn in September for electrocution. For collision, the peak was recorded in March (huge presence of mute swans on oilseed rape fields and spring migration) and in September (autumn migration). Such seasonal trends depend on migratory activity, density of bird populations and prey availability in the area around the power lines. During winter (December–January) and early summer (May–June), incidents were less common. Seasonal distribution was compiled from bird carcasses in all stages of decomposition and for both periods (12/2014–03/2015 and 04/2015–02/2016) of field surveys.

Electrocution mortality

After checking 60,296 poles, we identified 2,992 individuals killed by electrocution belonging to 35 bird species and 10 bird orders. Only medium-voltage lines (22 kV) were responsible for electrocution, and these lines killed birds primarily by electrocution rather than collision ($\chi^2 = 847.24$, df = 1, $P < 0.001$). Fig. 3 shows the mortality for different taxonomic groups. Birds from the family Corvidae are listed separately from the other Passeriformes. The number of carcasses found under a single pole varied from 1 to 24 (recorded under a metal branch pole).

The common buzzard (*Buteo buteo*) was the most common bird of prey detected and was associated with 85.39% (1,023 ind.) of all identified electrocution of raptors (n = 1,198), in 34.19% of all electrocutions and in 26.23% of all recorded bird carcasses (electrocution + collision). Second highest mortality was observed for the Eurasian magpie (*Pica pica*) with 20.08% (601 ind.) and third for the hooded crow (*Corvus cornix*) with 7.08% (212 ind.).

During the field survey (12/2014–2/2016) six carcasses of imperial eagle and eight of saker falcon were identified under 22 kV poles as a result of electrocution. In our study we also use the reported data from the period after the field survey (3/2016–9/2019) but only if

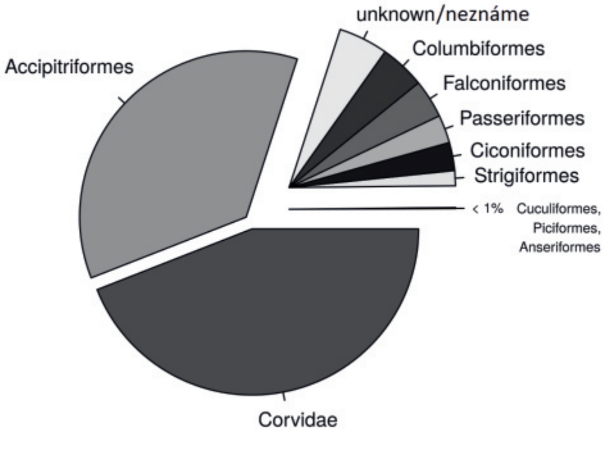

Fig. 3. Identified electrocutions in different taxonomic groups.
Obr. 3. Podiel úmrtnosti v dôsledku zásahov prúdom pre jednotlivé taxóny.

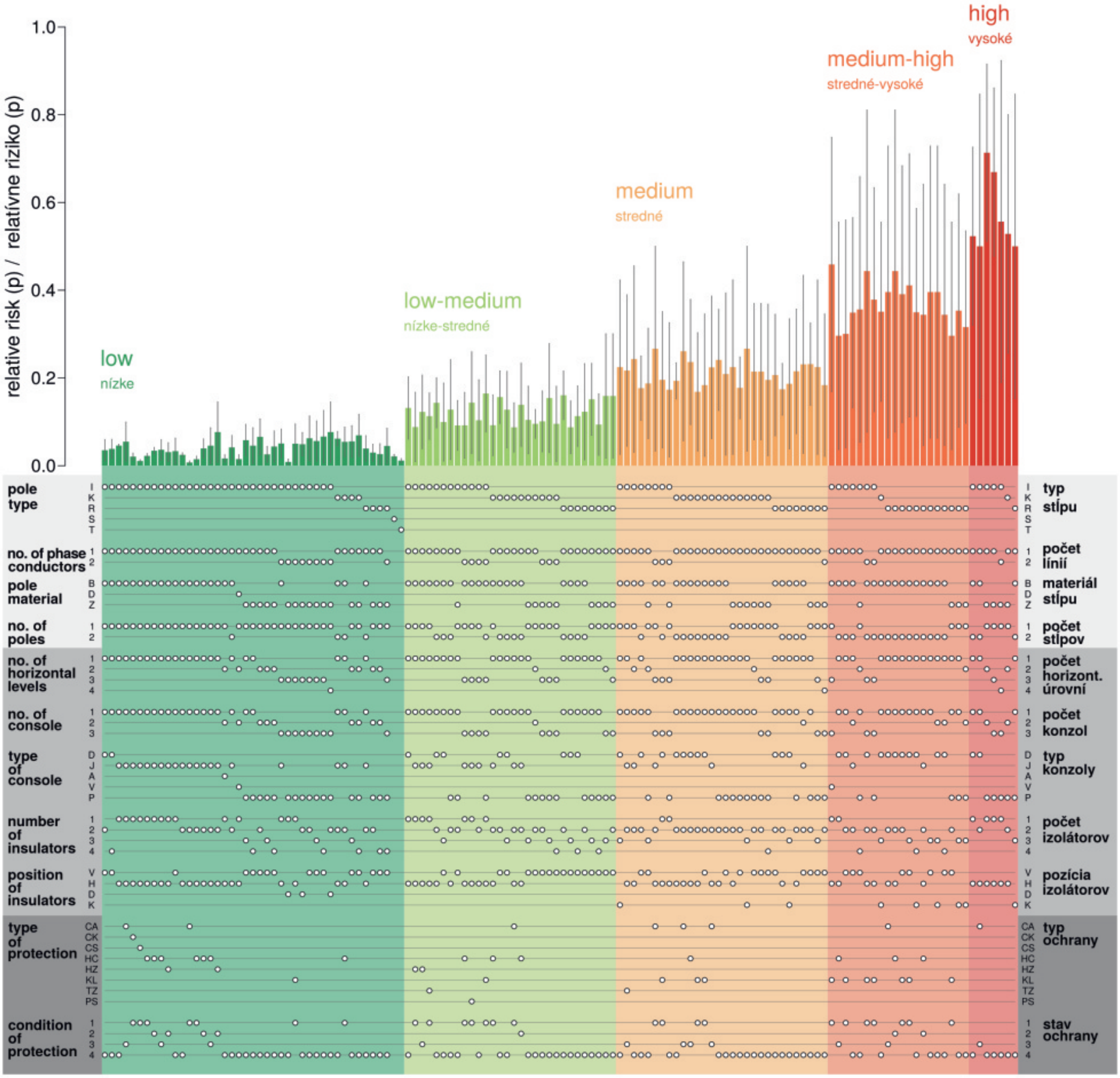

Fig. 4. Risk of individual types of utility poles (22 kV) to birds. Bar height represents the relative risk of electrocution of various types of utility poles. Vertical lines at each bar represents Blaker's exact confidence intervals (95%) for risk level. White points below bars on the horizontal axis represent presence/absence of individual pole components (white point/no point). Abbreviations: Pole type: I – utility pole in straight line, K – corner pole, R – angle pole, S – switcher, T – pole transformer; Pole material: B – concrete, D – wood, Z – steel; Type of console: D – double metal console J – metal console, A – antibird console, V – old wood console, P – heavy metal console; Position of insulators: V – horizontal, H – upright, D – hanging, K – combined; Type of protection: CA – console protection , CK – console insulation, CS – console insulation, HC – back plastic combs, HZ – green plastic combs, KL – plastic cover, TZ –plastic triangle, Condition of protection: 1 – OK, 2 – damaged, 3 – wrong application, 4 – no protection.

Obr. 4. Rizikovosť jednotlivých typov stĺpov (22 kV) pre vtáky. Výška stĺpcov vyjadruje priemernú hodnotu rizika zásahu prúdom. Vertikálne čiary prechádzajúce stredom každého stĺpca vyjadrujú Blakerove 95 %-tné intervaly spoľahlivosti pre priemernú hodnotu rizika. Biele body pod jednotlivými stĺpcami symbolizujú prítomnosť/neprítomnosť jednotlivých konštrukčných komponentov stĺpu (biely bod/žiadny bod). Skratky: Typ stĺpu: I – stĺp na priamej línií, K – odbočný stĺp, R – rohový stĺp, S – úsekový odpínač, T – transformátor. Materiál stĺpu: B – betón, D – drevo Z – oceľ; Typ konzoly: D – dvojitá, J – ľahká rovinná, A – antibird/ecobird, V –

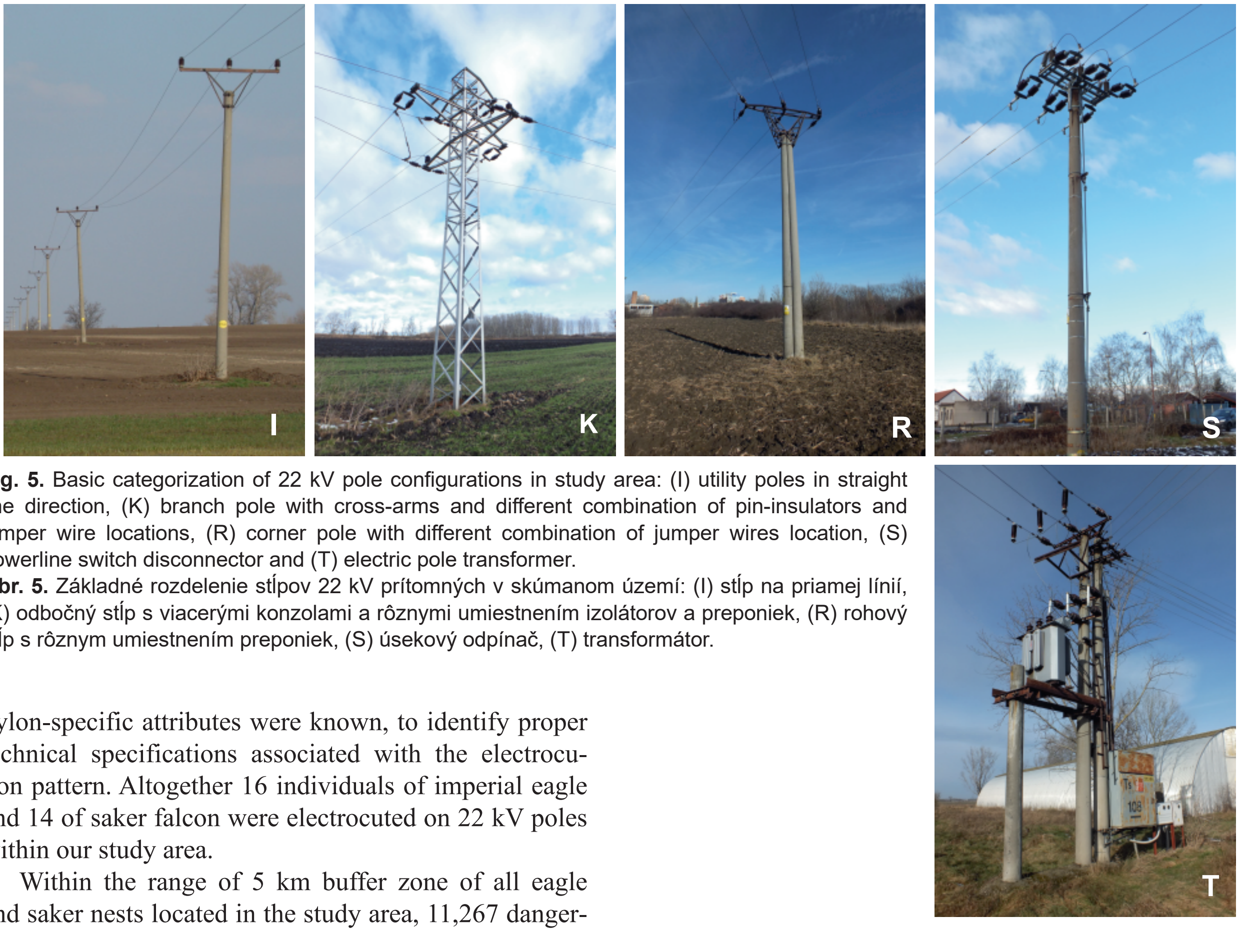

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Fig. 5. Basic categorization of 22 kV pole configurations in study area: (I) utility poles in straight line direction, (K) branch pole with cross-arms and different combination of pin-insulators and jumper wire locations, (R) corner pole with different combination of jumper wires location, (S) powerline switch disconnector and (T) electric pole transformer.

Obr. 5. Základné rozdelenie stĺpov 22 kV prítomných v skúmanom území: (I) stĺp na priamej línií, (K) odbočný stĺp s viacerými konzolami a rôznymi umiestnením izolátorov a preponiek, (R) rohový stĺp s rôznym umiestnením preponiek, (S) úsekový odpínač, (T) transformátor.

pylon-specific attributes were known, to identify proper technical specifications associated with the electrocution pattern. Altogether 16 individuals of imperial eagle and 14 of saker falcon were electrocuted on 22 kV poles within our study area.

Within the range of 5 km buffer zone of all eagle and saker nests located in the study area, 11,267 dangerous poles (without proper mitigation measures) were identified and reported to the power supply companies concerned.

Effect of different pole designs and bird size on electrocution mortality

The effect of different poles designs was compared. During the field survey 61,328 22 kV poles were surveyed and finally 60,926 poles were included in the statistical analysis.

Sorting algorithm "k-means" was used to divide the utility poles into five groups according to the level of risk (Fig. 4) for birds (low, $p_{kill} = 0.04 \pm 0.02$; low-medium, $p_{kill} = 0.12 \pm 0.03$; medium, $p_{kill} = 0.21 \pm 0.03$; medium-high, $p_{kill} = 0.37 \pm 0.05$; high, $p_{kill} = 0.57 \pm 0.09$).

Five types of basic pole configuration (position and main type of console design) were identified (Fig. 5). Utility poles with one horizontal cross-arm and one/two pin insulators per conductor were the most numerous type in the 22 kV grid in our study area (60.08%) and were responsible for 42.04% of electrocuted individuals (0.03 carcass/pole). Poles with complex construction, such as corner or branch types with several levels of cross-arms, pin-insulators and combination of jumper wires, were the most dangerous; such types only formed 12.52% of all 22 kV poles but were responsible for 34.72% of electrocution mortality (0.13 carcass/pole).

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stará drevená konzola, P – prútová; Poloha izolátorov: V – vodorovná, H – horizontálna, D – dolu K – kombinovaná; Ochranné opatrenia: CA – zábrana na dvojzávese, CK, CS – ekochránička na jednozávese, HC – hrebeňová zábrana čierna, HZ – hrebeňová zábrana zelená, KL – klobúková chránička, TZ – trojuholníková zábrana, PS – ekochránička na jednozávese. Stav ochrany: 1 – OK, 2 – poškodená, 3 – nesprávne inštalovaná, 4 – neprítomná.

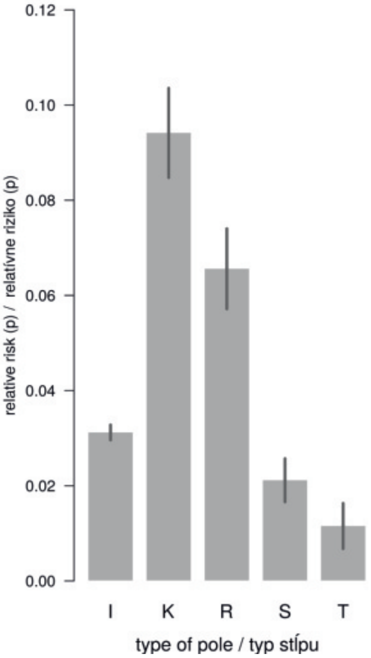

Fig. 6. Risk of various electrical pole configurations (22kV) to birds. Bar height represents the relative risk of electrocution on various types of poles. Vertical lines at each bar represent Blaker's exact confidence intervals (95 %) for risk level. Highest mortality risk was strongly associated with branch poles (K) and corner poles (R) followed by utility poles in a straight line (I), switch disconnectors (S) and electric pole transformers (T).

Obr. 6. Rizikovosť rôznej konfigurácie elektrických stĺpov (22 kV) pre vtáky. Výška stĺpcov vyjadruje priemernú hodnotu rizika. Vertikálne čiary v každom stĺpci vyjadrujú Blakerove 95%-tné intervaly spoľahlivosti pre priemernú hodnotu rizika. Najvyššia rizikovosť bola prítomná u odbočných stĺpov (K) a rohových stĺpov (R). Nasledujú stĺpy na priamej línií (I), úsekové odpínače (S) a transformátory (T).

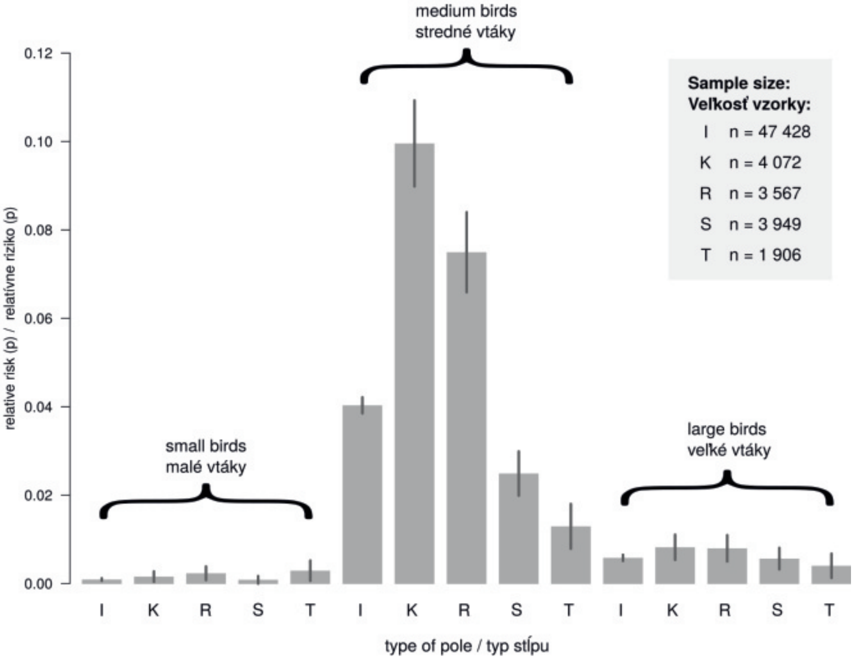

Fig. 7. Risk of poles (22 kV) with regard to pole type and bird size category. Bar height represents the relative risk of electrocution on various types of pole. Vertical lines at each bar represent Blaker's exact confidence intervals (95%) for risk level. Highest mortality risk was strongly associated with branch poles (K) and corner poles (R), especially for medium and less for large-sized birds.

Obr. 7. Rizikovosť stĺpov (22 kV) vo vzťahu ku typu stĺpu a veľkostnej kategórie vtákov. Výška stĺpcov vyjadruje priemernú hodnotu rizika, pričom vertikálne čiary prechádzajúce stredom každého stĺpca vyjadrujú Blakerove 95 %-tné intervaly spoľahlivosti pre priemernú hodnotu rizika. Najvyššia mortalita bola prítomná u stredne veľkých vtákov, a to najmä u odbočných stĺpov (K) a rohových stĺpov (R).

The correlation between pole configuration and bird mortality was statistically significant comparing different types of pole designs (Fig. 6).

For better perspective and risk assessment, all bird victims of electrocution were grouped in three main size categories; small, medium and large (22 kV) (Fig. 7). Medium and large bird species groups were composed mainly of birds of prey, owls and corvids.

Influence of presence of upper jumper wire

One main pole component (jumper wire) was tested. Presence of jumper wires can increase the potential for avian electrocution due to the proximity between these energized parts (Ferrer et al. 1991, APLIC 2006). Exposed jumper wires were used mainly on corner and branch poles or on some poles in straight line (Fig. 8).

The risk increases especially if jumper wires are located above the cross-arms (Fig. 9).

In the end we did not observe statistically significant differences in risk rate between types of jumper wires (i.e. overlapping confidence intervals). Wide confidence intervals are an inevitable consequence of smaller sample size, so we cannot fully exclude the possibility that their true risk rates differ. Some difference between risk rates could be at least partially deduced from estimated values of mean risk rate (height of bars).

Of all surveyed 22 kV poles, jumper wires in the upper position were identified in 4.5% (2,672 poles) but were responsible for 19.25% of all electrocution mortality.

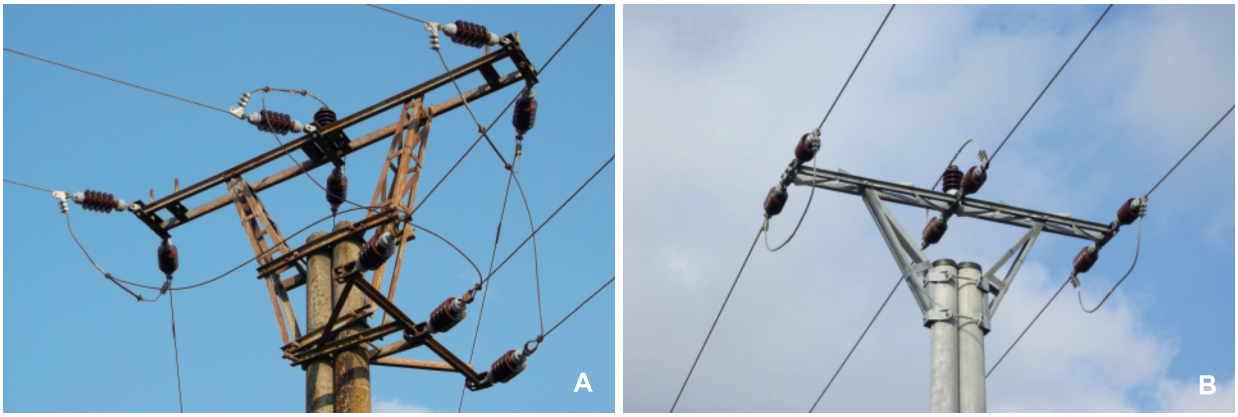

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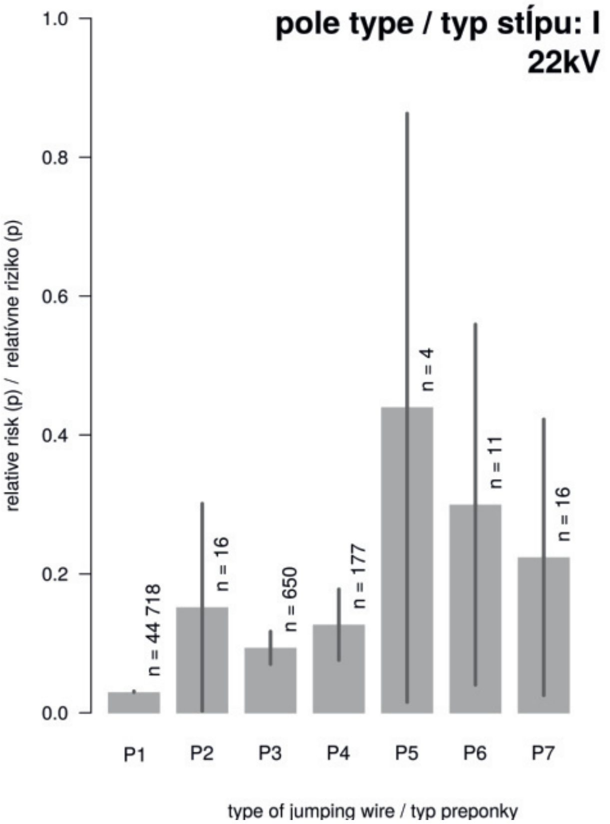
Fig. 8. Branch pole with many exposed jumper wire locations (A) and three phase conductor design of pole in a straight line (B) with exposed jumper wire over the middle phase (many risky variations were identified, either over the middle and/or over one or both other phases).

Obr. 8. Odbočný stĺp s rôznym umiestnením preponiek (A) a stĺp na priamej líníí s preponkou vedenou ponad strednú fázu (B). (identifikované boli mnohé kombinácie – ponad strednú a/alebo krajné fázy).

Effect of bird protection measures

During the field survey, 78.24% of bird carcasses were found under non-retrofitted poles, 5.05% under poles with a damaged product and 3.07% under poles where the product was installed incorrectly. These poles together made up 62.44% of all 22 kV poles surveyed.



◄ **Fig. 9.** Risk of electrical poles to birds with regard to type of jumper wires. Bar length represents the relative risk of electrocution for various types of jumper wires. Vertical lines at each bar represent Blaker's exact confidence intervals (95%) for risk level. All poles with the presence of jumper wires posed higher risk than basic utility poles without them. The wide confidence interval for some poles reflects the smaller sample in the surveyed area. Abreviations: P1 – without jumper wires, P2 – jumper wire passing over one pin-insulator at central phase, P3 – jumper wire passing over one pin-insulator et edge phase, P4 – jumper wire passing over two pin-insulator at central phase, P5 – jumper wire passing over two pin-insulator at central phase and one pin-insulator at edge phase , P6 – jumper wire passing over one pin-insulator at central phase and one pin-insulator at edge phase, P7 – jumper wire passing over pin-insulators at all phases.

◄ **Obr. 9.** Rizikovosť elektrických stĺpov so zameraním na typ preponky. Výška stĺpcov vyjadruje priemernú hodnotu rizika. Vertikálne čiary prechádzajúce stredom každého stĺpca vyjadrujú Blakerove 95 %-tné intervaly spoľahlivosti pre priemernú hodnotu rizika. Všetky stĺpy s prítomnými preponkami predstavujú pre vtáky vyššie smrtiace riziko a bežný stĺp na priamej línií bez nich. Veľmi široké intervaly spoľahlivosti u niektorých typoch stĺpov sú spôsobené menším (reálne existujúcim) počtom takýchto stĺpov v skúmanom území (t.j. menšou vzorkou použitou pre výpočet). Skratky: P1 – bez preponky, P2 – preponka vedená strednou fázou cez jeden izolátor, P3 – preponka vedená krajnou fázou cez jeden izolátor, P4 – preponka vedená strednou fázou cez dva izolátory, P5 – preponka vedená strednou fázou cez dva izolátory a krajnou fázou cez jeden izolátor, P6 – preponka vedená strednou a krajnou fázou cez jeden izolátor, P7 – preponka vedená všetkými fázami cez jeden izolátor.

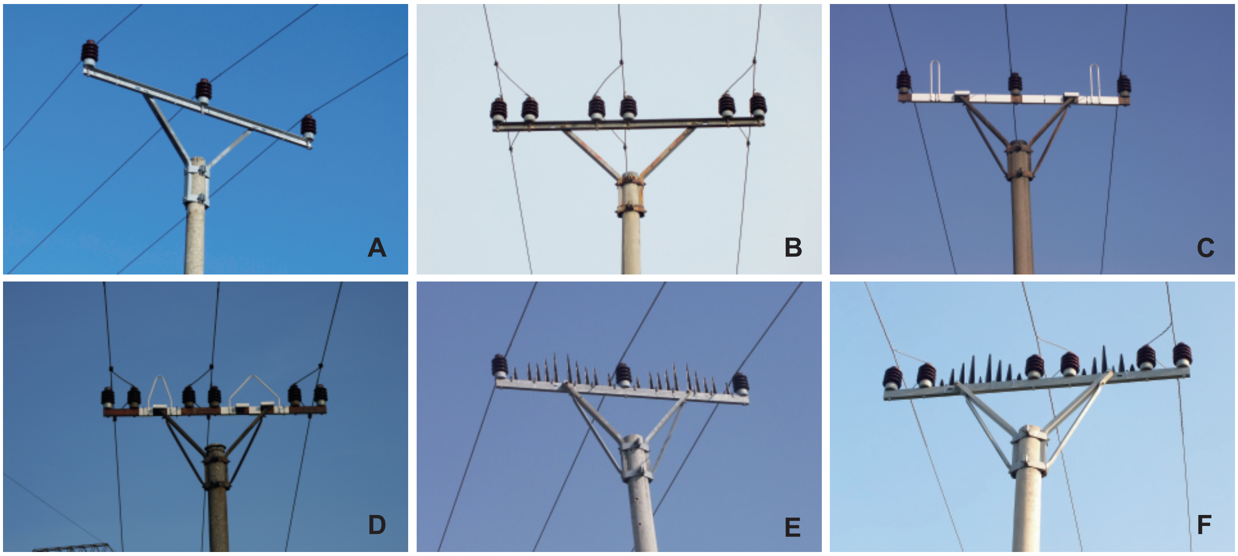


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Fig. 10. Common utility pole with one (A) and two (B) pin-insulators per phase without insulation, with protective devices which allow birds to perch safely (C) or prevent birds perching on the cross-arm but allow them to perch on top of the product (D) and plastic combs used as perch discourager (E, F).

Obr. 10. Stĺpy na priamej línií bez ošetrenia s jedným (A) a dvomi (B) podpernými izolátormi na jednu fázu, s ochrannými prvkami, ktoré umožňujú vtákom bezpečne dosadnúť (C) alebo im v dosadnutí bránia pričom im umožňujú sedieť na vrchole prvku (D) a plastové hrebene použité ako zábrana (E, F), ktorá bráni dosadnutiu.

13.64% of carcasses were located under poles which were retrofitted properly. Possible risk of electrocution was separately evaluated for (i) the most common 22 kV distribution pole (A, B) with a design of one/two insulators per phase conductor without retrofitting (ii) the first used (E, F) and (iii) the most common (C, D) protection measures (Fig. 10).

Statistically highest risk was identified for utility poles without insulation compared to the poles with present (safe perching or perch discourager) insulations. Utility poles with one phase per conductor posed higher risk than poles with two insulators per conductor. Lowest risk was identified for protective products which allow birds to perch safely on the cross-arm or on top of the product in comparison to products used as perch discourager (Fig. 11).

Different types of protective measures were also evaluated depending on the identified bird mortality for all species and separately for birds of prey (Tab. 2).

Not only the insulation products, but also changes in pole construction and position of pin-insulators and thus jumper wire location, could be rated as effective mitigation measures against electrocution. The most effective solution not only in Slovakia appears to be complete replacement of the construction with a new type, so-called Antibird and Ecobird consoles (Fig. 12). They are both effective thanks to the shape of the console (45° angle of the arms) (Škorpíková et al. 2019). Another option is a suspension construction with hanging jumper wires.

Spatial distribution of the poles with recorded mortality incidents can help optimize the application of mit-

Tab. 2. Bird mortality on poles depending on mitigation measures.
Tab. 2. Mortalita vtákov v závislosti od ochranných prvkov.

mitigation measures / ochranné opatrenia	total number of poles / celkový počet stĺpov	poles with mortality / stĺpy s mortalitou all species / všetky druhy	birds of prey / dravce
console insulation / izolácia konzoly	6,846	92 (1.34%)	32 (0.4%)
plastic combs / plastové hrebene	4,586	113 (2.46)	78 (1.7%)
plastic hat cover / plastové kryty	701	102 (14.5%)	12 (1.7%
plastic triangle / plastový trojuholník	182	27 (14.8%)	11 (6%)
other mitigation measures / ostatné ochranné opatrenia			
Antibird / Ecobird console / Antibird / Ecobird konzola	1,631	16 (0.9%)	15 (0.9%)
pole with hanging insulators / stĺp s vysiacimi izolátormi	2,094	38 (1.8 %)	6 (0.3%)

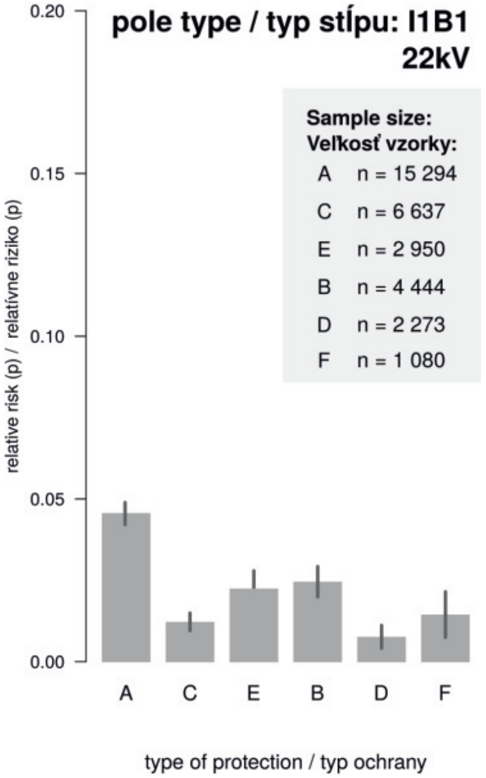

Fig. 11. Risk of various electricity poles (type I, 22kV) to birds with regard to presence/absence and type of protection. Bar height represents the relative risk of electrocution for various types of protection. Vertical lines at each bar represent Blaker's exact confidence intervals (95%) for risk level. Abbreviations: Common utility pole with one (A) and two (B) pin-insulators per phase without insulation, with a protective product which allows birds to perch safely (C) or prevent birds perching on the cross-arm but allow them to perch on top of the product (D) and plastic combs used as perch discourager (E, F).

Obr. 11. Riziko rôznych prevedení stĺpov typu I (22 kV stĺp na priamej línií) z hľadiska prítomného/neprítomného ochranného prvku a jeho typu. Výška stĺpcov vyjadruje priemernú hodnotu rizika, pričom vertikálne čiary prechádzajúce stredom každého stĺpca vyjadrujú Blakerove 95 %-tné intervaly spoľahlivosti pre priemernú hodnotu rizika. Skratky: Stĺpy na priamej línií bez ošetrenia s jedným (A) and dvomi (B) podpernými izolátormi na jednu fázu, s ochrannými prvkami, ktoré umožňujú vtákom bezpečne dosadnúť (C) alebo im v dosadnutí bránia pričom im umožňujú sedieť na vrchole prvku (D) a plastové hrebene použité ako zábrana (E, F), ktorá bráni dosadnutiu.

igation measures considering the risk of electrocution. This visualization (Fig. 13) can be used by power supply companies to focus their attention on the main "hot spots" with the highest risk of mortality.

Collision mortality and effect of power line construction

Identified collisions made up 23.28% (908 ind.) of all detected carcasses belonging to 72 bird species and 14 bird orders. Fig. 14 shows the mortality in different taxonomic groups. Birds from the Corvidae family are listed separately from the other Passeriformes. Both types of line (22 kV and 110 kV) were responsible for collisions.

Anseriformes and Passeriformes made up 54.62% of all identified collisions taken together. The percentage of raptors and corvids (3.85%) colliding with power lines was small, compared to electrocuted individuals (45.88%). In our results, the mute swan (*Cygnus olor*) was the most common bird detected with 20.8% (189 ind.) of all identified collisions (n = 908). The second highest mortality was observed for the common pheasant (*Phasianus colchicus*) with 13.2% (120 ind.) and third for the common blackbird (*Turdus merula*) with 6.3% (58 ind.).

In addition, habitats with oil-seed rape fields played an important role in this high mortality, especially if the power line was located close to such habitats (Fig. 15).

During our field survey the exact position of bird carcasses was recorded, to test the question whether the position of power lines relative to the cardinal points could influence bird mortality. Most carcasses (43.72%) were located directly under the wires, so field assistants were not able to identify the exact direction of flight from their position. For the carcasses where the position could be identified, the prevailing trend was to the south (20.48%) or north (18.17%) from the power lines (Fig. 16).

Influence of the number of conductor levels

Risk of collision for different vertical levels of medium voltage power lines (22 kV) vs. high voltage power lines (110 kV) was evaluated. Power lines of 110 kV pose higher risk than lower 22 kV lines (Fig. 17).

Discussion

Of the 4,353 victims identified under all surveyed power lines, the majority of them (76.72%, 2,992 ind.) was killed by electrocution, with 23.28% (908 ind.) due to collision with wires. 14 out of all 84 detected species are listed in the Red List of birds in Slovakia (Demko et al. 2013). In Bulgaria very similar results were obtained.

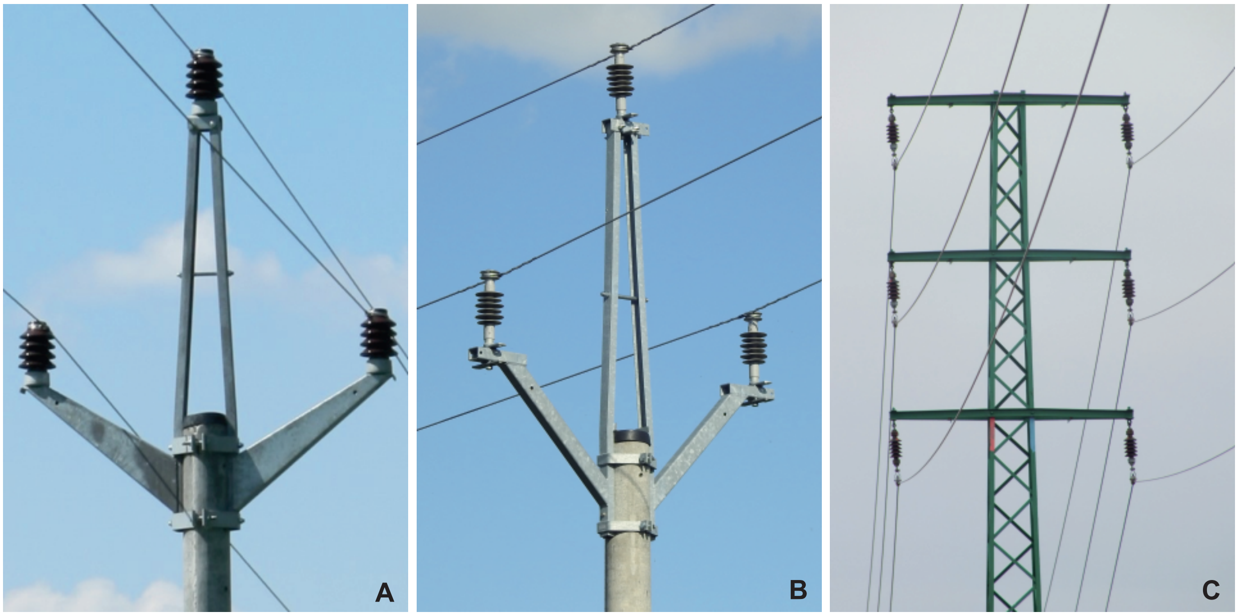

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Fig. 12. Effective solutions for protecting birds from electrocution: Antibird (A), Ecobird (B) consoles and suspension pylon with hanging jumper wires (C).

Obr. 12. Efektívne spôsoby ochrany vtákov pred zásahom prúdu: konzoly Antibird (A), Ecobird (B) a stožiar so závesnými preponkami (C).

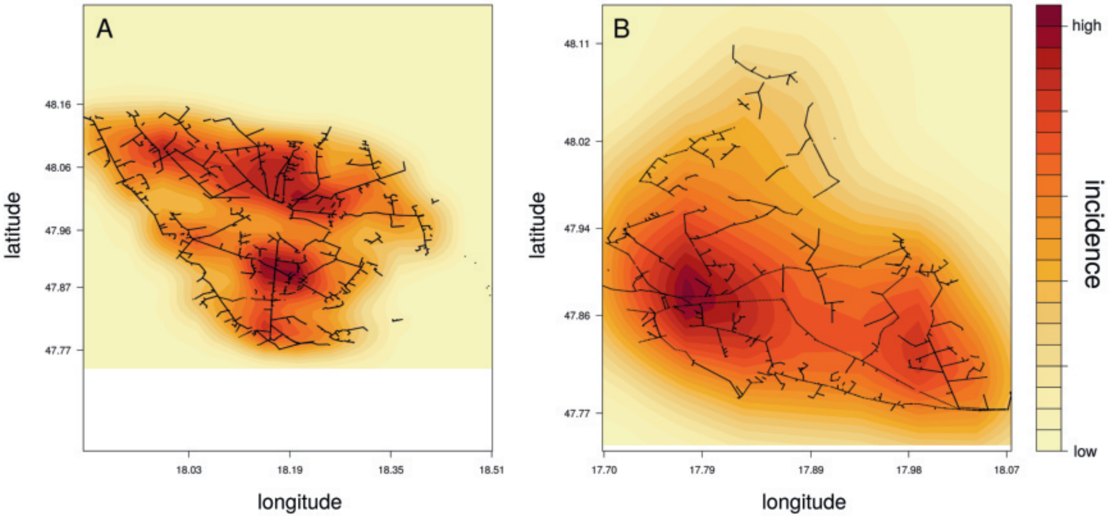

Fig. 13. Examples of possible visualization of incidence of bird mortality for specific areas (kernels for individual areas). Results of analysis suggest that incidences of electrocution tend to be concentrated in specific areas.

Obr. 13. Príklady možnej vizualizácie relatívnej frekvencie úhynov v skúmanom území (kernelové hustoty zachytávajúce frekvenciu úhynov pomocou farebnej škály). Výsledky týchto priestorových analýz naznačujú, že úhyny môžu byť v krajine koncentrovane do špecifických zón (tzv. "zóny smrti").

Electrocution was suspected for 77.1% of the detected carcasses, while 22.9% were suspected power line collisions (Demerdziev et al. 2009). Monitoring was carried out along a 139.3 km length of 20 kV power line featuring1,418 utility poles of various design. Even higher numbers and variety of bird mortality composition were identified in the Czech Republic. Electrocution was responsible for 88.24% of bird carcasses and collision for only 11.8% (Škorpíková et. al. 2019). Their field survey was carried out on a length of 6,429 km/76,432 poles of

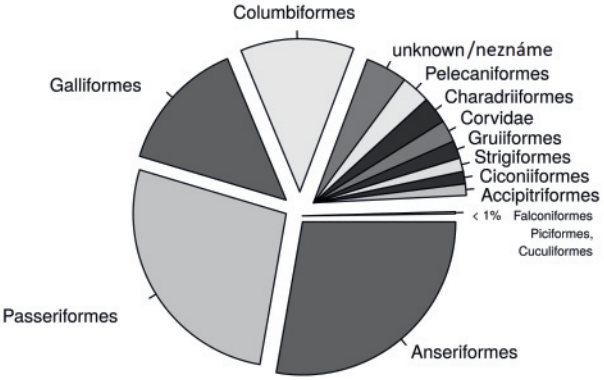

Fig. 14. Identified collisions in different taxonomic groups.
Obr. 14. Podiel úmrtnosti v dôsledku nárazov pre jednotlivé taxóny.

22 kV power line. During the survey 1,326 bird carcasses of 60 species and 12 orders were found. The results of many studies also suggest that small bird carcasses disappear earlier and in a higher proportion than larger birds, often leaving few or no remains (Prosser et al. 2008, Ponce et al. 2010). These results were also confirmed in our observations by only occasional finds of small bird remains (feathers, bones). The real number of small bird carcasses is therefore most probably underestimated. Mortality rates can vary by season (Bevanger 1995, Harness & Wilson 2001), with expected higher mortality rates for migratory birds during spring and fall migrations, and also for resident bird species (Loss et al. 2014). Given the characteristics of this study in which the majority of poles and pylons were only checked once in order to obtain a mortality range for the whole surveyed area, the data cannot be adjusted for total mortality rates with season patterns. Due to this limitation of our survey, we could expect that some utility poles or power line wires killed a large number of birds during the spring or fall migration periods, but since they were inspected only once and outside of these "high mortality rate" periods (therefore with zero mortality), these poles/wires appear to be safe for birds.

Strong correlation was identified between the spatial distribution and the riskiness of the utility poles. Zones with high incidence of bird mortality for individual geographical areas (so-called "death zones") were prepared. Observed electrocution incidence showed a patchy distribution across the study area, with high values in some specific areas. Our spatial analysis suggests that incidences of electrocution tend to be concentrated in specific areas. Bird mortality rates are not evenly distributed throughout the study area, suggesting the possible effect of spatially-related electrocutions. This clustering effect could be a result of different landscape composition and in the case of raptors also of the presence of prey sources.

The presence of identified bird carcasses may not reflect reliably the results of bird mortality surveys realized on range of 6,235 km of power lines.

We did not calculated correction factors for observer efficiency and scavenging rates influenced by season, vegetation type and habitat. The number of birds scavenged by predators (birds of prey, jackals, foxes, dogs and cats) was not assessed and monitored in our study,

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Fig. 15. Carcasses of mute swans in an oil-seed rape field used as foraging habitat, crossed by 22 kV power line (A) and visible burn marks on feathers (B) after collision-electrocution.
Obr. 15. Úhyny labute veľkej na repkovom poli, využívanom ako krmovisko (A), ktoré bolo križované vedením 22 kV a viditeľné stopy popálenín na perí (B) po náraze a následnom zásahu prúdom.

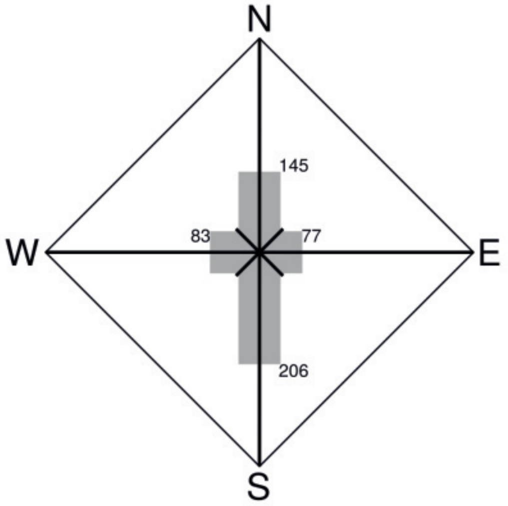

Fig. 16. Position of collision victims identified under surveyed power lines.
Obr. 16. Poloha úhynov po náraze identifikovaných na skúmaných vedeniach.

although carcass removal by scavengers often biases the mortality surveys (Ponce et al. 2010) in very high initial removal rates among smaller carcasses, most of which disappeared within the first days (Prosser et al. 2008). The estimated mean mortality of birds killed on power lines in this study should therefore be considered as a minimum estimate. Additionally, some authors have recommended against making generalizations on total mortality rates for large geographical areas (Moleón et al. 2007, Guil et al. 2011).

Electrocution mortality
Altogether 2,992 individuals were killed by electrocution solely on 22 kV poles (60,296). Electrocuted birds were found below 3.5% (2,016 poles) of 22 kV poles. For example in a study undertaken in Spain (Janss & Ferrer 2001), a dead bird was located under 5.3% of power poles. Very similar numbers are reported in Bulgaria, where electrocuted birds were concentrated under 4.6% of all surveyed poles (Demerdziev et al.

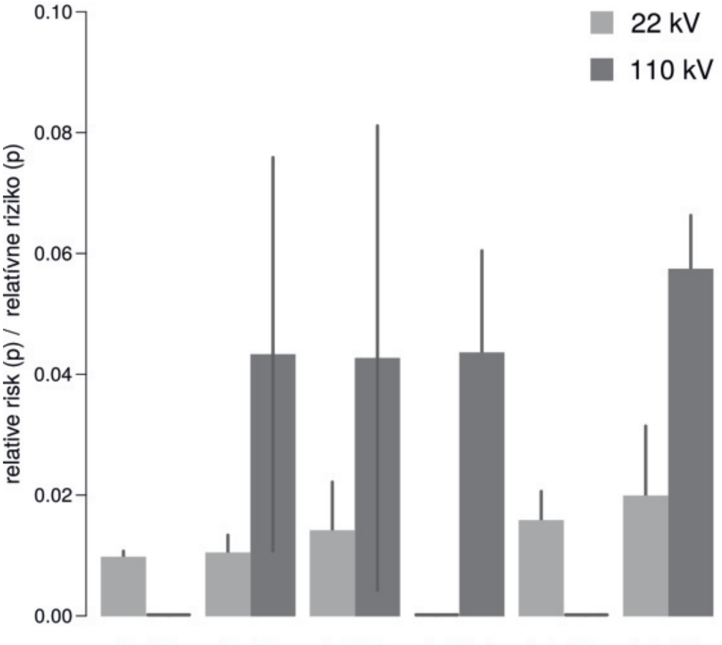

Fig. 17. Risk of power line to birds with regard to number of horizontal levels. Barplot height represents the relative risk of collision for various types of horizontal levels. Vertical lines at each bar represent Blaker's exact confidence intervals (95%) for risk level. Abbreviations: L – number of voltage circuits; R – number of conductor levels.
Obr. 17. Rizikovosť vedenia pre vtáky vzhľadom k počtu horizontálnych rovín. Výška stĺpcov vyjadruje priemernú hodnotu rizika. Vertikálne čiary prechádzajúce stredom každého stĺpca vyjadrujú Blakerove 95 %-tné intervaly spoľahlivosti pre priemernú hodnotu rizika. Skratky: L – počet okruhov vedenia; R – počet úrovní vodičov.

2009), and only 1.24% of all poles (718 pylons with 826 electrocuted birds) were responsible for mortality in a study carried out in the Czech Republic (Škorpíková et al. 2019).

According to our results, the number of dead birds per year and per utility pole was estimated as 0.05. A very similar number was presented in a study by Loss et al. (2014), with a median annual rate of 0.03 birds per distribution pole.

Power lines cause a large proportion of mortality for some species, especially raptors (Harness & Wilson 2001, Guil et al. 2011). Corvids and birds of prey often use poles for roosting or hunting, as they are often the tallest structures in grassland and open agricultural land (APLIC 2006, Demeter et al. 2018). These two groups are therefore often evaluated together. Corvids and birds of prey represented 85.25 % of all identified electrocutions in our study. Raptors were associated with 40% of all identified victims of electrocution. In Bulgaria, crows and birds of prey represented more than 53% of detected electrocutions (Demerdziev et al. 2009), while in the Czech Republic this percentage is even higher, up to 87.77% (Škorpíková et al. 2019). Our results are similar to those in other studies, such as Bayle (1999) in France where corvids and birds of prey made up 85% of electrocution records, and a study in Spain, where crows and birds of prey represented more than 80% of all identified electrocutions (Guyonne et al. 2001).

In our results the common buzzard was the bird of prey most frequently detected, and was involved in 85.39% (1,023 ind.) of all identified raptor electrocutions (n = 1,198), in 34.19% of all electrocutions and in 26.23% of all recorded bird carcasses (electrocution + collision). Second highest mortality was observed for the Eurasian magpie with 20.08% (601 ind.) and third for the hooded crow with 7.08% (212 ind.). Very similar composition of bird carcasses was published by Škorpíková et al. (2019). The common buzzard was the most frequently detected victim of electrocution (39.48%) followed by the Eurasian magpie (17.55%) and common kestrel (*Falco tinnunculus*) (13.89%). Based on the results of Janss & Ferrer (2001), most common casualties in Spain were the common raven (*Corvus corax*) (16.0%), jackdaw (*Corvus monedula*) (10.2%) and common buzzard (7.7%). In Hungary, of all identified electrocutions (n = 2,777) the common buzzard was the most often detected victim (18.9%), followed by the Eurasian magpie (13.8%) and white stork (*Ciconia ciconia*) (13.6%) (Fidlóczky et al. 2014). During the monitoring in a recent study done in Hungary (01/2004–12/2014), volunteer researchers surveyed 57,486 pylons. 3,400 bird carcasses of at least 79 species were identified as electrocuted (Demeter et al. 2018). Due to relative similar types of pylons in the listed countries (Slovakia, Czech Republic and Hungary), the different proportions of electrocuted species most likely reflect the differences in composition of bird populations in the surveyed habitats. Probably in most of our cases, the electrocution of small Passeriformes and Columbiformes occurred when these perched in higher numbers on support (pin) insulators or close to exposed jumper wires located on branch poles and transformers. This relatively small unprotected area can be lethal for this group of birds.

In our study, two endangered species were also separately evaluated as victims of electrocution, identified during 12/2014–09/2019: the imperial eagle (16 identified carcasses) and saker falcon (14 identified carcasses). The imperial eagle population was composed of at least 90–95 breeding pairs and for the saker falcon 30–32 breeding pairs for the whole of Slovakia (Chavko 2018). Both are endangered especially by human activities, but one of the main causes of mortality is electrocution on distribution power lines (Heredia 1996, Bagyura et al. 2002, Nagy & Demeter 2006, Karyakin et al. 2009, Chavko 2010, Horváth et al. 2011, Prommer et al. 2012, Kovács et al. 2014, Nemček et al. 2014, Demeter et al. 2018).

Young imperial eagle and saker falcon individuals are especially common victims of electrocution in Slovakia (Nemček 2014, 2016, Veselovský 2018), corresponding to results from other countries (Prommer et al. 2012, Kovács et al. 2014, Stoychev et al. 2014). Proximity to nests of non-insulated medium-voltage poles poses a fatal risk for many young and inexperienced birds with lower ability to fly, as they try to take offor land on poles (APLIC 2006). Many of the nesting pairs of saker falcon and imperial eagle have gradually resettled from the foothills to the neighbouring agrocenoses, with higher risk of possible electrocution and/or collisions (Danko & Chavko 2002, Chavko 2002, 2010). The negative impact of electrocution on endangered raptors, with many other direct and indirect mortality factors, can lead to great reduction in population strength and density. This is especially for species where the loss of a few or even one individual may impact a local population or the overall population viability (Crowder 2000).

Necessary mitigation measures were also adopted by distribution power-line operators during the LIFE

Energy project; one third of medium-voltage poles around the nests of both species were insulated with effective plastic devices to eliminate electrocutions. Moreover, jumper wires were relocated to new underslung and thus safe positions. This was also done on metal poles during the LIFE Energy project.

Corner and branch poles were significantly more dangerous for birds than utility poles in straight lines. Bird mortality was lowest for power-line switch disconnectors and pole-borne transformers, which are often situated at the edges of human settlements or are part of urban/industrial areas, with lower presence of birds. Corner and branch poles on medium-voltage lines were also identified as the most dangerous in a survey done in the Czech Republic (Škorpíková et al. 2019). Similar results are reported also in Bulgaria: metal branch poles featuring jumper wires accounted for 54.3% of total detected electrocution mortality (Demerdziev et al. 2009). Anchor poles in particular have been shown to pose a significant electrocution risk to birds, particularly due to the configuration of the jumper wires (Dixon et al. 2013, 2017, Škorpíková et al. 2019).

Medium and large bird species were significantly affected, as they are more likely to make simultaneous contacts with unprotected parts of the pole construction (Dwyer & Mannan 2007, Dwyer et al. 2015). These results are in strong correlation with our findings, as corvids and birds of prey made up 85.25% of all identified electrocutions. The proposed mitigation measures should therefore be generally focused especially on medium-sized birds and on corner and branch pole types. Medium and large perching birds can easily bridge the gap between wires, consoles and jumper wires, which are in much closer proximity on corner and branch poles. The electrocution of large birds such as raptors, owls and corvids can also cause damage and sometimes result in interruption of power distribution. Large electrocuted birds (eagles, storks) very often remain in place, resulting in failure of the circuit as the operating system tries to re-energize the grid.

Electrocution may occur even on retrofitted poles. The current quality status of already installed bird protective measures (O.K., damaged or wrong application) was also evaluated and compared with mortality due to electrocution. The highest percentage (78.24%) of bird carcasses were found under non-retrofitted poles. The rest consisted of 5.05% under poles with a damaged product and 3.07% under poles where the product was installed incorrectly.

The risk of possible electrocution is significantly higher on utility poles without insulation, especially for construction types with one pin-insulator per phase conductor. Plastic insulators which allow birds to perch safely on the console are more effective than plastic combs. Plastic combs (green or black) were the first and became the most widely-used bird protection measure in Slovakia. Many medium and large bird species were found electrocuted under a pole with a comb installed during our study, even if the product was in good condition and still fully covering the console. More species were electrocuted on damaged combs, especially if the remains of the product were located in the middle of two insulators, forcing birds to perch closer to the phase conductors or other energized parts. In the Czech Republic (Škorpíková et al. 2019) this protection measure was also replaced for being non-effective. A study by Dwyer et al. (2017) evaluated 52 retrofitted poles where 56 birds, including 17 golden eagles, were electrocuted due to incorrect installation of the product. The products used to mitigate the electrocution risk should be made from durable, long-lasting materials and should be installed properly to ensure protection of birds. If they are damaged or incorrectly installed, they are useless and more dangerous than non-insulated poles.

Collision mortality

Altogether 72 bird species and 14 bird orders were identified as victims of collision in our study. Anseriformes and Passeriformes made up more than half of all identified collision victims together. The percentage of raptors and corvids colliding with power lines was very small, compared to electrocuted individuals. The highest mortality (23.2%) was recorded for the mute swan. These results were not surprising, because large birds with slow manoeuvrability (high wing loading and low wing aspect ratio) are especially vulnerable to collision (Bevanger 1998, Erickson et al. 2001, Crowder & Rhodes 2002, Manville 2005, Jenkins et al. 2010). For this reason swans are among the commonly recorded victims (Perrins & Sears 1991, Brown 1993, Mathiasson 1993, Frost 2008, Kelly & Kelly 2009, Gális et al. 2018a, Franson et al. 2019). Other studies have shown very similar or higher numbers of casualties for the mute swan, accounting for 30–40% of all recorded deaths in Coleman et al. (2001), and up to 46% of deaths in study by Spray (1991). Many reports of mute swan collisions with power lines are available from the United Kingdom. The study by Frost (2008) presented a significant level of mortality in spring for mute swans colliding with overhead 132 kV power lines. The study by Perrins & Sears (1991) showed that 22% of all reported carcasses of swans were the result of collisions with wires. In Sweden between 19–38% of ringed mute swans were killed by collision with electrical wires (Mathiasson 1993). One input factor which could influence bird collision susceptibility (though not a significant factor in determining the risk of collision) is elevated blood lead level. Studies by Kelly & Kelly (2009) suggest that mute swans with elevated but moderate blood lead levels suffer an increased risk of collision, while those with intermediate to high levels have a much reduced risk of collision, possibly because they are too weak to fly. The large number of dead mute swan individuals in our study area was probably a result of their behaviour, as they fly mainly in flocks. They also require long stretches for take-off and landing. Moreover, species with narrow visual fields (e.g. swans, ducks, herons) are at higher collision risk as they can not see the wires from a certain angle (Martin & Shaw 2010, Martin 2011).

Positive effect of the height of tree growth on collision probability was identified during our field survey. On one particular 22 kV power line with a total length of 600 m, of which 250 m was in the neighbourhood of trees, all collisions (18 mute swans) were recorded only on the remaining 350 m without the presence of nearby tree growth producing a lower probability of collision. The correlation of presence of nearby tree growth was studied by Bevanger & Broseth (2004), where collision spots generally had lower trees compared to places with tall trees alongside power lines, which were without any recorded collisions.

Although different bird species fly at differing heights above the ground, there is a prevailing consensus that the lower power-line cables are to the ground, the better they are for preventing bird collision. There is also a consensus that reduced vertical separation of cables is preferred as it poses less of an “obstacle” for birds to collide with. Horizontal separation of conductors is therefore preferred (Prinsen et al. 2011). Based on our findings, 110 kV power lines pose a higher risk than lower 22 kV lines.

Increasing the number of conductor levels leads to higher risk of possible collision. Our results are in line with those of many studies (Drewitt & Langston 2008, Jenkins et al. 2010). On the other hand, the effect of vertical levels was not in correlation with collision rates in studies by Infante et al. (2005) and Neves et al. (2005). Higher risk could be correlated with the presence of a shield wire on 110 kV lines. It is the highest wire and can be difficult for birds to see (APLIC 2012) because of its small diameter compared to phase conductors. The number of vertical levels can pose greater risk, but many studies reporting the positive/negative effects of number of vertical levels of wire were reviewed in the excellent study by Bernardino et al. (2018), where the authors conclude that there is little scientific evidence in support of these effects due to the practical difficulties involved in testing them (APLIC 2012).

Orientation of power lines relative to biological characteristics (e.g. flight behaviour, season, habitat and habitat use) and environmental conditions (e.g. topographical features and weather patterns) can also influence collision risk. Brown (1993) suggested that north-south orientation of lines increased collision frequency for cranes and waterfowl in the San Luis Valley, Colorado, because birds crossing them on an easterly heading were often subjected to prevailing westerly winds. More studies from different sites are needed to test whether or not the risk of collision could be increased by sun glare, as bird collision risk could also be correlated to sun glare, mainly when birds undertake flights over lines oriented in west-east pattern. The carcasses whose position could be identified in our study, and whose prevailing position was south or north from power lines, could indicate that birds flying in north-south direction, and thus into the sun, could be blinded by the glare and thus collide with the wires. Just after sunrise and before sunset the sun can shine directly into birds´ eyes, leaving many flying into a glare. This glare can make it much harder to see power lines ahead, turning them into potential hazards creating an added risk for birds.

Conclusions

The main focus of this study was on collision and electrocution, to recognize the range of the problem and its relevance for different bird species, power lines and pole/pylon designs. The field monitoring was the most comprehensive and systematic study of its kind ever carried out in Slovakia. The majority of all identified bird victims was killed by electrocution, especially corvids and birds of prey (including the endangered saker falcon and imperial eagle). Only medium-voltage lines (22 kV) were responsible for electrocution and these lines killed birds primarily by electrocution rather than collision. The risk of possible electrocution was correlated to the size of birds. Medium and large bird species were most affected as they consist mainly of birds of prey, owls and corvids, which very often use poles for perching or hunting. Because of their bigger wing span and/or other body parts, larger bird species can easily short-circuit the energized parts and/or phase conductors on poles compared to smaller bird species. Poles with complex construction, such as corner or branch types with several levels of cross–arms, pin–insulators and combination of jumper wires, were much more dangerous than poles in straight lines, switch disconnectors and poles bearing transformers. The risk of possible electrocution was significant higher for utility poles without insulation than for poles with effective protection devices, but only if they are in good condition and installed in the proper way. The most dangerous medium-voltage power poles identified in our survey were insulated to prevent electrocution, especially in buffers around the nests of saker falcons and imperial eagles.

Much fewer bird individuals (but more bird species) were killed by collision than electrocution. The incidence of raptors and corvids colliding with power lines was very small, compared to electrocuted individuals and large heavy-bodied species such as the mute swan, which had the highest mortality rate recorded in our study area. Habitats with oil-seed rape fields played an important role in this high mortality, especially if the power line was located close to them. Increasing vertical separation of cables posed more of an ‘obstacle’ for birds to collide with.

Based on the results from our field survey (12/2014–02/2016), 13 mitigation plans were designed for the project area with recommendations of particular measures for each SPA and neighbouring areas, including the installation of bird flight diverters on sections of power lines with the highest risk of possible collisions. 1,120 km of power lines were included in the group in the highest category (17.9% of all inspected power lines) concerning the relative risk of collision evaluation. Of these, 77 km were given the highest priority and were provided with increased visibility by means of 8,000 bird flight diverters within the LIFE Energy project period.

The risk posed by power lines to birds is still an underestimated reason for their mortality in some countries or areas, and the data are either missing or absolutely insufficient. The bird vs. power line issue is dealt with in a large number of reports and publications from various countries. In some countries only sporadic data have been recorded by local experts and the general public, and up to now the phenomenon of collisions has not been credibly studied and evaluated worldwide. More knowledge about the factors increasing collision and electrocution mortality rates will produce essential guidelines for proper bird-friendly measures in the case of existing and/or for the construction of new power lines. In Slovakia a special legal obligation for this was imposed in 2003, based on Law No. 543/2002 Coll. on the Conservation of Nature and Landscape:

(i) Everyone building or doing a reconstruction of an aerial power line according to a plan is required to use a technical solution which prevents the electrocution of birds.

(ii) If cases of bird mortality are proven on a power line or telecommunications device, the Nature Conservancy Authority can decide that the operator of it must undertake technical measures to prevent such incidents.

Any problems so far have always been resolved after mutual communication. Construction of safer cross-arms has been adopted, or they have been insulated to protect birds from electrocution. Diverters are being installed to prevent collisions. Since implementation of the LIFE Energy project, the electricity companies have started considering the protection of birds even prior to (re)construction. The good relationship, cooperation and trust which we have built with the electricity companies are now far more effective, useful and important than the obligations set by the law.

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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

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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

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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,

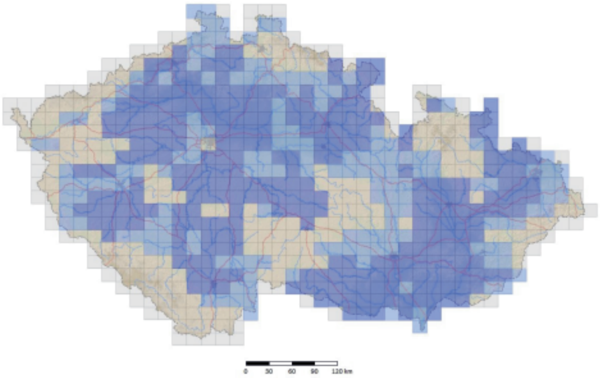

Fig. 1. A map of the Czech Republic with a network of grid squares, where squares suitable, i.e. open landscape below 500 m a.s.l. forming min. 80% of their area are highlighted (blue); and squares chosen for field work are in dark blue.
Obr. 1. Kvadrátová mapa České republiky, kde kvadráty vhodné (otevřená 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.

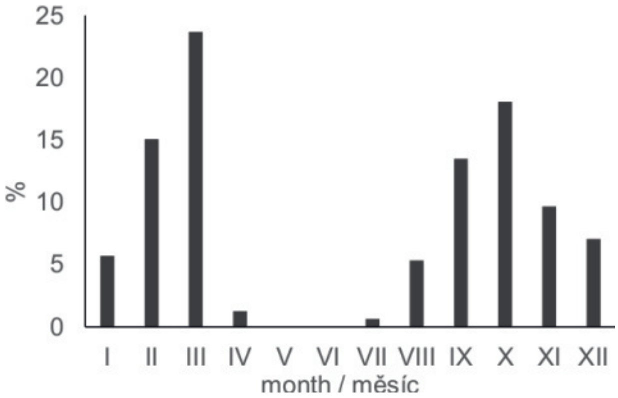

Fig. 2. Percentage of pylons checked monthly in the period from July 2015 to April 2016.
Obr. 2. Množství sloupů (v %) kontrolovaných v jednotlivých měsících od července 2015 do dubna 2016.

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).

Statistical analysis

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-*

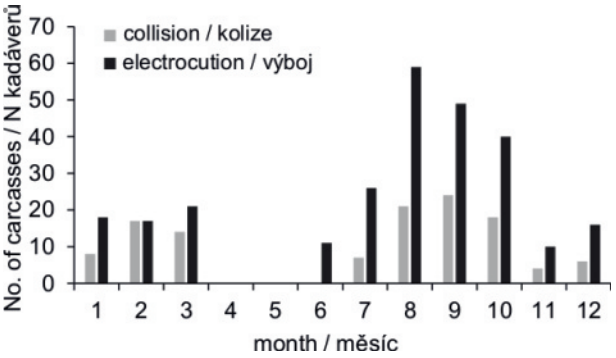

Fig. 20. Bird mortality on medium-voltage electrical lines in months of the year based on carcasses not older than two months (n = 119 collided and 267 electrocuted birds).
Obr. 20. Mortalita ptáků na elektrických vedeních vysokého napětí v jednotlivých měsících roku podle kadáverů ne starších než dva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

cross-arm type / typ konzoly	no. of pylons / n sloupů	all species / všechny druhy: pylons with mortality / sloupy s mortalitou (n / %)	no. of carcasses / n kadáverů	target species / cílové druhy: 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

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.

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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

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Monitoring of effectiveness of bird flight diverters in preventing bird mortality from powerline collisions in Slovakia

Monitoring účinnosti odkloňovacích prvkov z pohľadu prevencie úmrtnosti vtákov v dôsledku nárazov do elektrických vedení na Slovensku

Marek GÁLIS & Michal ŠEVČÍK

Abstract: Flight observations and carcass searches were carried out along distribution power lines in Slovakia. 77 km of 22 kV and 110 kV lines were marked on a total of 108 sections to evaluate the effectiveness of three types of bird flight diverters (FireFly Bird Diverter, RIBE Bird Flight Diverter and SWAN-FLIGHT Diverter) designed to increase power line visibility. Numbers of carcasses were compared before and after installation of the devices and reaction distances on marked power lines were surveyed. We observed a 93.5% reduction (93 vs. 6) in the number of fatalities under the marked power lines after line marking (06/2016–06/2019) compared to the period before installation (12/2014–02/2016). 2,296 flight reactions were observed and an estimated total of 41,885 individuals (57 bird species belonging to 13 orders) were recorded with their reactions to marked lines in the period 06/2016–06/2019. After installation of bird diverters, there was a low proportion of flight distance observations at the closest distance, i.e. up to 5 m, indicating that birds reacted further away from marked lines. Although we lack flight observations for the period before the installation of diverters, the reactions of birds at greater distances and reduced number of bird victims under marked lines indicate that all tested diverters have a positive effect on reducing the number of avian collisions with power lines.

Abstrakt: Monitoring reakcií vtákov a vyhľadávanie uhynutých jedincov boli realizované pozdĺž distribučných elektrických vedení na Slovensku. Na 108 označených úsekoch 22 kV a 110 kV vedení v dĺžke 77 km bola hodnotená efektivita troch typov odkloňovacích prvkov (FireFly Bird Diverter, RIBE Bird Flight Diverter a SWAN-FLIGHT Diverter), určených na zvýšenie viditeľnosti elektrických vedení. Porovnávali sme počet uhynutých jedincov pred a po inštalácií odkloňovacích prvkov a sledované boli reakcie a reakčné vzdialenosti na ošetrených vedeniach. Po inštalácií odkloňovacích prvkov (06/2016 – 09/2019) bolo v porovnaní s obdobím pred inštaláciou (12/2014 – 02/2016) zistené 93,5 % zníženie (93 vs. 6) úmrtnosti jedincov. V období (06/2016 – 09/2019) sme na ošetrených vedeniach zaznamenali 2296 reakcií vtákov v počte približne 41 885 reagujúcich jedincov (57 druhov patriacich do 13 radov). Po inštalácií odkloňovacích prvkov bola pozorovaná nižšia početnosť reakcií vo vzdialenosti do 5 m, čo naznačuje, že jedince reagovali na ošetrené vedenia vo väčších vzdialenostiach. Napriek tomu, že nebol realizovaný monitoring reakcií vtákov pred inštaláciou odkloňovacích prvkov, môžeme na základe zaznamenaných reakcií vo väčších vzdialenostiach od ošetrených vedení a zníženého počtu úhynov konštatovať, že všetky tri hodnotené typy odkloňovacích prvkov majú pozitívny efekt z hľadiska redukcie početnosti nárazov do elektrických vedení.

Key words: avian collisions, FireFly Bird Diverter, RIBE Bird Flight Diverter, SWAN-FLIGHT Diverter, mitigation measures

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Introduction

Around the world, the availability of electricity has become an indicator of the standard of living. The transmission of electricity from power plants to users is mainly via overhead power lines. World-wide, this "wiring" of the landscape continues to increase and to advance even into the most remote parts of the inhabited continents. Most powerlines constructed so far pose fatal risks for a wide range of bird species and significantly affect the habitats of large birds in terms of their breeding, staging and wintering areas (Perrins & Sears 1991, Savereno et al. 1996, Bevanger 1998, Janss & Ferrer 2000, Coleman et al. 2001, Haas et al. 2005). Mortality from collisions with power lines and other electric utility structures has been documented for some 350 bird species (Manville 1999) with possible population level impacts (APLIC 1994, Janss & Ferrer 2000, Bevanger & Brøseth 2004, APLIC 2012, Loss et al. 2012, Rioux et al. 2013, Bernardino et al. 2018).

Collisions of birds with power lines are related to the main cause: the flying individual is unable to register such an obstacle ahead. Problems of collisions with power lines can be generally divided into three main categories based on factors of origin, including species-specific factors, site-specific factors and power line-specific factors (Bernardino et al. 2018). Frequently they can be observed especially in open areas where the power line crosses feeding, foraging and nesting habitats (APLIC 2012) used by birds, and can occur equally with transmission and distribution lines (Bevanger & Brøseth 2004, Bahat 2008, Jenkins et al. 2010). Overhead lines are significant sources of avian collision mortality, particularly at dusk and dawn, and during the night when the lines are effectively invisible (APLIC 1994, Brown & Drewien 1995, Janss & Ferrer 2000). Some bird species which are active in the vicinity of power lines are more susceptible to collision risk than others. Morphology also plays a decisive role (Brown 1993, Bevanger 1998, Janss 2000, Crowder & Rhodes 2002). Birds with low maneuverability, i.e. those with high wing loading and low aspect, such as bustards, pelicans, waterfowl, cranes, storks and grouse, are among the species most likely to collide with power lines (Bevanger 1998, Janss 2000, Shaw et al. 2010, Quinn et al. 2011, Barrientos et al. 2012). Species with narrow visual fields are also at high collision risk as they do not see the wires (Martin & Shaw 2010, Martin 2011). Power line features can also influence the risk of bird collision based on different power line voltage (Shaw et al. 2018) and thus configuration, especially including the number of vertical levels (Drewitt & Langston 2008, Jenkins et al. 2010), wire height (Haas et al. 2005, Murphy et al. 2009) and presence of shield wire (Murphy et al. 2009, APLIC 2012).

Many species in the highest survival risk categories are threatened, and reducing power line collision rates may therefore play an important role in their population persistence. The loss of a few or even one individual may impact a local population or the overall population's viability (Crowder 2000). Collisions with power lines are also a problem for power supply companies due to the possible power outages following collisions (collision-electrocution) and resulting financial losses (Haas et al. 2005, Bahat 2008).

Even if collisions themselves cannot be completely eliminated, they can still be reduced by means of proper mitigation measures. Line marking is one of the best solutions, based on making the wires more visible to birds in flight (Morkill & Anderson 1991, Brown & Drewien 1995, Frost 2008, Jenkins et al. 2010). This has become the preferred mitigation option worldwide. A wide range of potential line marking devices has evolved over the years, including avian balls, swinging plates, spiral vibration dampers, strips, ribbons, tapes, plates, flags and crossed bands (APLIC 2012). The effect of marking lines has varied widely across studies, primarily with habitat, bird species, season and type and configuration of power lines (Koops 1994, Bevanger & Brøseth 2004, Wright et al. 2008, Mojica et al. 2009). Barrientos et al. (2011) reviewed 21 wire marking studies and similarly concluded that wire marking reduced bird mortality by 55–94%. Understanding the nature of bird collisions is essential for minimizing them.

To date, fewer studies have attempted to reduce avian collisions with distribution power lines (Bevanger & Brøseth 2004, Yee 2007, Barrientos et al. 2012), and more attention has been paid to transmission power lines (Savereno et al. 1996, Janns & Ferrer 2000, De La Zerda & Rosselli 2002, Bevanger & Brøseth 2004, Frost 2008, Murphy et al. 2009, Sporer et al. 2013).

In this study a total of 77 kilometers of distribution power lines rated 22 kV and 110 kV in Slovakia were equipped with almost 8,000 devices representing three types of bird fight diverters: FireFly Bird Diverter, black and white RIBE Bird Flight Diverter and orange spiral SWAN-FLIGHT Diverter (SFD). The exact locations of spans suggested for installation of devices, were selected within the LIFE Energy project based on the results of special methodology evaluating electric power line risk levels from the viewpoint of bird deaths caused by collision with power lines and based on the technical possibilities (load capacity of phase conductors) of selected power lines. Placement of devices was selected to ensure that each device covered all types of habitats (same/different site specific conditions and bird species composition) present in the project area. The main aim was to study the effectiveness of the selected bird diverters by comparing the bird mortality before/after installation and by monitoring bird reactions and reaction distances to marked power lines. Preliminary results of our findings were published in studies by Gális et al. (2016, 2017, 2018a, 2018b) and Šmídt & Gális (2018).

Material and methods

Study area

Monitoring the effectiveness of three types of bird diverters was carried out on 108 selected sections of power lines. The project area was located in the southern part of Slovakia (Fig. 1), in lowland agricultural landscapes. The selected surveyed area is of high avifaunal importance, including high bird populations and high percentages of migratory birds (Karaska et al. 2015). Agricultural fields and ponds also attract many bird species due to the presence especially of grain crops, oilseed rape and rodents. Many of the marked lines were very close to wetlands, marshes, rivers, lakes and ponds. The exact locations of all marked sections of 22 kV and 110 kV power lines can be found at page https://www.lifeenergia.sk/.

Selection of power lines suggested for installation of bird flight diverters

In the period between 12/2014–02/2016 6,235 km of power lines were inspected twice during two periods (12/2014–3/2015 and 04/2015–02/2016) of field survey. In addition to this, intensive research was conducted during the second field survey at one-month intervals on power lines identified as the most dangerous for birds to collide with. The main focus of this survey was on collision, to recognize the range of the problem and its relevance for different bird species, habitats and power line configurations. Thirteen mitigation plans were designed for the project area with recommendations of particular measures for each Special Protection Area (SPA) and neighbouring area (Fig. 1), including the installation of bird flight diverters. 1,120 km of power lines were included in the group of hot spots (17.9% of all inspected power lines) concerning the relative risk of collision evaluated. Out of this, 77 km were given the highest priority and were proposed for installation of three bird flight diverters. The exact method of selection of these highest priority sections is described in Šmídt et al. (2019).

Mortality surveys under marked power lines

Systematic carcass searches were conducted during 12/2014–02/2016 along 77 km of power lines before the

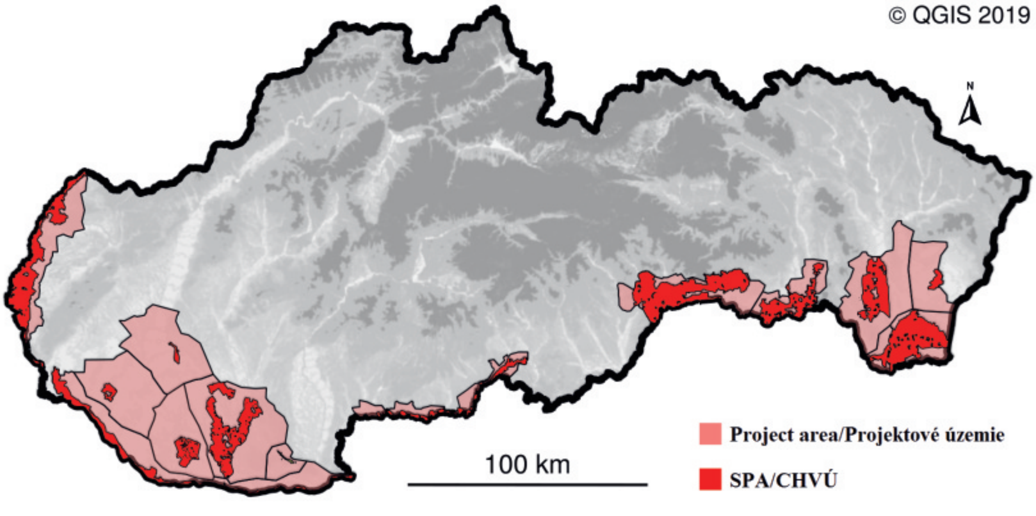


Fig. 1. All marked lines were situated within the project area covering 13 Special Protection Areas (SPA) and their adjacent areas.
Obr. 1. Všetky ošetrené vedenia sa nachádzali v rámci projektového územia pozostávajúceho z 13 Chránených vtáčích území (CHVÚ) a ich priľahlého okolia.

installation of the first diverters, and then continued as carcass searches during 06/2016–06/2019 after diverters were put in place. Bird flight observations on marked lines also included carcass searches. Each marked line section was searched on foot before evening and after morning flight observation periods directly under the lines of 22 kV and 110 kV and two buffer zones 25 m from the center on either side of the line section (total 50 m buffer was checked). These line sections were monitored once per month. When a carcass or remains (e.g. feather scatter) were located, they were assigned an ID number, photographed, and identified to species whenever possible. GPS coordinates of each bird carcass or remains found were recorded, and carcass distance from the line estimated in meters. Cause of death was determined (if possible) in the field, and carcasses were collected out of the site, to prevent double counting during the next field survey.

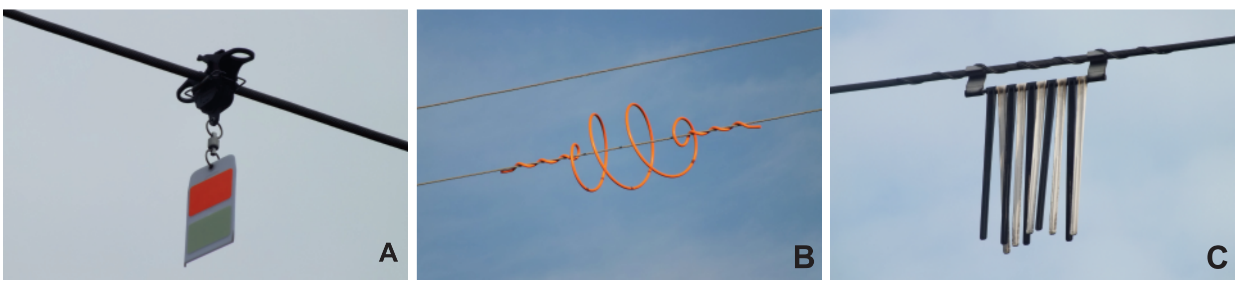
The body condition of bird carcasses was also taken into account, to estimate the possible date of death. Altogether 21 field assistants were trained to ensure proper survey data collection. Moving in zig-zag pattern was performed only in high and dense vegetation. Nearby tree and shrub vegetation was inspected up to 100 m, because injured birds often moved by themselves and hid because of bird fears, or were moved by a predator. All field assistants were trained by ornithologists and a GIS expert during two theoretical and two practical training sessions and several field meetings to ensure proper survey data collection for flight observations and also for mortality surveys. Theoretical training also consisted of analyses of video recordings of different types of reactions, to standardize the monitoring pattern between different assistants. The experts (in the position of supervisors) joined the field assistants during flight observations and field surveys to decrease searcher bias and ensure proper data collection and transcription. All marked line sections were divided among the field assistants, so the same assistant always searched and observed the same line.

All gathered data were verified and revised by experts in ornithology and recorded in an offline database. Monitoring was performed only in suitable weather and site conditions, to avoid unsuitable climatic factors (snowfall, rain) affecting bird activity. Results of carcass searches were not corrected for various bias factors including scavenger bias, crippling bias, habitat bias and searcher bias, analyzed in many studies (Bevanger 1999, Morrison 2002, Ponce et al. 2010, Jödicke et al. 2018).

Power line characteristics and bird flight diverters used

Two types of distribution power lines were selected for installation of bird diverters: a single/double circuit 22 kV line and double circuit 110 kV line. The 110 kV lines had one earth wire about the phase conductors as protection against lightning. The earth wire was located above the phase conductors as the highest part of the pylons. All vertical levels of phase conductors (22 kV) and all levels of phase conductors + earth wire (110 kV) were marked with bird flight diverters.

Three types of diverters commonly used for minimizing bird collisions worldwide were selected for testing their effectiveness: (A) FireFly Bird Diverter, a dynamic type of device produced by the Hammarprodukter company in Sweden. This is a high impact plastic plate with snapfast clamp that rotates in the wind at speeds > 8.04 km/h. The FireFly utilizes reflective and UV absorption parts to prevent bird collisions during day and night. Only this device selected for our testing glowed for up to 10 to 12 hours after sunset. (B) SWAN-FLIGHT Di-



M Gális

Fig. 2. FireFly Bird Diverter (A), SWAN-FLIGHT Diverter (B) and RIBE Bird Flight Diverter (C) selected for testing their effectiveness in preventing bird collisions.

Obr. 2. Odkloňovacie prvky FireFly Bird Diverter (A), SWAN-FLIGHT Diverter (B) a RIBE Bird Flight Diverter (C) vybrané pre testovanie ich efektivity v prevencii pred nárazmi vtákov.

verter, a double-ended spiral device from Spain. It is manufactured from high-impact PVC with UV protection and minimal wind resistance. Orange color was selected for our testing. (C) RIBE Bird Flight Diverter, with separate moving black and white strips sized 48x30 cm with flashing effect contrasting with the surroundings (Fig. 2). All devices were attached at 10-meter intervals. In the case of the RIBE Bird Flight Diverter, the selection of exact sections of power lines also depended on the age and thus the technical condition of the phase conductors, because of the product's weight. Only FireFly bird diverters were installed on 110 kV lines (all levels of phase conductors + earth wire).

A total of 77 kilometers of distribution power lines rated 22 kV (63 km) and 110 kV (14 km) were marked with almost 8,000 diverter devices. The length of marked lines were: FireFly Bird Diverter (30 km of 22 kV) + (14 km of 110 kV), RIBE Bird Flight Diverter (14 km of 22 kV) and SWAN-FLIGHT Diverter (19 km of 22 kV). Installation was carried out from the ground, using a bucket truck and boat. Two types of special devices were used for installation of FireFly Bird Diverters on 110 kV lines and on 22 kV lines above rivers or in difficult terrain (Fig. 3).

Flight observations

Monitoring took place along 22 kV and 110 kV distribution power line sections with total length 77 km, rated as having the most risk potential for possible bird collisions, immediately after diverters were installed in the period 06/2016–06/2019. It was done twice for each monitored day. (A) Morning, starting 0.5 hour before dawn, and continuing for another 1.5 hours after sunrise. (B) Evening, starting 1.5 hours before dusk and continuing for 0.5 hour after sunset. In these time periods the light conditions are insufficient and birds are most active at the same time, hence there is a high risk of possible collision. Total monitoring time was 4 hours/day. Marked power lines were monitored once per month, but if the power line exhibited many repeated bird overflights, the frequency of bird flight observations increased. The goal was to capture as many birds' reactions as possible to confirm/refute the diverter effectiveness. We applied this approach to all marked lines. Moreover the presence of bird species in proximity to the marked power lines was monitored by experts in ornithology, and the intensity of flight observations were set based on the presence/absence of bird species.

One person monitored power lines in a 500-meter range of marked spans. Two persons carried out monitoring of sections longer than 500 meters, or if the power line changed direction significantly or it was divided by a barrier (e.g. horizon, vegetation).

For each monitored power line the following data were assessed: (1) location (ID), (2) date and time of monitoring, (3) observed time of sunrise and sunset, (4) biotope, vegetation close to (< 300m) the monitored section, (5) weather, wind direction and intensity converted to the Beaufort wind scale.

During the observation period, the occurrence of individuals and flocks was recorded. Flocks were considered to be two or more individual birds of the same species. The responses protocol consisted of 9 types for various reactions of an individual bird to the power line: (0) no reaction, (1) bird flew through the line with no reaction, (2) bird changed the primary course and flew through the line, (3) bird flew up and over line (4) bird flew down and under line, (5) bird turned the primary course and flew away from or along the line, (6) bird collided but continued in flight, (7) bird collided and fell dead or injured, (8) bird landed on line.

For reaction types 2, 3, 4 and 5 a reaction distance relative to the line was recorded according to three categories: (1) 0–5 m from the line, (2) 6–25 m, and (3) < 25 m away. Distance did not apply for reaction types 0, 1, 6, 7 and 8.

Statistical analyses

In all analyses only selected bird species were used (medium and large-sized birds with a higher susceptibility to collision) selected based on Bevanger (1998) categor-

VSD, a. s.

Fig. 3. Special devices constructed and used for installation of FireFlyBird Diverter in Slovakia ©VSD, s. s.

Obr. 3. Špeciálne zariadenia skonštruované a využité pri inštalácií prvku FireFly Bird Diverter na Slovenku ©VSD, a. s.

ization. They are frequently reported as collision victims (Janss 2000, Crowder & Rhodes 2002, Rubolini et al. 2005).There were two types of bird responses to different diverters: reaction type and reaction distance. Because observing actual collisions is rare, statistical analyses were reserved for reaction types 2, 3 and 4, which represent positive reactions. Similarly as in the study by the Ventana Wildlife Society (2009), our variable reaction types represented counts of positive reactions (types: 2, 3 and 4) observed during each occasion (2-hour observing period). Differences in counts of positive reaction types between diverters were analyzed using the generalized linear mixed model (GLMM) with negative binomial error distribution and logarithmic link function (negative binomial distribution was used to account for overdispersion in the data). Because of the diversity of sampling over time and space, attributes of month and locality were used and tested as random factors. Although the amount of variability explained with months was negligible, the contribution of locality was considerable, so locality was used as the only random variable with varying intercept. The same type of model (GLMM with negative binomial error distribution) was used to compare positive reaction types between different power lines (22kV vs. 110kV) marked with FireFly Bird Diverter. Differences between reaction distances were analyzed using ordinal logistic regression with multilevel structure using the cumulative distribution function with the logit link function. As with reaction type analyses, localities helped explain a considerable amount of variability and were used as a random variable with varying intercept. The same type of model was also used to compare reaction distances between different power lines (22kV vs 110kV) marked with FireFly Bird Diverter. All analyses were created in the Bayesian framework using Stan language (http://mc-stan.org/) accessed with the brms package (Bürkner 2017) in R (R Core Team 2019). To improve convergence and guard against overfitting, we specified mildly informative conservative priors (population-level effects = normal (0, 10); intercept and sd = student_t(3, 0, 10); shape = gamma (0.01, 0.01) To compare different models we used leave-one-out cross-validation (LOOCV) using Pareto smoothed importance sampling (PSIS) in the loo package (Vehtari et al. 2019). This framework provides more precise and informative intervals of estimated parameters (compared to the most frequently used penalized quasi-likelihood approximation) and automatically penalize more complex models, providing a way to select the best model. For further information see Bolker et al. (2009) and Gelman et al. (2013). The number of collisions was estimated based on carcass search results from the period before (12/2014–02/2016) and after (06/2016–06/2019) the diverters installation. Numbers of carcasses found were not corrected to account for carcass losses due to removal by scavengers or inadvertence in carcass detection by field assistants. Only raw numbers of dead birds found were used for calculation of mortality before/after diverters installation.

Results

Mortality survey

A total of 93 bird carcasses belonging to 8 bird species were identified under the selected power lines (77 km), checked before installation of diverters, in the period from 12/2014 to 02/2016. Mute swans (*Cygnus olor*) were the most commonly encountered bird carcasses, accounting for 55 individuals (59.2%) of the total, and 19 mallards (*Anas platyrhynchos* – 20.4%), 6 great egrets (*Ardea alba* – 6.5%), 4 passerines (4.4%), 4 white storks (*Ciconia ciconia* – 4.3%), 2 common pheasant (*Phasianus colchicus* – 2.1%), 2 northern lapwings (*Vanellus vanellus* – 2.1%) and 1 common pochard (*Aythya ferina* – 1%) were also recorded. All identified bird carcasses were removed from the area to prevent double counts. Only 6 bird carcasses (93.5% reduction in observed casualties) belonging to 2 bird species were

Tab. 1. Percentages of type of reaction (2, 3, 4 and 5) on marked power lines.
Tab. 1. Percentuálny podiel reakčného typu (2, 3, 4 a 5) na ošetrenom elektrickom vedení.

observed reaction type / number of records / zaznamenaný typ reakcie / počet záznamov /	all bird species / všetky druhy vtákov n = 2,296	swans / labute n = 308	ducks / kačice n = 412	herons / volavky n = 303	geese / husi n = 153
2 - through wires + maneuvering / pomedzi vodiče + manévrovanie (%)	3.6	4.10	1.90	1.3	-
3 - flew over / prelet ponad (%)	78.0	73.3	80.0	80.8	88.2
4 - flew under / prelet popod (%)	10.6	7.7	9.3	8.3	3.2
5 - changed previous direction / zmena pôvodného smeru (%)	7.8	14.9	8.8	9.6	8.6

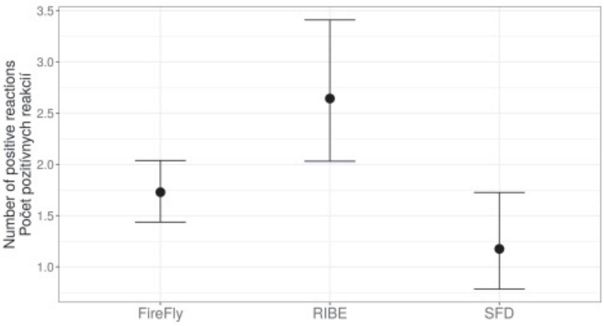


Fig. 4. Differences between diverters in terms of an estimated number of positive reactions represented with posterior means (solid points) and theirs 95% credible intervals (n = 560). The number of positive reactions is highest for RIBE (2.64 [95% CI: 2.03, 3.41]) then FireFly (1.73 [95% CI: 1.44, 2.04]) and SWAN-FLIGHT Diverter (1.18 [95% CI: 0.78, 1.73]).

Obr. 4. Rozdiely v odhadovaných počtoch pozitívnych reakcií pre každý odkloňovací prvok, vyjadrené priemermi pre jednotlivé odkloňovače (plné body) s ich 95 % intervalmi dôveryhodnosti (n = 560). Počet pozitívnych reakcií bol najvyšší pre prvok RIBE (2,64, 95% CI [2,03, 3,41]), potom pre prvok FireFly (1,73 [95 % CI: 1,44, 2,04]) a prvok SWAN-FLIGHT (1,18 [95 % CI: 0,78, 1,73]).

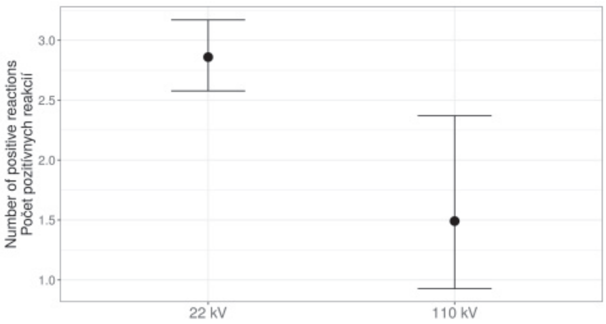


Fig. 5. Differences between different voltages of power lines (for FireFly Bird Diverter), in terms of an estimated number of positive reactions, represented with posterior means (solid points) and theirs 95% credible intervals (n = 250). The number of positive reactions is highest on 22 kV lines (22 kV = 2.86 [95% CI: 2.58, 3.17]; 110 kV = 1.49 [95% CI: 0.93, 2.37]).

Obr. 5. Rozdiely v odhadovaných počtoch pozitívnych reakcií medzi linkami vysokého napätia (pre prvok FireFly), vyjadrené odhadmi priemerov (plné body) s ich 95 % intervalmi dôveryhodnosti (n = 250). Počet pozitívnych reakcií je najvyšší na 22 kV linkách (22 kV = 2,86 [95% CI: 2,58, 3,17]; 110 kV = 1,49 [95 % CI: 0,93, 2,37]).

found only under marked 22 kV power lines, checked immediately after installation, in the period from 06/2016 to 06/2019. After installation of diverters in 2016 and 2017, no collision victims were recorded. Two mute swans (both under the same line marked with FireFly Bird Diverter) and three great egrets (one under a line marked with FireFly and two with SWAN-FLIGHT Diverter) were killed in March 2018. One mute swan died after collision and consequent electrocution (line marked with RIBE Bird Flight Diverter) in January 2019.

Flight observations

A total of 6,151 records and an estimated total of 75,175 individuals (95 bird species) were recorded during the flight observations in seasons from 06/2016 to 06/2019. Only in 2,296 flight observations, reaction type (2, 3, 4 and 5) was observed and an estimated total of 41,885 birds (57 bird species belonging to 13 orders) were recorded along the total length of 77 km of marked power lines (63 km of 22 kV and 14 km of 110 kV). Similar observations were made during the morning (1,183) and during the evening period (1,113). Of the 2,296 observations, birds crossed power lines during the study as follows: 1,791 times (78%) they changed the altitude and flew above as they approached the line; 244 times (10.6%) they flew below and 179 times (7.8%) they changed their primary direction or 82 times (3.6 %) they flew between the wires in double-circuit configuration of 22 kV and 110 k V power lines (Tab. 1).The remaining percentage consisted of observations with no reactions, because the birds flew over at higher levels than the power lines.

There were considerable differences between the diverters in terms of positive reaction type (Fig. 4). In addition to the differences between the diverting devices themselves, the effects of several independent variables were also tested (monitoring time = morning/evening; low visibility conditions = rain, fog, snow, categorized as good/bad conditions; country part = west/east; quantity = individual/flock). Before considering the locality as a random factor, most of these independent variables had a significant effect, but with this random factor included, none of the two-way or three-way interactions between diverting and independent variables was credible (elpd diff (difference in expected log predictive density) ≤ standard error). This suggests that the specific characteristic of each locality has considerable influence on the effectiveness of different diverters.

After filtering only FireFly Bird Diverters, there were considerable differences between the types (22 kV and 110 kV) of power lines (Fig. 5). Similarly as in the

L Kňazovičová

M Zemko

Fig. 6. Young mute swan after collision with double circuit 22 kV line marked with FireFly continued to fly (A) and power outage (B) recorded on 22 kV line marked with RIBE diverters after collision of mute swan as the bird crossed as a member of a big flock.

Obr. 6. Mladá labuť po náraze do dvojitého vedenie 22 kV ošetreného prvkom FireFly pokračovala v lete (A) a záblesk (B) zaznamenaný na vedení 22 kV ošetrenom prvkom RIBE, po náraze jednej z labutí počas preletu početného kŕdľa.

differences between the diverters in terms of positive reaction type, after accounting for the locality factor, none of the interactions with independent variables (monitoring time, visibility conditions, country part, quantity) was credible.

Observations of collisions were rare during our study (Fig. 6). Only two collisions were observed during a survey of marked lines. A young mute swan hit a 22 kV line marked with FireFly Bird Diverters on 29 March 2018 at 8:20 a.m. The observer stated that it was a collision based on the sound and movement of the lowest phase conductor as the bird crossed the line. The mute swan hit the ground after the collision, but after less than two minutes it continued to fly again and did not appear injured. A second collision of a mute swan was recorded on digital camera on a 22 kV power line marked with RIBE Bird Flight Diverter on 17 January 2019 at 16:59 p.m. One mute swan hit the wires as the bird crossed (in 78th position) as a member of a big flock of 150–170 swans and caused an outage, confirmed by the distribution network operator.

P Petluš

Fig. 7. Mute swans feeding in oilseed rape fields with power lines in close proximity.

Obr. 7. Labute veľké kŕmiace sa na repkovom poli v tesnej blízkosti elektrického vedenia.

Spring growth of winter wheat and oilseed crops on surrounding arable land provides a timely alternative food supply for the swans and geese, resulting in large numbers flying out of the wetlands to feed in these fields, returning to the wetlands for safe refuge when they cease feeding (Fig. 7). From the middle of April onwards grazing of the winter wheat and oilseed decreases as the crop becomes too tall and the swans disperse to their breeding or moulting grounds.

For altitude change and flutter/flare reaction types, the recorded distances of the reactions from the marked power lines were evaluated for all bird species. Swans, ducks, herons and geese were separated from other bird species, as they are among the species most likely to collide with power lines (Bevanger 1998).

After treatment there was a lower proportion of distance observations in the closest distance category (i.e. distance category 1, 0–5 m away from the line) (Tab. 2). Conversely, proportions in the more distant categories 2 (6–25 m) and 3 (> 25 m) were more than half, indicating that birds reacted further from lines after diverters were installed.

In the case of reaction distances on marked lines, there was no credible difference between diverters (all diverters had similar effect), but there was considerable difference between closer and farther reaction distances (Fig. 8).

Tab. 2. Percentage of reaction records in each distance category on marked power lines.
Tab. 2. Percentuálny podiel záznamenaných reakcií v jednotlivých reakčných zónach na ošetrených vedeniach.

reaction distance / number of records / reakčná vzdialenosť / počet záznamov	all bird species / všetky druhy vtákov n = 2296	swans / labute n = 308	ducks / kačice n = 412	herons / volavky n = 303	geese / husi n = 153
1 (0-5 m) (%)	19.0	13.7	13.3	11.8	14.4
2 (6-25 m) (%)	43.4	50.90	43.2	42.9	35.2
3 (>25 m) (%)	37.6	35.40	43.5	45.3	50.4

Similarly as in the reaction type models, after accounting for locality as a random factor, none of the independent variable interactions had credible effect except quantity (individual/flock), which had a slightly positive impact on the predictive accuracy of the model (elpd diff = -8.5; SE = 4.8) (Fig. 9).

In terms of power lines, we can see similar behavior with 22 kV and 110 kV lines (Fig. 10).

Discussion

As mentioned in many expert studies, the presence of bird flight diverters is associated with a decrease in collision mortality (Morkill & Anderson 1991, Brown & Drewien 1995, Frost 2008, Jenkins et al. 2010, Sporer et al. 2013). Placement of various designs of diverter devices on wires has been shown to effectively reduce bird collisions in a range between 55 to 94% (Barrientos et al. 2011). Evaluating the efficacy of diverters relies heavily on comparing the number of dead birds found under marked and non-marked power lines. We compared the carcass mortality along distribution power lines before and after installation of three types of bird flight diverters. There was a considerable reduction in bird collision rates in response to the fitting of diverters, namely by 93.5% (06/2016–06/2019) comparing the years before (12/2014–02/2016) – 93 vs. 6 bird carcasses. All carcasses were found within 25 m of the power lines, indicating that the designated search area (50 m) provided sufficient opportunity to find carcasses of birds having collided with monitored 22 kV and 110 kV distribution power lines. The occurrence of fewer collision victims under marked lines provides some evidence that all selected types of flight diverters are effective and have positive impact on reducing avian collisions.

The presence of identified bird carcasses (93 vs. 6) may not reflect reliably the results of bird mortality surveys carried out under power lines before and after diverter installation. Although we tried to minimize the sampling biases, it is possible to expect that the final mortality may be higher due to such biases.

Especially for bird collisions, crippling loss bias could also increase the real mortality associated with power lines, as after colliding with the power line an injured bird may move on and out of the search area. This sort of case was recorded in our observations, as one mute swan hit the ground after collision with a marked line, but after less than two minutes continued to fly again and did not appear injured (but could have died later as a result of internal injuries). Many birds injured after collisions could move far enough away from the power line before dying, and thus they are not found during carcass searches, even if the designated search area is sufficient. The study by Bevanger (1999) cites

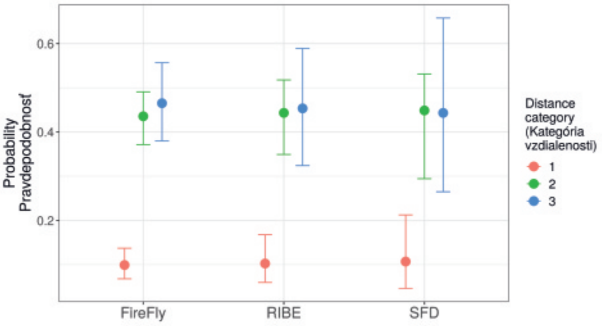


Fig. 8. Probability of individual reaction distances (category 1–3) for each type of bird diverter. Solid points show the mean of fitted posterior distribution and theirs 95% credible intervals (n = 1251). While marginal the most credible difference between first and second reaction distances for all diverters was 33.2% [95% CI: 29.0, 37.4], between first and third it was 35.1% [95% CI: 22.6, 46.8] and between third and second it was 1.5% [95% CI: -11.5, 16.7], what suggests a higher likelihood of early bird response to marked power lines.

Obr. 8. Pravdepodobnosť jednotlivých reakčných vzdialeností (kategórie 1 – 3) pre každý odkloňovací prvok. Pevné body znázorňujú odhadnuté priemery s ich 95% intervalmi dôveryhodnosti (n = 1251). Zatiaľ čo celkový rozdiel (cez všetky prvky), medzi prvou a druhou vzdialenostnou kategóriou bol 33,2 % [95% CI: 29,0, 37,4], bol medzi prvou a treťou 35,1 % [95% CI: 22,6, 46,8] a medzi treťou a druhou 1,5 % [95% CI: -11,5, 16,7], čo značí vyššiu pravdepodobnosť skoršej reakcie vtákov na ošetrené elektrické vedenie.

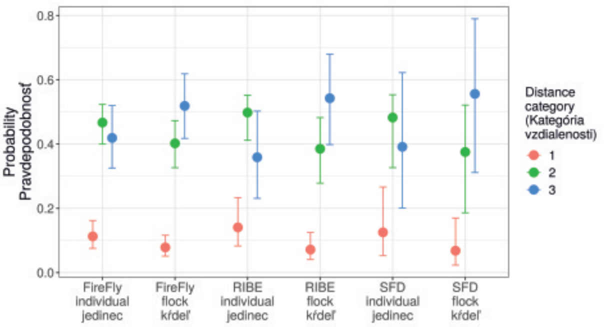


Fig. 9. Probability of birds reaction distances (category 1–3) for each type of bird diverter based on their quantity (individual or flock). Solid points show fitted values: the mean of posterior distribution and theirs 95% credible intervals (n = 1251). While marginal the most credible difference between individuals and flocks in first reaction distance cross all diverters was 5.5% [95% CI: 2.1, 9.6], and 8.9% [95% CI: 3.7, 15.3] at the second reaction distance and 14.5% [95% CI: -0.23, -6.3] at the third reaction distance, what suggests, that flocks have a higher likelihood of early response to power lines.
Obr. 9. Pravdepodobnosť jednotlivých reakčných vzdialeností (kategórie 1 – 3) pre každý odkloňovací prvok na základe početnosti (jedinec, alebo kŕdeľ). Pevné body znázorňujú odhadnuté priemery s ich 95% intervalmi dôveryhodnosti (n = 1251). Celkový rozdiel (cez všetky odkloňovače), medzi jedincami a kŕdľami pre prvú vzdialenostnú kategóriu je 5,5 % [95% CI: 2,1, 9,6], 8,9 % [95% CI: 3,7, 15,3], druhú 8,9 % [95% CI: 3,7, 15,3] a tretiu 14,5 % [95% CI: -0,23, -6,3], čo značí, že kŕdle majú vyššiu pravdepodobnosť skoršej reakcie na elektrické vedenie, ako jednotlivec.

several studies which found 22% (Hiltunen 1953) to 50% (Renssen et al. 1975) and even 74% (Beaulaurier 1981) of possible crippling loss bias. Crippling loss bias estimates are extremely difficult to obtain, and they are the least likely to be calculated (APLIC 2012).

The same observers were used throughout the mortality surveys to minimize observer bias, which may in some cases reach the level of only 45% of small bird species being found in dense vegetation (Homan et al. 2001). Searcher efficiency is highly variable, with several studies reporting relatively low rates (i.e. 35%–50%) and others reporting relatively high rates (i.e. 75%–85%) of recovery (Morrison 2002). Efficiency is mainly influenced by the height and type of vegetation present and the bird species composition in the surveyed area. Moreover carcass removal by scavengers often biases the mortality surveys (Ponce et al. 2010), with very high initial removal rates among smaller carcasses, most of which disappear within the first few days (Prosser et al. 2008).

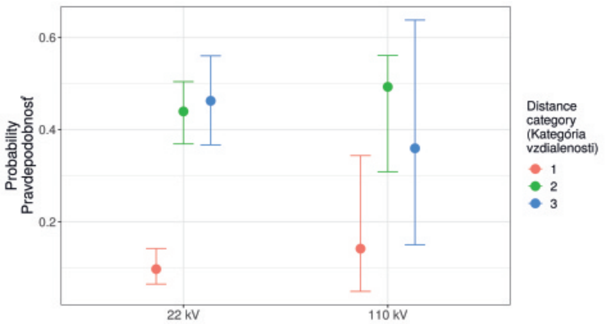


Fig. 10. Probability of bird reaction distances (category 1–3) (for FireFly Bird Diverter) in terms of different voltages lines. Solid points show fitted values: the mean of posterior distribution and 95% credible intervals (n = 787). In both types was estimated higher likelihood of early bird response to power lines. Increased uncertainty with 110kV was caused by the small number of observations.
Obr. 10. Pravdepodobnosť jednotlivých reakčných vzdialeností (kategórie 1 – 3) (pre FireFly odkloňovač) pri rôznych typoch elektrického vedenia. Pevné body znázorňujú odhadnuté priemery s ich 95% intervalmi dôveryhodnosti (n = 787). Pri oboch typoch je vyššia pravdepodobnosť skoršej reakcie vtákov na elektrické vedenie. Zvýšená neistota pri 110 kV vedení je spôsobená nižším počtom pozorovaní.

It should be made clear that even if some bird flight diverters (FireFly Bird Diverter and RIBE Bird Flight Diverter) were found to be better, the percentage of positive reaction type for the "worst" diverter (SWAN-FLIGHT Diverter) was 91%, and the differences between all diverters were only in the remaining few percent, hence the efficiency of all diverters was at a high level. Statistical analyses were reserved only for reaction types 2, 3 and 4, which represent positive reactions, and thus good diverter performance. Evaluating diverter effectiveness based on reaction type 5 (bird turned off the primary course and flew away from or along the line) was debatable. In our pattern for flight observations, it was thought that birds exhibiting this type of reaction in the closest distance category (< 5 m) might have had difficulty seeing the marked line, and were therefore not selected for further statistical analyses as positive reaction. This type of reaction to marked lines could indicate lower diverter effectiveness. On the other hand, the presence of diverters and abrupt changes in primary flight course at the last moment could also indicate that diverters increased the line visibility for birds which would otherwise have collided with a non-marked wire.

The effectiveness of our devices was higher in comparison with spiral PVC vibration dampers (61%) and fiberglass plates (63%, Brown & Drewien 1995), aviation balls (54%, Moorkill & Anderson 1991 and 53%, Savereno et al. 1996) and SFD with 73% reduction (Crowder 2000). Using FireFly Bird Diverters, 60% reduction in avian collisions was observed in sandhill crane collisions with 12 kV distribution lines in California, USA (Yee 2007). Diverter effectiveness was tested in three consecutive years (2003–2006) by comparing the number of birds found under the control power lines with the number found under treatment-marked power lines. The number of collisions per span increased with distance from the treatment spans, which also appeared to affect neighboring unmarked spans. More attention has been paid in many studies to the effects of bird diverters attached to transmission power lines. Based on carcass recoveries under these lines, Janss & Ferrer (1998) reported an 81% decrease in avian mortality associated with white SFDs on a transmission line in west-central Spain. Small but significant (9.6%) decrease in the number of casualties after line marking with SFDs compared to before line marking on experimental lines was observed in central Spain (Barrientos et. al 2012). The overall decrease in the number of carcasses recorded in the sample of 15 experimental lines was 88 birds (189 birds before marking, 101 birds after marking, 47% reduction in observed casualties). They also did not find any significant difference in mortality reduction comparing marked transmission lines (220 kV) with marked distribution (15–45 kV) lines when all species were considered together.

No bird collisions occurred during a nine-month period of installed FireFly Bird Diverters with 100% effectiveness in reducing bird mortality in the Lee Kay Ponds area. 70% of power line overflights were observed after the birds gained altitude by rising up and passing over the transmission line shield wire (Chervick 2004). Collision susceptibility may be influenced by flight behavior. Birds such as ducks, swans and geese tend to form large flocks and fly closely grouped together over the power lines. Our results suggest that individuals grouped in large flocks reacted better and at a greater distance from marked power lines. This is in line with the results of Crowder (2000), who observed that flocks with >10 individuals reacted at greater distances to power lines than single birds, suggesting that with more birds scanning for obstacles, flocks can adjust their flight path faster and better avoid power lines. Despite these studies and our findings, flocking species still seem to be more vulnerable to collision than solitary bird species (Crowder & Rhodes 2002, Drewitt & Langstone 2008) when they fly closely grouped together, because birds at the rear of the flock have their vision somewhat occluded by those at the front, and they are more dependent on flock response to obstacle avoidance (Jenkins et al. 2010). This was also confirmed by our above-mentioned observation of a mute swan collision with a marked line. Moreover, collisions of cranes with high numbers of killed or crippled individuals occurred mainly in the case of large flocks when suddenly flushed upward, towards the powerline (Murphy et al. 2009). Flocks of birds could collide with a nearby power line especially as a result of panic after sudden disturbances (APLIC 2012).

After installation of flight diverters, there was a lower proportion of reaction distance observations in the closest distance category 1 (i.e. up to 5 m). Conversely, proportions in the more distant categories 2 (6–25 m) and 3 (>25 m) were dominant, indicating that birds reacted further from lines after diverters were installed. Bird species with highest susceptibility of collision (swans, ducks, herons and geese) reacted to power lines (even in flocks) earlier and at greater distances after diverters were installed. If birds are able to react at greater distances from the lines, the risk of collision with them is most likely reduced, as confirmed in our study as well. Researchers reporting significantly effective diverters, based on collision reduction, have also reported differences in reaction distance (De La Zerda & Rosselli 2002). In any case, our observations suggest that all diverters may alert bird species to powerlines earlier, giving them more time to react and avoid conductors and/or earth wires.

In our results, the mute swan was the most common species detected as victims of collision before and after installation of bird diverters, 55 vs. 3 carcasses (94.5% reduction). Collisions of mute swans often led to many power outages (result of collision-electrocutions) on 22 kV lines, thus decreasing the power distribution reliability for customers.

A similar reduction of 95% in swan collision rates in response to fitting flight diverters in 2007 compared to 2006 was observed on 135 kV power lines in Abberton Reservoir Special Protection Area, England (Frost 2008). 500 red ‘SWAN-FLIGHT Diverters’ (320 mm long, 175 mm diameter) were installed at 5 m intervals along a 1.5 km length of the power lines. 100% reduction in collisions was found for the SWAN-FLIGHT Diverter in a study by Rasmussen (2001), and quicker reactions to a marked 69 kV line by sandhill cranes after the line was marked with FireFly Bird Diverters (Murphy et al. 2009).

Although our results indicate higher levels of effectiveness for all three types of diverters used, further study of different habitats and bird species composition is needed especially on distribution power lines worldwide. They are often located close to the habitats used by many species with the highest susceptibility risk of collision, especially if the power line is close to their area of taking off or landing. Many devices designed to increase line visibility may not be effective in heavy fog, at night or in low-light conditions. It is therefore also necessary to test different types of products especially for species with nocturnal flight habits.

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Methodology of risk assessment for electricity distribution lines in Slovakia with regard to potential bird mortality due to collisions with power lines

Metodika hodnotenia rizikovosti elektrických vedení na Slovensku z pohľadu možného úhynu vtákov spôsobeného nárazom do vedenia

Ján ŠMÍDT, Ervín HAPL & Marek GÁLIS

Abstract: Power lines represent an important and increasing worldwide cause of avian mortality due to collisions involving flying birds. One positive and very important fact is that only some parts of potentially dangerous lines are responsible for the majority of killed birds. These sections need to be identified and treated with proper mitigation measures. In this article we present a specially-prepared methodology aimed at classifying power lines according to the risk they present. The identification of power lines with the highest risk of possible bird collision requires easily-accessed biological, technical and landscape information. In addition to analyses of these main inputs, our methodology also evaluates the influence of power line orientation relative to the important migration routes of birds, the effect of nearby tree growth higher than the evaluated power lines, and the complexity of landscape relief. Based on these three additional inputs, it is possible to produce a digitalized map showing with one-meter accuracy the location of power line sections with the high/middle/low mortality risk due to collision for any existing or newly-planned grid. Sections with highest risk should be considered as priority for the implementation of mitigation measures including e.g. installation of bird flight diverters. Our methodology was prepared for 22 kV and 110 kV distribution power lines in Slovakia. It is flexible enough to be applied equally to any geographic conditions and/or bird community, different voltage levels and construction designs of power lines. Our methodology can be applied by ornithologists, nature conservancy organization and power line system operators to implement environmental and cost-effective mitigation measures.

Abstrakt: Elektrické vedenie predstavujú v celosvetovom meradle významnú a narastajúcu príčinu mortality vtákov v dôsledku nárazov. Pozitívny a veľmi dôležitý fakt je, že za väčšinu usmrtených vtákov sú zodpovedné iba najrizikovejšie úseky vedení. Tie je potrebné správne identifikovať a ekologizovať vhodnými opatreniami. V článku predstavujeme špeciálne vytvorenú metodiku zameranú na klasifikáciu elektrického vedenia podľa rizika, ktoré predstavuje. Identifikácia úsekov s najvyšším rizikom nárazov vtákov si vyžaduje pomerne ľahko dostupné vstupné biologické, technické a topografické informácie. Okrem analýz týchto hlavných vstupov naša metodika hodnotí aj vplyv orientácie elektrického vedenia vo vzťahu k dôležitým migračným trasám vtákov, vplyv blízkeho stromového porastu vyššieho ako hodnotené elektrické vedenie a členitosť reliéfu krajiny. Na základe týchto troch ďalších vstupov je možné pre existujúcu alebo novo plánovanú sieť vytvoriť digitalizovanú mapu ukazujúcu polohu úsekov elektrického vedenia s vysokým/stredným/nízkym rizikom s presnosťou na jeden meter. Úseky s najvyšším rizikom, je potrebné považovať za prioritné pri následnej implementácii prijatých opatrení akými sú napr. inštalácia odkloňovacích prvkov. Metodika bola pripravená pre distribučné vedenia 22 kV a 110 kV na Slovensku, je však dostatočne flexibilná, aby sa dala aplikovať aj na iné geografické podmienky a/alebo iné ornitocenózy a rôzne napäťové úrovne a konštrukcie elektrických vedení. Metodika môže byť využitá pre potreby ornitológov, orgánov ochrany prírody a prevádzkovateľov elektrických vedení tak, aby boli prijaté ekologicky účinné a cenovo efektívne opatrenia.

Key words: collision risk, bird mortality, impact assessment, power lines

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Introduction

Birds have to adapt themselves constantly to anthropogenic changes in the countryside. These happen too quickly, however, for adequate genetic adaptation to develop in the bird population. Not only do people transform their natural environment in radical ways, they also put up many kinds of artificial barriers in the land such as electric power lines. The growing numbers of observed interactions between birds and power lines is linked with the worldwide increase in extent of such lines, which was estimated in 2010 at more than 65 million kilometers of transmission and distribution lines (Jenkins et al. 2010). Collisions with power lines are a studied and confirmed cause of bird mortality in many countries of the world (Alonso & Alonso 1999, Rubolini et al. 2005, Derouaux et al. 2012, Gális et al. 2016, Bernardino et al. 2018) and may have fundamental negative impact on endangered and reduced populations on the local level (Crowder 2000, Drewitt & Langston 2008, Shaw et al. 2010, Raab et al. 2012). It is possible to observe collisions most frequently in areas where the power lines cross the hunting and nesting biotopes used by large bird populations (Andriushchenko & Popenko 2012). Even if the power lines are just in the vicinity of those areas, there is still high probability of numerous collisions (Erickson et al. 2005), especially near places used for taking off and landing (Heck 2007, Quinn et al. 2011). A particular problem arises when there are frequent movements of large flocks between their hunting and nesting biotopes, or if the power lines pass perpendicularly across the birds' main migration routes (Crowder 2000, Shobrak 2012).

In order to apply effective protection measures, it is necessary to know to what degree a certain power line is “problematic” for birds. It is important to precisely establish the extent to which the protection measures need to be applied, so that only the sections of power line representing the greatest risk are targeted, i.e. where the probability of bird mortality is highest.

According to current scientific knowledge and published studies, the principal causes making up the set determining the degree of risk are divided into three categories (Bernardino et al. 2018). These consist of the environmental conditions of the site, the morphology/ecology of the bird species and the technical parameters of the power line. The individual factors are closely interlinked, and they participate together with various weightings in the resulting degree of risk associated with collisions.

From the biological point of view the group most susceptible to collisions and therefore at greatest risk are the large, heavy bird species (Janss 2000, Janss & Ferrer 2000, Rubolini et al. 2005, APLIC 2012, Barrientos et al. 2012) and certain specific orders of birds, e.g. Anseriformes, Ciconiiformes, Gaviiformes and Pelecaniformes (Bevanger 1998), defined according to their morphological parameters (e.g. weight, wing size/area, manner/type of flight). The species which tend to group together into large flocks are also included here, as they are associated with higher probability of collision (APLIC 1994, Drewitt & Langston 2008, APLIC 2012).

The environmental conditions of the site influencing the resulting degree of risk of collision are above all the character and composition of the landscape. Open, flat land with low vegetation enables birds to fly low and close to the terrain, seeking out sources of food and resting places. As a result, they may tend to have reduced levels of concentration on potential obstacles such as electric power lines. Birds have a general tendency to look downwards, and thus for certain species the space ahead of them becomes a so-called blind zone (Martin & Shaw 2010, Martin 2011). Tall tree growth in the vicinity of power lines may alert such birds to the potential obstacle, but only if the trees reach up above the highest part of the power line (Bevanger & Brøseth 2004, APLIC 2012). The principal technical parameters affecting the degree of risk represented by a power line are the thickness of the cables, the height of the line and the number of parallel lines. Higher lines increase the risk of collision (APLIC 1994, Haas et al. 2005). Not only do the birds have to overcome a higher barrier, but relatively often they then collide with the earth wire which is present at the top of higher-tension distribution and transmission lines to protect them from lightning strikes, and at the same time is much thinner than the live cables. This is connected with the fact that birds try to avoid power lines primarily by flying over them (Murphy et al. 2009), so they react to the visibly thicker live cables but then fly into the practically “invisible” earth wire above them. Denser networks of parallel power lines are more visible to birds, so they manage to react to the obstacle earlier (Bevanger 1994, Crowder 2000, Drewitt & Langston 2008), and they can usually fly over sets of parallel lines with a single soar.

In identifying the causes of collisions and establishing the degree of risk represented by power lines, it is important to start out from the above-mentioned categories of factors. They should be applied as input variables in any method of assessing the degree of risk in power lines with regard to collisions. Various categorizations of power lines into groups with similar degrees of risk and designations of priority areas can be found in a range of foreign studies, for example from Belgium (Derouaux et al. 2012), Portugal (Silva et al. 2014), Portugal and Spain (D'Amico et al. 2019), the USA (Heck 2007, Quinn et al. 2011) or South Africa (Shaw et al. 2010).

We set out from the same categories of input variables in our methodology too, which was developed as part of the LIFE Energy project. It was based on a systematic approach to resolving the problems of bird collisions with power lines, involving proposals of suitable ways of identifying and eliminating this kind of risk in 13 Special Protection Areas (SPAs) in Slovakia. This methodology was developed for the purposes of primary identification of risky sections of power lines, so that the protection measures subsequently applied could be focused solely on those sections representing the greatest risk where there is a high probability of bird collisions. In addition to the basic procedures as used in other methodologies (i.e. identifying relative locations of power lines vs. sites with concentrated bird population vs. migration routes, for instance), in the methodology presented here we also calculate in the influence of power line orientation relative to the presumed prevailing direction of bird movement, the influence of the slope of the terrain, and the influence of tree growth present near the power lines. These three additionally assessed input variables have the effect of significantly reducing the resulting length of line sections which are evaluated as risky, since the real degree of risk is reduced or even eliminated by them. In creating our methodology we made use of the available foreign literature, especially the documents APLIC (1994) and APLIC (2012). The presented methodology also reflects the current state of knowledge and experience among members of the project team from Raptor Protection of Slovakia with regard to issues of bird collisions with power lines in this country, acquired during monitoring of 22 kV and 110 kV distribution lines in the period 12/2014 to 02/2016, and also makes use of insights derived from previous practice going back to 2010. An evaluation of risk levels on 6,235 km of 22 kV and 110 kV power lines within Slovakia was presented in the work by Šmídt et al. (2017). According to that methodology it is possible to divide lines into three categories of degree of risk and need for application of suitable protection measures. Apart from its application on existing lines, it is also possible to apply this methodology to the identification of potential risky sections during the design phase for new distribution and transmission lines. On the basis of these recommendations it is possible to change the routing of lines, or plan in advance for the measures required and include the financial costs incurred into the project documentation.

This assessment methodology was developed for the bird species and types of power lines present in Slovakia. It is flexible enough however to be potentially adapted for other geographical conditions, or for different ornithocenoses and other power line tension ratings and construction designs. In this article we present only the methodology of the assessment procedure, and we do not deal with the correlation of bird mortality recorded during monitoring with the evaluated sections of lines with low, medium and high degrees of risk.

Material and methods

The procedure itself of categorizing degrees of risk on power lines is composed of several interlinked logical steps. These involve identifying the ornithofauna, the type and composition of the landscape structure, and the technical parameters of the power line in the area in question.

The most suitable tool for assessing power line risk levels in our view is a digital model of the particular area being studied created in the geographical information system (GIS) environment. This digital model consists of individual geographical digital sources, either vector or raster layers.

The input data are made up of the following sources:

- an orthophotomap of the assessed area* (in the visible spectrum); ideally we work with at least two orthophotomaps of the assessed area taken at different times (at least one year apart), and a standard 1:10,000 scale map may be of supplementary assistance,
- a satellite image in the infrared spectrum,
- a layer or point array* of key sites where regular concentrations of the indicated bird species occur (this applies only when such sites exist in the assessed area),
- a flood map of the area*; it is also possible to use a geological map (floodplains) or a digital relief

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* Obligatory sources without which the model would be incomplete; if any of the sources are not available, a relevant alternative must be obtained.

model, or floodplains may be identified from the contours on the standard 1:10,000 scale map,

- a map of the geomorphological composition of the area*,
- a relief map showing slope distribution*; alternatively a digital relief model or a map showing valuations of agri-ecological units (BPEJ). If the latter is used, the slope in the relief is given in each BPEJ code, namely in the fifth digit of the seven-place code,
- a layer of vegetation features reaching higher than the power line in question: this may be created based on the orthophotomap supplemented with data from practical investigation of the terrain; for wooded areas in particular it is possible to use a map showing tree cover,
- a layer of power lines*; this layer must contain data on the tension rating of the line, the number of horizontal cable-bearing crossbars, and cable thickness.

Calculation of power line risk level

For assessing the degree of risk on a section of power line with regard to bird collisions, we applied the following equation:

$$R = K \times L \times P$$

where: R = degree of risk of bird collision on the section of power line, K = criterion of "key site", quantifying the attractivity of the locality for birds, L = criterion of "landscape elements", quantifying their influence on the degree of risk, P = criterion of "power line", quantifying the influence of power line features on the degree of risk.

The calculated values for criterion K range from 0–100, and are subsequently confirmed or reduced by the values for criterion L (0–1) and criterion P (0–1).

The result of this assessment is that sections of power line can be categorized on three levels based on the R values reached (Fig. 1):

- values between 75–100 indicate sections with high risk of collision,
- values between 50–75 indicate sections with medium risk of collision,
- values between 0–50 indicate sections with low/negligible risk of collision.

Assessment is done based on the overlap of power lines with buffer zones. For 22 kV lines the buffer zones are set at distances of 80 m, 160 m and 240 m, and for 110 kV they are set at distances depending on the vicinity of key or potential key sites. In this way it is possible to determine precisely (with one-metre accuracy in the GIS environment) the extent of influence of a power line.

Key sites (criterion *K*)

This criterion takes into account the presence of sites which are attractive for susceptible bird species in the relevant vicinity of the assessed section of power line,

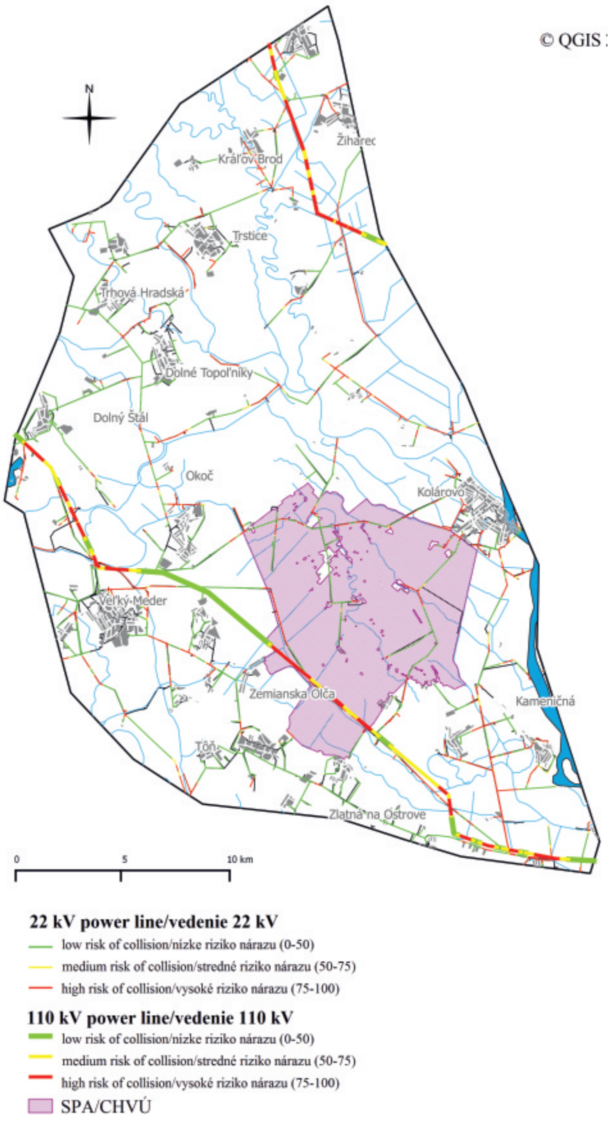

Fig. 1. Example of resulting visualization of categorization of 22 kV and 110 kV power lines with regard to degree of risk of collisions.

Obr. 1. Príklad výslednej vizualizácie zatriedenia vedení 22 kV a 110 kV do kategórií rizikovosti.

and its weight depends on the real or potential numbers of birds. For each power line section assessed the higher of the two subcriterion values K_1 and K_2 is used.

$$K = max.(K_1, K_2)$$

The factors in the two subcriteria are quantified in such a way that the values of criterion K for any given power line section (or for any given point in the landscape) range between 0 and 100.

Known key sites (K_1)
An evaluation of the current known status of populations of indicated bird species at key sites in the relevant vicinity of a power line (for 22 kV lines up to a distance of 240 m from the edge of the site, and for 110 kV lines up to a distance of 600 m from the edge of the site). We consider a site as key when a concentration of a large number of birds from a susceptible (indicated) species occurs there, i.e. it is that species' regular (annual) nesting, roosting or gathering site, a place for resting or gathering food. We consider a bird species as susceptible (indicated) when individuals are relatively often killed as a result of colliding with power lines, i.e. their cadavers indicate relatively higher frequency of collision on specific sections of power line. With regard to possible differentiation in the species' composition and the occurrence of similar species in other regions, it is necessary also to take into account data on related species which may appear to be susceptible (indicated) in other regions as well. This mainly concerns taxonomic groups selected in line with the categorization according to Bevanger (1998), e.g. Anseriformes, Ciconiiformes, Gaviiformes, Gruiiformes and Pelecaniformes. These are orders comprising species of large, heavy birds with a high ratio of body weight to wing area and limited manoeuvrability (Janss 2000), as well as species which tend to congregate in large flocks (APLIC 2012) and have poor periferal vision (Martin 2011).

Based on the categorization of species according to their morphological and behavioural parameters indicating higher risk of collision, and also on our previous observations in the field, it was possible to specify the following species as susceptible (indicated) in the conditions of Slovakia: mute swan *Cygnus olor*, grey heron *Ardea cinerea*, black-crowned night heron *Nycticorax* nycticorax, great egret *Ardea alba* and mallard *Anas platyrhynchos*.

The value of subcriterion K_1 is calculated using the equation:

$$K_1 = k_{1a} \times k_{1b}$$

where: K_1 = subcriterion of known key site, quantifying the real (current) attractivity level for birds, k_{1a} = factor of size of population of indicated bird species, k_{1b} = factor of power line distance from the key site.

The real attractivity level of the site is indicated by the size of population of the indicated bird species (Tab. 1) regularly making use of the particular site. Factor k_{1a} expresses the real attractivity level of the site and of individual buffer zones in the vicinity affected by factor k_{1b} (Tabs. 2 and 3) for the indicated species (i.e. distances up to 80, 160 and 240 m from the edge of the site for 22 kV lines up to 200, 400 and 600 m from the edge of the site for 110 kV lines), whereby the combined total of numbers in their local populations is applied.

Factor k_{1b} reflects the assumption that the degree of risk of bird collision with power lines is reduced with increasing distance from the key site. As a result of the

Tab.1. Values of factor k_{1a} depending on the population size of indicated species.
Tab. 1. Hodnoty faktora k_{1a} v závislosti od početnosti populácií indikačných druhov.

population size of indicated species / početnosť populácií indikačných druhov	value of factor k_{1a} / hodnota faktora k_{1a}
> 100 individuals / jedincov	100
51–100 individuals / jedincov	75
20–50 individuals / jedincov	50
< 20 individuals / jedincov	0

Tab. 2. Values of factor k_{1b} (k_{2b}) for 22 kV lines.
Tab. 2. Hodnoty faktora k_{1b} (k_{2b}) pre 22 kV vedenia.

distance from real (potential) key site / vzdialenosť od reálnej (potenciálnej) významnej lokality	value of factor k_{1b} (k_{2b}) / hodnota faktora k_{1b} (k_{2b})
< 80 m	1
81–160 m	0.67
161–240 m	0.33
> 240 m	0

dispersal of birds in various directions from the site, with increasing distance there is most likely a drop in frequency of their occurrence at any given point. At the same time with increasing distance the flying height of the individual above the ground also increases, and so similarly with increasing distance the probability of hitting a power line is reduced. If we presume the same angle of climb for individuals from the site, then the higher 110 kV lines represent greater probability of collision at the same distance compared with the lower 22 kV lines.

Potential key sites (K_2)

These are defined as sites which are potentially attractive for an indicated species, where concentrations of large numbers of individuals of that species may be expected in the future, for example after floods or a change in the ecological conditions in a geographically close key site.

The value of subcriterion K_2 is calculated using the equation:

$$K_2 = k_{2a} \times k_{2b} \times k_{2c}$$

where: K_2 = subcriterion of potential key site, quantifying the site's potential attractivity level for birds, k_{2a} = factor of character of the potential key site, k_{2b} = factor of power line distance from the potential key site, k_{2c} = geographical factor accounting for differing quality of biotopes and migration routes of birds in a wider context.

The factor of character of a potential key site k_{2a} quantifies the otherwise qualitative characteristics of particular landscape features with values ranging from 25 to 50 (Tab. 4). In this case the feature is a flood area, either the floodplain of a river/stream or some wetlands, a water body, marsh, water course including oxbow lakes, or an occasionally flooded depression in the terrain. The selection of these features is based on our local (regional) knowledge and the availability of data on numbers of birds in the given region. This means that in decision-making on taking a specific landscape element into account, it is not just the size of that element or the width of the watercourse which is important, but also the species composition and size of the bird population in the region. We do not take into consideration landscape elements in a region which do not have the potential to concentrate more than twenty individuals of an indicated species. The selection may be based on the results of ornothological census.

Identification of potential key sites is one of the more time-consuming operations in the assessment process. Water bodies and marshes can be found on standard 1:10,000 scale maps, but these do not enable identification of occasionally flooded depressions in arable or grass land. These have to be found using orthophotomaps from at least two different time periods, which can then be compared. Should the source maps not be up to date, we recommend combining the available graphic material with physical investigation of such sites. Factor k_{2b} is similar to factor k_{1b} in that it also expresses the declining level of risk of collisions with power lines as the distance from the potential key site increases. Values of factor k_{2b} are given in tables 2 and 3 together with those for factor k_{1b}.

Factor k_{2c} is a geographical factor taking into account the differing quality of biotops and landscapes as well as the migratory routes of birds. Values for factor

Tab. 3. Values of factor k_{1b} (k_{2b}) for 110 kV lines.
Tab. 3. Hodnoty faktora k_{1b} (k_{2b}) pre 110 kV vedenia.

distance from real (potential) key site / vzdialenosť od reálnej (potenciálnej) významnej lokality	value of factor k_{1b} (k_{2b}) / hodnota faktora k_{1b} (k_{2b})
< 200 m	1
201–400 m	0.8
401–600 m	0.6
> 600 m	0

Tab. 4. Values of factor k_{2a} for landscape elements which may be potential key sites.
Tab. 4. Hodnoty faktora k_{2a} pre krajinné prvky, ktoré môžu byť potenciálnou významnou lokalitou.

character of the landscape element / charakter krajinného prvku	value of factor k_{2a} / hodnota faktora k_{2a}
water body / vodná plocha	50
watercourse or oxbow lake / vodný tok, napájadlo	50
marsh / mokraď	50
flooded depression in terrain / zaplavená poľná depresia	50
area liable to flooding / záplavové územie	25

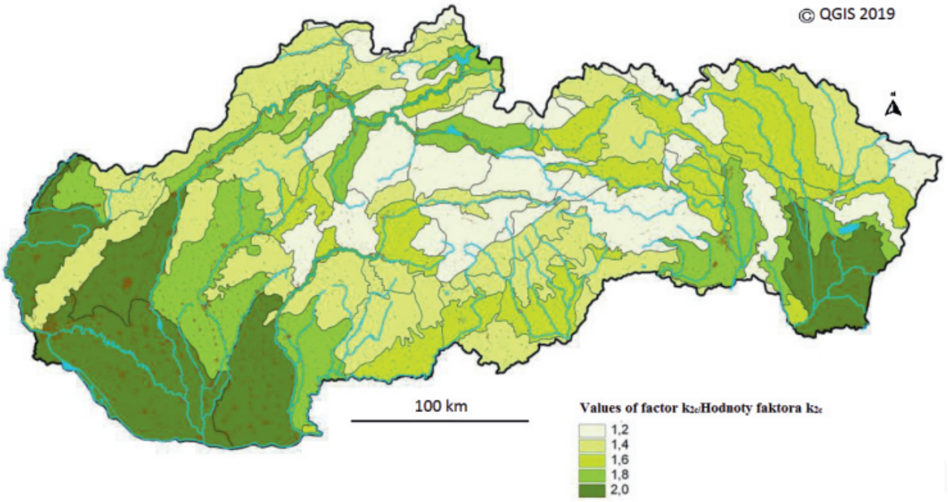

Fig. 2. Example of the differentiation of the territory of Slovakia based on values of factor k_{2c}.
Obr. 2. Príklad rozdelenia územia Slovenska s hodnotami faktora k_{2c}.

k_{2c} may range from 1.2 in geomorphological areas which are unsuitable for the indicated species (e.g. highlands) and 1.8 for basins and hill ranges up to the highest value 2.0 in geomorphological areas (lowlands) with optimal biotopes for the indicated species. We can use the territory of the Slovak Republic as an example, which can be differentiated into five categories and for each one the value of factor k_{2c} can be assigned. The resulting topographical map is shown in Fig. 2.

In the GIS environment all the key and potential key sites have zones (buffers) created around them reaching the distances shown in Tab. 2 and Tab. 3 for the assessment of 22 kV and 110 kV power lines. The values of factors k_{2a} and k_{2b} are determined for the individual buffer zones in the sense that the factor values decrease for the zones which are further away from the site. For the key and potential key sites themselves the factor value is set at 1.0. To save work, for the purposes of vectorizing (creating digital maps) it is possible to ignore sites further than 240 m from assessed sections of 22 kV lines and sites further than 600 m from assessed sections of 110 kV lines. The reason is that the digital model does not show concentrations of birds at more distant sites as incurring any risk of collision with power lines which are sufficiently far away.

Landscape and landscape elements (criterion *L* – landscape)

The value of criterion *L* is calculated as the product of two landscape factors which we monitor in assessing the degree of risk on sections of power line:

$$L = l_1 \times l_2$$

where: L = criterion of landscape elements, quantifying the influence of such elements on the power line risk level, l_1 = factor of slope in relief, l_2 = factor of proximity of tall tree growth.

Values of criterion *L* range between 0 and 1.

Slope in relief

The basis for obtaining data on slopes in relief may be a digital relief model, or a relief map showing slopes in degrees may be produced in the GIS raster environment. In both cases slopes are divided into three classes 0 to 3°, 3 to 7° and more than 7°, and the corresponding value of factor l1 is taken from Tab. 5.

Tab. 5. Values of factor l_1 for increasing slopes in relief.
Tab. 5. Hodnoty faktora l_1 v závislosti od sklonu reliéfu.

slope in relief / sklon reliéfu	value of factor l_1 / hodnota faktora l_1
0–3°	1.0
3–7°	0.3
> 7°	0.0

Vegetation in proximity of power lines

As in the case of identifying potential key sites using orthophotomaps, finding vegetation features taller than the nearest power line can also be quite time-consuming. This can also be done by reading from orthophotomaps. The height of tree growth in particular can be estimated based on the structure and length of shadow of vegetation features studied on the orthophotomap, or it can be determined directly by means of personal field study. It is not possible to automate the identification of such elements. Moreover, the orthophotomap may show trees which in reality have already been felled, so in any case it is advisable to carry out a physical inspection of the given site.

We consider it relevant to assess tree growth up to a maximum distance of 300 metres from any power line. The closer the tree growth is to a power line, the lower the potential risk of collisions for birds. The value of factor l_2 is calculated based on the distance from the power line and whether the tree growth is taller than the height of the line:

$$\text{If } l_r > 300 \text{ m, then } l_2 = 1.0$$
$$\text{otherwise } l_2 = l_r/300$$

where: l_2 = factor of proximity of tall tree growth, l_r = perpendicular distance of the assessed section of power line from the edge of the vegetation feature reaching higher than the top of the power line.

Electrical distribution line (criterion *P* – Power line)

Criterion *P* is given by the characteristics of the power line itself. From the practical point of view it is convenient if grid company provides the risk assessor with a database (or GIS layer) containing the necessary attributes which form the basis for determining the values of the power line factors for individual sections of line.

Criterion *P* is calculated as the product of individual factors representing the key features of the power line in question, according to the formula:

$$P = p_1 \times p_2 \times p_3 \times p_4$$

where: P = criterion of the power line, quantifying the influence of power line characteristics on the degree of risk on the line, p_1 = factor of power line direction, p_2 = factor of cable thickness, p_3 = factor of number of cable levels, p_4 = factor of number of parallel power lines.

Values of criterion *P* range between 0 and 1.

Direction of power line

The orientation of a power line relative to a water course is one of the key factors increasing the degree of risk on the power line for local and migrating bird species. Power lines proceeding in parallel with a water course represent a distinctly lower risk than those crossing perpendicularly over it (Crowder 2000). The input data for assessing the factor of power line direction are the azimuth of the main direction of the water course and a line vector layer of the power line. The power line is divided into sections from one change in direction to the next, or from one pylon point to the next. The value of factor p_1 is determined based on the angle of divergence of the power line from the water course as shown in Tab. 6.

Thickness of cables

The cables on 22 kV power lines may be carried along in the form of above-ground cable bundles. Sections with this arrangement of cables are considered as problem-free with regard to collisions due to their increased visibility, so the value of p_2 for this type is 0. Lines with uninsulated cables of standard thickness have a p_2 value of 1. Information about cable thickness should be contained in the attributes table of the database provided by the grid company. For 110 kV lines the factor of cable thickness is not assessed, as its value is automatically set at 1.

Tab. 6. Values of factor p_1 depend on the angle of divergence between the azimuths of the assessed power line section and the prevailing direction of main water courses.

Tab. 6. Hodnoty faktora p_1 v závislosti od uhla odklonu azimutov hodnoteného segmentu vedenia voči prevažujúcemu smeru veľkých vodných tokov.

divergence between azimuths of power line and main water courses in the region / odklon azimutov vedenia a veľkých tokov v regióne	value of factor p_1 / hodnota faktora p_1
75.01–90°	1.00
15.01–75°	0.95
> 15°	0.90

Number of horizontal levels of cables

Factor p_3 is determined based on the attributes of the vector layer supplied to the risk assessor by the grid company. The values of factor p_3 depend on the number of horizontal levels of cables on 22 kV lines as shown in Tab. 7. The greater the number of levels, the better the visibility of the line and the lower the potential risk of collision.

For 110 kV power lines the factor of number of cable levels is not assessed, as its value is automatically set at 1.

Number of parallel power lines

The number of power lines running in parallel can be read from the map (or vector layer) of lines provided by the grid company. Values of factor p_4 depend on the number parallel power lines as shown in Tab. 8.

Power line sections with low risk of collisions, once the calculations are adjusted and verified, need no further attention paying to them. On the other hand, sections with high and medium risk of collisions on paper need to be attentively inspected in the field, critical sections targeted for finds of birds killed as a result of collisions, their causes analyzed, and measures for their elimination subsequently proposed. These may consist for example in the installation of flight diverter devices (Janss & Ferrer 1998, Morkill & Anderson 1991, Yee 2008, Barrientos et al. 2011, 2012, Sporer et al. 2013), laying the power line cables in the ground (APLIC 2012, Raab et al. 2012), or proposing a change in the line's route through the countryside (Haas et al. 2005, D'Amico et al. 2019).

Discussion

Within the territory of the Slovak Republic alone we have records of almost 35,000 kilometres of transmission and distribution power lines. Not all of these pose a risk of bird collision however, and it not necessary to take measures against collisions along their whole length. For the electricity companies as well, it would be unrealistic from the technical, personnel and above all financial points of view to implement protective measures on such a scale.

One of the possibilities of identifying priority sections for fitting with protective devices lies in the application of the methodology presented above, which makes use of a digital model to apply in practice the available knowledge and key parameters which are put forward in specialist studies as the principal factors influencing the final degree of risk of bird collisions. This methodology also starts out from the data gathered by the LIFE Energy project team and from more than 15 years of experience with issues of bird collisions with power lines within Slovakia (Šmídt et al. 2017).

This methodology was developed for 22 kV and 110 kV distribution lines. It was applied to a total of 6,235 km of power lines within the framework of the LIFE Energy project. After application of the methodology and based on the results of field research in the period 12/201–02/2016, flight diverter devices were initially installed on a total of 77 km of power line sections in the category of greatest degree of risk. Moreover almost 90% correlation was found between sections with high risk of collisions and numbers of outages involving power installations recorded by the grid companies.

The initial selection of so-called indicated species turned out to be very important. The selected species

Tab. 7. Values of factor p_3 depending on the number of horizontal levels of cables on the power line.
Tab. 7. Hodnoty faktora p_3 podľa počtu horizontálnych úrovní vodičov elektrického vedenia.

number of cable levels on 22 kV line / počet horizontálnych úrovní vodičov na vedení 22 kV	value of factor p_3 / hodnota faktora p_3
1	1.00
2	0.95
3 and more / a viac	0.90

Tab. 8. Values of factor p_4 depending on the number of parallel power lines.
Tab. 8. Hodnoty faktora p_4 podľa počtu paralelných vedení.

number of parallel line / počet paralelných vedení	value of factor p_4 / hodnota faktora p_4
1	1.00
2	0.95
3 and more / a viac	0.90

Cygnus olor, *Ardea cinerea*, *Nycticorax nycticorax*, *Ardea alba* and *Anas platyrhynchos* were more frequently killed, and new finds were made at the same sites just a few dozen or at most a few hundred metres apart. These finds both indicated and confirmed to us which sections of power line were risky in terms of bird collisions, because we came to expect higher frequency of collisions with nearby power lines wherever we found concentrated populations of these species in the countryside. The universality and possibility of setting the values of parameters in this methodology (especially the technical variables) enabled the same procedure of calculating the degree of risk of collision to be applied in the case of 400 kV transmission lines as well (data not shown). Through its use, sections of line with high probability of collisions were identified during the preparation phase of planning documentation. Based on our assessments, specific sections were identified and assigned for installation of flight diverter devices on the overland cables as compensation measures with regard to birdlife conservation.

It is possible to find categorization of power lines into various degrees of risk in several foreign studies. They make use of more or less similar approaches, in the sense that they apply parameters quantifying the degree of risk for individual species in order to define those which attract higher risk of collision with power lines. They also apply a selection of criteria (morphological parameters) based on the work by Bevanger (1998). Some of them also utilize factors based on the topography of the assessed area and the type of construction of the power lines. Subsequently these variables are vectorized using GIS tools and then visualized in map form with various scales of resulting degree of risk. The assessment in a Belgian study for example (Derouaux et al. 2012) sets out from the principle of identifying the priority species with regard to risk of collision, then key biotopes and migration routes. These data were subsequently filtered through power line layers and then a system of assigning scores was introduced based on expert evaluation. The output of this method applied in Belgium is a map of risk levels in the regions plotted with a colour gradient from green (areas with low risk of collisions) up to red (areas with most critical potential for collisions). In Spain, D’Amico et al. (2019) for example defined species at risk according to their morphological and behavioural parameters. Based on their distribution in the country a map of so-called hot spots was created, where it was necessary to carry out measures against collisions. In our methodology we present a different principle according to which we first employ similar input variables, but then supplement them with information about the topography of the landscape and the type of power line construction, and on the basis of their interaction we are able to define not only hot spots, i.e. areas where it is necessary to implement measures against collisions, but also to distinguish precisely between sections and spans of power lines with differing degrees of risk. A similar principle of creating a precise model sorting power lines into categories of risk is also applied in the work by Heck (2007) in the USA. This author starts with an analysis and subsequent superimposing or weighting with parameters corresponding to the biotope composition and type of power line being assessed for risk. The development of any methodology to a certain extent necessarily reflects the particular geographical variety compared to other, even neighbouring countries. This is the result partly of differing species composition and topography and partly of differing structural versions of power lines. For instance the model created for the territory of Spain (D’Amico et al. 2019) was also tested in the conditions of Portugal, whereupon it revealed differences deriving from the partially different species composition and status of birdlife protection in that country as well as different density of the power line network there. In developing the methodology presented here we set out using the same basic procedures as applied in other methods(i.e. including factors such as mutual positioning of power lines, sites with concentrations of birds, or their migration routes), but we also calculate in the impacts of power line direction relative to the expected prevailing directions of bird movement, slope distribution in the terrain and the presence of tall tree growth. These additionally assessed inputs significantly shorten the resulting lengths of power lines sections which are ultimately assessed as representing some degree of risk, since the real degree of risk is restricted by factors of landscape (slope and vegetation) or the parameters of the power lines themselves.

With increasing worldwide expert knowledge of issues of bird collisions with distribution and transmission power lines, it is possible to improve the appropriacy of values of input variables and their weighting in the modelling process. Identification of risky power line sections and targeted application of available and effective measures (e.g. installation of diverting devices, or changes in power line routing and configuration) in the places with the highest degree of risk is a more effective way in terms of time, technology and financial cost of dealing with collisions of birds with power lines, not only on the existing electricity grid but also preventively with regard to newly-planned routes. This is particularly important in the context of the constant growth in extent and density of the power grid in proximity to or passing directly through sites with prevalence of critically endangered species.

We have proposed a method enabling the identification of risky power line sections where there is the highest probability of bird collisions. This method may also be applied in areas with different geographical conditions wherever there is information available about key and potential key bird sites, their species composition and the power lines present in the assessed area. If this method is to be applied for the first time in a particular area, we recommend supplementing it with field observations, especially on sections of power line where a discrepancy appears between the results of categorization and recorded finds of bird mortality. This will help to identify cases of incorrectly evaluated factors, enabling them to be adjusted and the model to be tuned so as to reflect as accurately as possible the degree of risk posed to birds by power lines, and at the same time ensure the easy application of the model in practice.

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Changes in nesting habitat of the saker falcon (*Falco cherrug*) influenced its diet composition and potentially threatened its population in Slovakia in the years 1976–2016

Zmena hniezdneho habitatu sokola rároha (*Falco cherrug*) mala vplyv na zloženie jeho potravy a hrozby pre populáciu na Slovensku v rokoch 1976 – 2016

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Abstract: In the period between the years 1976 to 2016 we monitored the nesting site distribution of two populations of saker falcon (*Falco cherrug*) concentrated in the highlands and adjacent lowlands of western and eastern Slovakia. In western Slovakia we recorded nesting by 56 pairs and 514 nestings, and in eastern Slovakia we observed nesting by 32 pairs and 245 nestings. There were similar nesting success rates in both regions, with pairs producing on average 3.2 young in every successful nest. During the monitored period as a whole a total of 1,788 young saker falcons were raised. At the same time all the pairs gradually resettled in the lowlands, and in the new environment the nesting success rate significantly improved (81.1% compared with 57.1 % in the highlands). This change of nesting biotopes was caused by the impacts of intensive exploitation and environmentally inappropriate forest management, with the accompanying excessive disturbance of nesting birds, but at the same time the disappearance of ground squirrel (*Spermophilus citellus*) colonies led to a change in the food spectrum for the observed saker falcon pairs. We evaluated the falcons' feeding habits in western Slovakia between the years 1977 and 2016 (49 pairs; 1–17 pairs/year) and in eastern Slovakia between 2009 and 2016 (12 pairs; 1–3 pairs/year). Altogether 17,669 prey items were identified. From 1976 onwards mammals (Mammalia, 19.8%, 24 species) became gradually less represented as a component in the falcons' diet compared with birds (Aves, 79.9%, 58 species). In areas of western Slovakia we found stable and predominant proportions of domestic pigeons (*Columba livia* f. *domestica*) ranging from 52% to 62%. The proportion of pigeons was distinctly lower in eastern Slovakia (31.5%), compensated for by larger shares of common vole (*Microtus arvalis*), common starling (*Sturnus vulgaris*), Eurasian magpie (*Pica pica*) and hooded crow (*Corvus cornix*). The common starling (9.5%) was a significant prey species in the lowlands of western and eastern Slovakia alike. Mammals were mostly represented by common voles (9.8%), European hamsters (*Cricetus cricetus*, 5.3%), ground squirrels (2.1%) and hares (*Lepus europaeus*, 1.6%). Changes over time in the composition of falcons' prey were also evaluated over five periods in western Slovakia.

Abstrakt: V období rokov 1976 až 2016 bola monitorovaná distribúcia hniezdisk dvoch populácii sokola rároha (*Falco cherrug*), sústredených v pohoriach a v priľahlých nížinách západného a východného Slovenska. Na západnom Slovensku sme zaznamenali hniezdenie 56 párov a 514 hniezdení, na východnom Slovensku sme sledovali hniezdenie 32 párov a 245 hniezdení. V oboch regiónoch bola podobná úspešnosť hniezdenia a páry produkovali priemerne 3.2 mláďaťa na jedno úspešné hniezdo. Za celé sledované obdobie bolo vyvedených spolu 1788 mláďat sokola rároha. Počas sledovaného obdobia sa všetky páry postupne presídlili na nížiny. V novom prostredí sa signifikantne zvýšila úspešnosť hniezdenia (81,1 % oproti 57,1 % v pohoriach). So zmenou hniezdnych biotopov, ktorá bola spôsobená vplyvom intenzívneho a environmentálne nevhodného lesohospodárskeho využívania a nadmerného vyrušovania, ako aj zánikom kolónií sysľa pasienkového (*Spermophilus citellus*), došlo aj k zmene potravového spektra sledovaných párov sokolov rárohov. Vyhodnotená bola potrava sokola rároha zo západného Slovenska za roky 1977 až 2016 (49 párov; 1–17 p./year) a z východného Slovenska za roky 2009–2016 (12 párov; 1–3 p./year). Spolu bolo determinovaných 17 669 kusov koristi. Cicavce (Mammalia, 19,8 %, 24 druhov) boli po roku 1976 postupne stále menej zastúpenou zložkou potravy než vtáky (Aves, 79,9 %, 58 druhov). V oblastiach západného Slovenska sme zistili stabilné a dominantné zastúpenie domácich holubov (*Columba livia* f. *domestica*) od 52 do 62 %. Výrazne nižší bol podiel domácich holubov na východnom Slovensku (31,5 %), kompenzovaný vyšším podielom hrabošov (*Microtus arvalis*), škorcov obyčajných (*Sturnus vulgaris*), strák obyčajných (*Pica pica*) a vrán popolavých (*Corvus cornix*). Významným druhom koristi v nížinách západného a východného Slovenska bol aj škorec (9,5 %). Z cicavcov boli najviac zastúpené hraboše poľné (*Microtus arvalis*, 9,8 %), chrčky (*Cricetus cricetus*, 5,3 %), sysle (2,1 %) a zajace (*Lepus europaeus*, 1,6 %). Vyhodnotené boli aj časové zmeny v zastúpení koristi na západnom Slovensku v 5 periódach.

Key words: *Falco cherrug*, nesting distribution, food, management, threats, Slovakia

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Introduction

The saker falcon (*Falco cherrug*) inhabits the extensive steppe zone stretching from the Pannonian Basin eastwards through Moldavia, southern Ukraine, Russia and Kazachstan as far as the Asian steppes in southern Siberia, central Asia and western China. Outside the nesting period these falcons penetrate into western and southern Europe, the Middle East, western India and eastern China (Baumgart 1994). The Asian population reaches levels of 8,000–17,000 pairs, nesting in 10 to 13 countries (Dixon 2009). The European population (640–720 pairs) makes up 7% of the world's total (Kovács et al. 2014). With regard to Pannonia these falcons nest further north in Slovakia, to the west in southern Moravia (Beran et al. 2012) and Lower Austria (Frey & Senn 1980, Zink et al. 2015) and to the south in Vojvodina, Serbia (Puzović 2008). The centre of the European population is in Ukraine and Hungary (Bagyura et al. 2004, Kovács et al. 2013).

In western Slovakia the last saker falcon pairs nested in their original nesting sites in the Strážovské vrchy Hills up until 1994, and in the Malé Karpaty Mts. until 2008. In the wetlands of the river Morava saker falcons nested up until 2001.

In eastern Slovakia the last pairs nested in their original nesting areas in the Slovakian Karst until 2002, in the Slovenské Rudohorie Mts. till 1981 and in the Slánske vrchy Hills until 2003.

The principal causes of the decline in saker falcon numbers in their distribution area are considered to be firstly the reduction in availability of key prey species due to human activity, and secondly the direct weakening of the population through nest robbery for falconry purposes. In some places this decline represents a threat to the very existence of these falcons (Horák 2000, Levin 2000, Moseikin 2000, Galushin et. al. 2001, Karyakin 2001, 2005, 2008, Levin et al. 2010, Štefanová & Šálek 2013, Stretesky et al. 2018). This negative trend has however been successfully stopped in several countries, mainly in Europe, thanks to preservation activities, and the species has exhibited population growth in recent years (see e.g. Beran et al. 2012, Gamauf 2012, Gamauf & Dosedel 2013, Zink et al. 2015). On the other hand, in many countries with large falcon populations, the species continues to suffer decline (Kashkarov & Lanovenko 2011, Galushin 2012, Rajković 2016).

The saker falcon is physically adapted to hunting animal prey on the ground and in the air, where it combines dynamic acceleration and flexible flight control. For this reason its preferred prey are small and medium-sized diurnal land-based rodents and lagomorphs, predominantly ground squirrels (*Spermophilus citellus* in Europe, *S. dauricus*, *S. erythrogenys*, *S. leptodactylus*, *S. relictus*, *S. pygmaeus*, *S. major*, *S. fulvus* and *Urocitellus undulatus* in Asia); hamsters (*Cricetus cricetus* in Europe, *Ellobius talpinus* in Asia), voles (*Microtus arvalis* mainly in Europe, *M. brandtii*, *M. gregalis*, *M. mongolicus* in Asia), gerbils (*Meriones meridianus*, *M. unguiculatus*, *Rhombomys opimus*) and hares, but also pikas (*Ochotona curzoniae*, *O. daurica*, *O. melanostomata*), marmots (*Marmota sibirica*, *M. bobak*) in mountain areas, and wood and field mice (*Apodemus sylvaticus*), rats, jerboas (*Alactaga sibirica*) and steppe lemmings (*Lagurus lagurus*). The proportion of mammals in the prey, while usually the principal diet component everywhere, naturally depends on their availability, so it differs seasonally, annually and regionally (Kovács et al. 2014). Birds are generally less represented as the primary food, but they can make up from 30 to 60% of the falcons' diet during the nesting season (Kovács et al. 2014). Older data on the saker falcon diet throughout its distribution area were summarized by Baumgart (1980). In the Pannonian Lowlands the main prey in the past used to be medium-sized rodents such as ground squirrels and hamsters (Baumgart 1980). Obuch & Chavko (1997) studied the falcons' diet in western Slovakia especially in the period from 1978 to 1995, when the majority of nests was still located in the highlands (Chavko 2002a). Chavko & Deutschová (2012) and Chavko et al. (2014) then reported updated information about the species' diet in Slovakia. The situation has changed in Slovakia compared to the state found in those published works, and we have comprehensively reworked the data covering the whole monitored time period, focusing on finding the missing correlations between changes in nesting habitat, food sources and population threats. In addition we have supplemented data on trends in the falcon population and diet in eastern Slovakia. In this way we have potentially achieved our aim of documenting the development and composition of the saker falcon diet within the whole nesting population in Slovakia during the last forty years.

In Hungary the diet of this species has been studied for example by Bagyura et al (1994) and later also by Balázs (2008). The typical feature of these falcons is kleptoparasitism (see e.g. Pfeffer 1994, Braun & Lederer 1996, Puzović 2008).

The principal aim of this study was to describe the change in the saker falcons' preferred nesting habitat in two geographical areas of western and eastern Slovakia in the period between 1979 and 2016, namely their shift from the hills down into agricultural country. We compare the success rates of pairs nesting in trees and rocky outcrops with those nesting in boxes and on platforms attached to power line pylons in agricultural areas. We also track the range of prey hunted during the last 40+ years in the studied nesting sites of the falcon poppulation around Slovakia, and compare their diet compositions in several orographic regions in this country. We additionally focus on monitoring and identifying threats to the falcon population, and on directly implementing management measures for their mitigation.

Materials and methods

In the period from 1976 till 2016 we monitored the disribution of nesting sites of two populations of saker falcon in Slovakia, concentrated in the hills and adjacent lowlands in the western and eastern parts of this country. In western Slovakia we monitored the nesting of 56 pairs, and in the period 1976 to 2016 we recorded a total of 514 nestings.

In eastern Slovakia in the period 1979 to 2016 we monitored the nesting of 32 pairs, and in the monitored period we recorded a total of 245 nestings.

We evaluated the results of collections of saker falcon food remains between 1978 and 2016 taken from 49 pairs in western Slovakia (314 annual collections) and in the years 2009, 2010, 2015 and 2016 from 9 pairs in eastern Slovakia (15 annual collections).

Monitoring of nesting was performed using the direct observation method. In the autumn and winter seasons we mapped the nests in the selected upland areas. During spring we then verified their occupancy by direct observation and based on the falcons' behaviour (courting flights).

Since 1991 we have been working in cooperation with the Slovakian Power Transmission Grid (SEPS) to progressively create new nesting opportunities for falcons in the form of boxes fitted to pylons in in selected parts of prey-hunting areas and known wintering sites.

We verified nesting and the occupancy of nests in trees and on electricity pylons by means of direct observation of all known nests and installed nesting-boxes. In addition we also checked all relevant historical nesting sites, even if previously abandoned, to verify whether or not they had been newly reoccupied. We checked nest occupancy at least four times a year, and we checked every occupied nest or box physically by climbing up at least twice in every season, the first time in order to ring the young birds and the second time after the young birds flew from the nest in order to collect food remains. We paid special attention to finds of particular prey species indicating that the falcons also brought remnants of found carrion to their nests. Data obtained prior to 1975 from two abandoned nests in rocky outcrops, which have been included in the comparison of changes over time, were taken from our previous study (Obuch & Chavko 1997). In the same way for the purposes of this work we have made use of data from the study by Chavko & Deutschová (2012). Their study presents only partial data with no details of saker falcons' diet in eastern Slovakia, and with no reference to the comprehensive comparison over time of the diets of individual pairs in various orographic areas.

Food remains were collected in eight orographic areas around Slovakia (Malé Karpaty Mts., Burda Mts., Borská nížina Lowlands, Podunajská rovina Plain, Trnavská pahorkatina Uplands, Nitrianska pahorkatina Uplands, Košická kotlina Basin and Východoslovenská rovina East Slovakian Plain). Nest and nesting-boxes were cleared annually of all prey remains, so that samples taken in the following year were not spoilt with admixtures of remnants from the previous period. The osteological material obtained was treated with 5% NaOH solution, then washed in water and prepared for identification. This was done using the jaws of mammals (maxilla and mandibula), for birds also with the humerus, metacarpus and tarsometatarsus, and particular body parts for lower vertebrates and invertebrates. Proportions of prey species in individual collections were established on the basis of the most numerous identified bones of particular prey species. In the case of birds the most frequently identified bone was the humerus. Collections of food remnants from nesting-boxes were more comprehensive than those from tree nests, where part of the food remnants had always fallen into the vegetation on the ground. The authors estimate that during their monitoring of nests in the period from 1979 onwards they had around 95–97% of all nesting pairs in Slovakia under constant observation, and food samples were taken from 87.5% of all monitored pairs in western and 28% of pairs in eastern Slovakia.

Data analysis

Data on the saker falcon diet were processed separately for each of the orographic areas, and subsequently they were compared with each other (seven groups, as the areas of the Malé Karpaty Mts. and Burda Mts. were evaluated together as one group). With regard to diet changes over time, five time periods were set up: prior to 1975, 1977–1989, 1990–1999, 2000–2009 and 2010–2016.

The results of the diet composition research were evaluated using the calculation method of marked differences from the mean (MDFM, Obuch 2001). They are presented in tables in which the ranking of prey species and samples is set up so that the diagnostic species with positive deviations from the mean create closed blocks. More numerous species with no clear deviations, i.e. evenly represented in all compared samples, are placed below the dotted line and ranked from the most to the least numerous. The diversity index H' was calculated using the formula of Shannon & Weaver (1949). The Zber database program (Šipöcz 2004) was used in compiling the tables.

The predominance of species in the food spectrum in particular years (seasons) was calculated based on the work of Losos et al. (1985), i.e. as the percentage representation of individual species in the given year (season) in the monitored nests.

In order to visualize the differences between food remnants we used indirect gradient analysis (principal component analysis, PCA), since the gradient length found with detrended correspondence analysis (DCA) had a value of 1.166. We used relative numbers (predominance) of identified prey species as our input data at the level of individual time periods and/or orographic areas. Data were processed for 47 prey species, seven orographic areas and/or five time periods. For PCA analysis we used square root transformation of the species data. In the scaling we focused on inter-species correlations. The data were centred within the samples (in our case: locations, years). The analyses were carried out using CANOCO 4.5 software (Microcomputer Power, USA; TerBraak & Šmilauer 2002).

The nesting success rate was set as the ratio of successful nests to the total number of monitored nests in particular years, and it was tested using the χ^2 test. Analysis was performed using the Statistica 7 program (Statsoft, USA).

Results

Population trend and nesting success rate

In the period 1976–2016 nesting by 88 pairs of saker falcons was recorded in Slovakia (altogether 759 nestings). Of these in that period 56 pairs nested in south-western Slovakia and 32 pairs in south-eastern Slovakia. In western Slovakia 196 nestings were recorded in the hills and wetland forests and 318 nestings in the

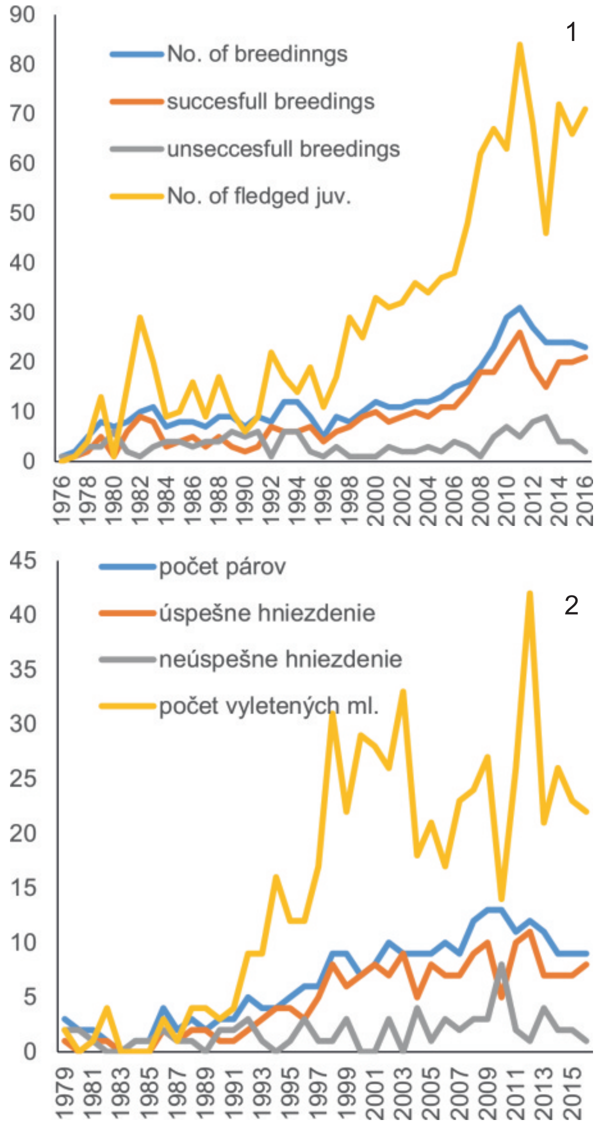

Fig. 1–2. Development trend in saker falcon population in western Slovakia in 1976–2016 (1) and in eastern Slovakia in 1979–2016 (2).

Obr. 1 – 2. Trend vývoja západoslovenskej populácie sokola rároha v období rokov 1976 – 2016 (1) a východoslovenskej populácie v období rokov 1979 – 2016 (2).

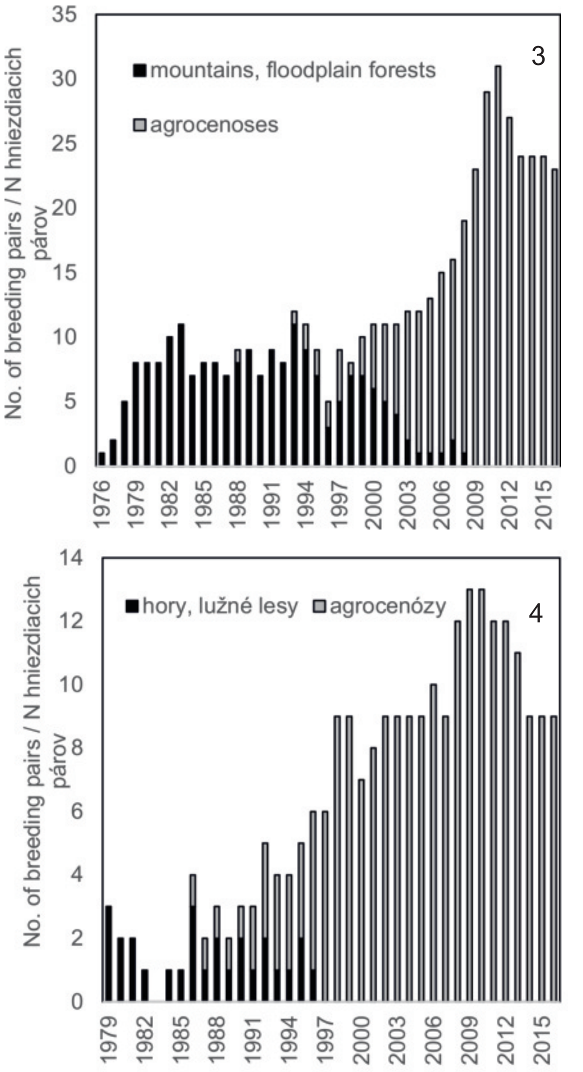

Fig. 3–4. Course of changes in saker falcon nesting habitat in western Slovakia in 1976–2016 (3) and in eastern Slovakia in 1979–2016 (4).

Obr. 3 – 4. Priebeh zmien hniezdneho habitatu sokola rároha na západnom Slovensku v období rokov 1976 – 2016 (3) a na východnom Slovensku Slovensku v rokoch 1979 – 2016 (4).

lowlands on agricultural land (Fig. 1). In eastern Slovakia 27 nestings were monitored in the hills and 218 in lowland agricultural areas in the period 1979–2016 (Fig. 2).

During the monitored period a change in the saker falcons' preference for nesting habitat was recorded. While at the beginning of the monitored period all pairs in both western and eastern Slovakia nested in upland forest environments, over time they gradually resettled in agricultural country, and they started using boxes and platforms installed on power line pylons for their nesting (Figs. 3, 4, 5a, 5b). We recorded the first nesting in farmland in western Slovakia in 1988, the falcons using an old crows' nest on a pylon, and we assume that the

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Fig. 5. Nesting box (a) and nesting platform (b) on a power line pylon occupied by saker falcons. This kind of nesting is currently most frequent throughout agricultural countryside in Slovakia.

Obr. 5. Hniezdna búdka (a) a hniezdna podložka (b) na stožiari elektrického vedenia obsadená sokolom rárohom. Tento typ hniezdenia je v dnešnej dobe v poľnohospodárskej krajine Slovenska najčastejší.

reason for their absence up to that point was the distinct lack of natural nesting opportunities in the intensively-cultivated agricultural countryside. Nesting by the first pair in farmland was recorded in the Košice Basin (south-eastern Slovakia) as early as 1986, however. Since 2002 in western Slovakia and since 1991 in the east, the majority of pairs have nested in the changed biotope of agricultural land, and the last instances of active nesting in upland areas were recorded in the Slánske vrchy Hills (eastern Slovakia) in 1996 and in the Malé Karpaty Mts. (western Slovakia) in 2008.

As a result of the resettlement of the monitored saker falcon pairs from the hills and wetland forests into agricultural countryside, there have been changes in the borders of their nesting areas. The dimensions of that area in western Slovakia have however remained almost unchanged: the original area extended over 355,247 hectares while the area occupied by pairs in the lowlands was 395,692 ha. In eastern Slovakia the current extent of the nesting area in agricultural country has become slightly smaller than the original one in the hills: 186,426 ha vs. 123,419 ha (Fig. 6, 7).

During the whole study period a total of 1,788 saker falcon young were raised in all types of nest in both monitored regions. Significantly higher nesting success rates were found for falcons nesting in agricultural country compared with the nesting sites in the hills, and this is true for both studied geographical areas (eastern as well as western Slovakia), and moreover when the data were combined ($\chi^2 = 37.94$, $P < 0.001$). In agricultural country the average success rate was 81.1% for all nests with 2.7 young raised per nest overall, or 3.3 young for each successful nest. In the hills the average was 1.7 young flying per nest overall, or 2.9 young from each successful nest, the proportion of successful nests being just 57.1% overall.

In the monitored period the nesting success rate for saker falcons nesting in boxes on pylons was significantly higher than for pairs nesting in the past in natural nests in upland areas (81.1% compared to 57.1% respectively), and pairs nesting in boxes were also more productive, with a higher average number of raised young for each successful nest (3.3 compared to 2.9 young for each successful nest respectively). The two monitored populations, although 250 to 300 km distant from each other, displayed almost identical long-term average success rates. The west Slovakian population had average success rates of 2.4 young per nest overall and 3.2 young per successful nest, and in the east Slovakian population the figures were 2.3 and 3.2 young per nest respectively (Appendix 1, 2).

Food

From all the saker falcon pairs we monitored we obtained samples of 17,669 prey items from 61 different nests (45 in farmland, 16 in uplands and wetland woods). Mammals (Mammalia, 19.8%, 24 species) became from 1980 onwards a progressively less important component of the falcons' diet compared to birds (Aves, 79.9%, 58 species). There was an occasional occurrence of amphibians (Amphibia, 3 species: *Rana* cf. *esculenta*, *Bufo bufo*, *Pelobates fuscus*), reptiles (Reptilia, 1 species: *Lacerta agilis*) and fish (Pisces, 1 unidentified instance); invertebrates were represented mainly by Coleoptera (0.1%).

The most frequently hunted prey species was the domestic pigeon (*Columba livia* f. *domestica*), which made

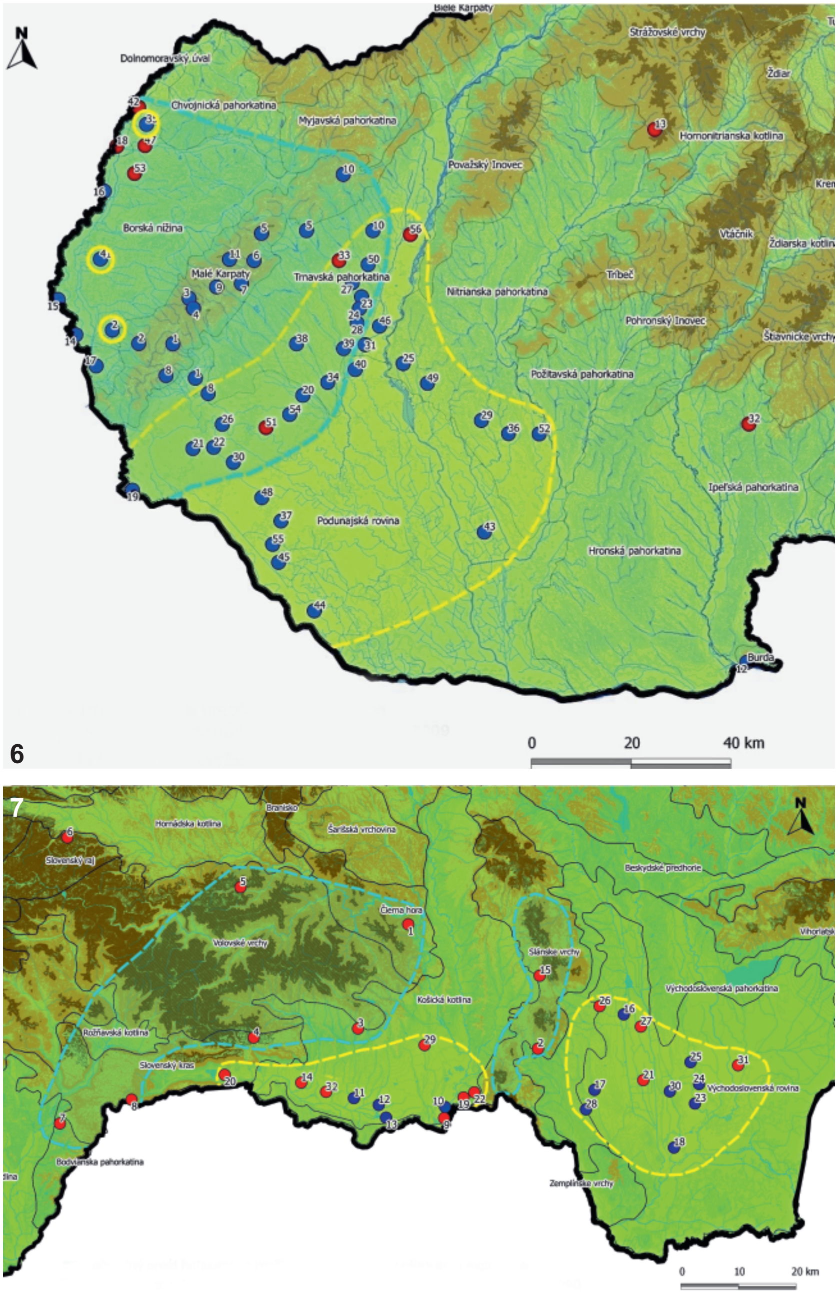

Fig. 6–7. Distribution of saker falcon nesting sites and territorial changes in nesting distribution in western Slovakia (1976–2016) (6) and in eastern Slovakia (1979–2016) (7). Blue colour indicates the original area of nesting distribution up until 2008 (6) and 1996 (7), and yellow indicates the area of nesting distribution 2002–2016 (6) and 1991–2016 (7). Nesting sites where no sample collection took place are marked in red.

Obr. 6 – 7. Distribúcia hniezdisk sokola rároha a územné zmeny hniezdneho rozšírenia na západnom Slovensku (1976 – 2016) (6) a na východnom Slovensku (1979 – 2016). Modrou je vyznačený pôvodný areál hniezdneho rozšírenia do 2008 (6) a 1996 (7) a žltou je vyznačený areál hniezdneho rozšírenia v období 2002 – 2016 (6) a 1991 – 2016 (7). Červenou farbou sú vyznačené hniezdiská, kde nebol vykonávaný zber vzoriek.

up on average 57% of the food spectrum throughout the monitored period. The next most frequently hunted prey were starlings, common voles and hamsters (Tab. 1).

Comparing the prey compositions in the five separate time periods, we were able to plot the changes connected with resettlement of the saker falcon populations from the hills down into open countryside. The indirect ordination diagram produced from PCA differentiates the food spectrum found up until 1975 from the prey remnants collected in the later periods (Fig. 8). The period prior to 1975 was characterized by a relatively low share of domestic pigeon (16.8%) and a higher proportion of wild pigeons *Columba oenas* and *C. palumbus*. Before 1975 there was considerably greater diversity of prey species (H‘ = 2.45) compared to the last forty years, during which the diversity index varied

Tab 1. Comparison of saker falcon diet components in selected orographic areas of Slovakia. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods).

Tab. 1. Porovnanie potravy sokola rároha v orografických celkoch Slovenska. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku).

area / územie	**MK**	**BN**	**PdR**	**TrP**	**NP**	**KK**	**VsR**		
taxa / taxón	**5**	**1**	**2**	**3**	**4**	**6**	**7**	**∑**	**%**
Spermophilus citellus	2+ 235	19	106	5- 0	3- 4	1- 2	3- 0	366	2.70
Sciurus vulgaris	1+ 10							10	0.06
Perdix perdix	1+ 83	13	77	73	1- 11	1- 1	2- 3	261	1.48
Vanellus vanellus	1+ 43	4	30	1- 12	9	1	14	113	0.64
Streptopelia turtur	1+ 46	1- 1	21	1- 7	1- 3		12	90	0.51
Turdus philomelos	1+ 18	6	2- 0	1- 1	5	1	1	32	0.18
Coccothraustes coccothr.	1+ 10	1	1				1	13	0.07
Corvus frugilegus	1+ 7		2			1	1	11	0.06
Phasianus colchicus	1- 49	1+ 57	1+ 183	128	44	1- 3	40	504	2.85
Chroicocephalus ridibundus	1- 22	1+ 31	1+ 101	1- 23	2- 2	1- 0	2- 2	181	1.20
Columba oenas	87	25	1+ 178	1- 78	45	1+ 34	1- 25	472	2.67
Columba palumbus	1- 29	1- 11	1+ 140	1+ 110	1- 18	1- 4	1- 16	328	1.86
Cricetus cricetus	1- 144	3- 4	1- 167	1+ 404	117	21	72	929	5.26
Lepus europaeus	1- 28	13	79	1+ 86	1+ 59	1- 2	1- 10	277	1.57
Nyctalus noctula	1- 3	1	10	1+ 24	1+ 12	1	2	53	0.30
Talpa europaea	1- 1	1	6	7	1+ 16	2	6	39	0.22
Mus cf. *musculus*			2	1	1+ 7	1	2	13	0.07
Sturnus vulgaris	422	1+ 166	1- 300	1- 176	1+ 271	1+ 74	1+ 263	1,672	9.46
Pica pica	2- 2.7	2- 0	2.8	51	1- 5	2+ 34	2+ 71	176	1.00
Microtus arvalis	2- 151	1- 40	1- 244	1+ 548	215	1+ 113	2+ 425	1,736	9.83
Corvus cornix	3		1- 0	1- 0	1		2+ 13	17	0.10
Alauda arvensis	13	2	12	10	7	4	1+ 10	58	0.33
Coleoptera sp.	1- 0		1- 0	1- 0		4	2+ 21	25	0.14
Lacerta agilis		1	3	1- 0	1		2+ 12	17	0.10
Apodemus agrarius							1+ 5	5	0.03
Garrulus glandarius	9		1- 1	12	8	3	4	37	0.21
Columba livia dom. (n)	2,486	609	2,684	2,378	1,019	1- 205	1- 395	9,776	55.33
%	62.10	58.67	60.10	56.48	52.72	38.83	26.49		
Coturnix coturnix	14	5	27	18	5	1	7	77	0.44
Streptopelia decaocto	11	3	14	19	13	2	7	69	0.39
Turdus merula	11	4	4	5	4		3	31	0.18
Passer montanus	3		6	3	5	1	5	23	0.13
Passer domesticus	1		4	4	3	2	3	17	0.10
Apodemus flavicollis	1	1	3	2		2	5	14	0.08
Coloelus monedula	1	1	3	3	1		2	11	0.06
Rattus norvegicus	3		2	2			3	10	0.06
Falco tinnunculus	1	1	5	1	1			9	0.05
Asio otus	1		1	4	1		1	8	0.05
Turdus pilaris	2		2	1		1	2	8	0.05
Apodemus sylvaticus	2		3		2			7	0.04
Apodemus microps				1	1	1	4	7	0.04
Mammalia, 24 species	**1- 583**	**2- 82**	**1- 631**	**1+ 1,077**	**435**	**1+ 148**	**1+ 541**	**3,497**	**19.79**
Aves, minim. 58 species	**3,420**	**954**	**3,832**	**3,132**	**1,497**	**376**	**1- 913**	**14,124**	**79.94**
Amphibia, Reptilia, Pisces	**1- 0**	**2**	**3**	**1**	**1**	**0**	**2+ 14**	**21**	**0.12**
Evertebrata	**1- 0**	**0**	**1- 0**	**1- 0**	**0**	**4**	**2+ 23**	**27**	**0.15**
∑	**4,003**	**1,038**	**4,466**	**4,210**	**1,933**	**528**	**1,491**	**17,669**	**100.00**
Diversity Index H'	1.64	1.61	1.74	1.68	1.78	1.95	2.20	1.86	

Area no. / územie: 5, MK – Malé Karpaty Mts. + Burda Mts., 1, BN – Borská nížina Lowlands, 2, PdR – Podunajská rovina Plain, 3, TrP – Trnavská pahorkatina Uplands, 4, NP – Nitrianska pahorkatina Uplands, 6, KK – Košická kotlina Basin, 7, VsR – Východoslovenská rovina Plain.

Other species (Area no.–number) / ostatné druhy (územie č. –počet):

Sorex araneus (5–1; 2–3; 6–1; 7–1), *Sorex minutus* (7–1), *Crocidura leucodon* (2–2; 4–1; 7–1), *Crocidura suaveolens* (2–1; 7–1),

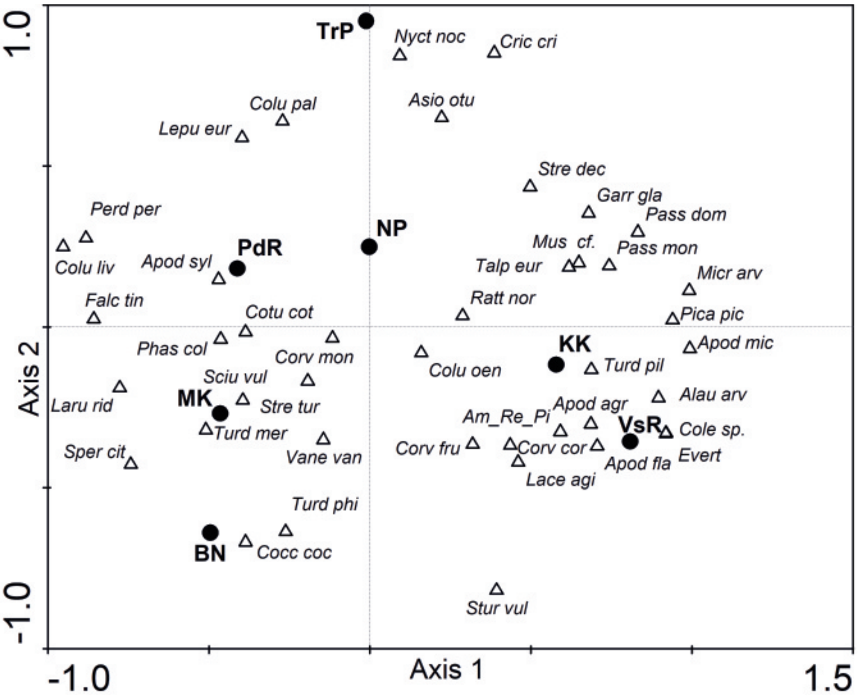

Fig. 8. Ordination diagram of PCA analyses. relative proportions of species identified in the saker falcon diet and their distribution in the individual orographic areas (MK – Malé Karpaty Mts. + Burda Mts., BN – Borská nížina Lowlands, PdR – Podunajská rovina Plain, TrP – Trnavská pahorkatina Uplands, NP – Nitrianska pahorkatina Uplands, KK – Košická kotlina Basin, VsR – Východoslovenská rovina Plain.)

Obr. 8. Ordinačný diagram PCA analýzy – vzťahy medzi druhmi zaznamenaných v potrave sokola rároha a ich distribúciou v jednotlivých orografických celkoch (MK – Malé Karpaty + Burda Mts., BN – Borská nížina, PdR – Podunajská rovina, TrP – Trnavská pahorkatina, NP – Nitrianska pahorkatina, KK – Košická kotlina, VsR – Východoslovenská rovina.)

in the range from 1.45 to 1.80 with indirect dependence on the share of domestic pigeon from 66.5% to 55.0%. The share of domestic pigeons culminated during the decade 1990–1999, and then gradually declined to a minimum in the period 2010–2016 (Tab. 2).

The shift of nesting pairs down into agricultural country is associated with changing preferences among the falcons for certain mammal species, whose share in the falcons' diet then rose (e.g. *Microtus arvalis*, *Lepus europaeus*, *Cricetus cricetus*, *Nyctalus noctula* and *Talpa europaea*), and similarly the representation of the common pheasant *Phasianus colchicus* also increased during the decade 2000–2009. In contrast, while the saker falcons nested up in the hills, the species more often found in their diet were *Sciurus vulgaris*, *Sturnus vulgaris* and *Turdus philomelos*. During the first periods of monitored nesting, 1977–1989 and 1990–1999, the proportion of species *Spermophilus citellus*, *Streptopelia turtur*, *Perdix perdix* and *Vanellus vanellus* gradually declined, while the species *Coturnix coturnix*, *Alauda arvensis*, *Garrulus glandarius* and *Turdus merula* maintained similar relative proportions throughout the time periods being compared (Tab. 2).

We also found differences in diet composition among the saker falcons nesting in the separate orographic areas of Slovakia. Comparing their food in the individual time periods, we found a difference in the analyzed samples between nests in the orographic areas of western and eastern Slovakia. Despite the clearly highest proportion of the domestic pigeon in the falcons' diet in all types of countryside, in western Slovakia they hunted a roughly twofold greater number of domestic

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◄ *Eptesicus serotinus* (5–1), *Muscardinus avellanarius* (5–1), *Apodemus* sp. (3–1), *Arvicola amphibius* (1–2; 2–1; 3–1; 6–1), *Terricola subterraneus* (5–1; 7–1), *Vulpes vulpes* (2–1), *Mustela erminea* (7–1), *Capreolus capreolus* (5–1; 1–1; 2–1; 4–1), *Artiodactyla* sp. (6–1; 7–1), *Anas platyrhynchos* (1–1; 2–2), *Anas crecca* (2–2), *Gallus gallus dom.* (2–1; 6–1), *Rallus aquaticus* (2–1), *Crex crex* (2–2; 4–1; 7–1), *Pluvialis apricaria* (5–1), *Tringa totanus* (5–1), *Philomachus pugnax* (2–1; 3–1), *Scolopax rusticola* (5–1; 2–1), *Larus canus* (5–2), *Larus michahellis* (3–2), *Tyto alba* (4–1), *Asio flammeus* (4–1), *Apus apus* (5–1; 3–1; 6–1), *Melopsittacus undulatus* (5–1; 2–2; 3–1; 4–1), Psittacidae (2–2; 3–1; 4–3), *Dendrocopos major* (5–1), *Dendrocopos* sp. (5–1), *Lullula arborea* (3–4), *Galerida cristata* (5–2; 7–1), *Motacilla alba* (7–1), *Bombycilla garrulus* (5–1), *Lanius collurio* (4–2), *Turdus iliacus* (3–1), *Turdus viscivorus* (5–2; 1–1; 2–1), *Parus major* (5–2; 7–1), *Emberiza citrinella* (5–1), *Fringilla coelebs* (1–1; 2–1; 4–1; 6–1), *Carduelis carduelis* (2–1; 7–2), *Carduelis spinus* (2–2; 6–1; 7–1), *Carduelis cannabina* (3–1; 7–1), *Carduelis chloris* (5–1; 7–1), *Pyrrhula pyrrhula* (5–1), *Loxia curvirostra* (5–1), Passeriformes (5–21; 1–11; 2–7; 3–2; 4–4; 7–3), Aves (3–1), Aves juv. (2–2; 4–2), *Pelobates fuscus* (7–1), *Bufo bufo* (7–1), *Pelophylax* cf. *esculentus* (3–1), Pisces (1–1), *Gryllotalpa gryllotalpa* (7–2).

Tab. 2. Temporal changes in the diet of saker falcon in western Slovakia. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods).

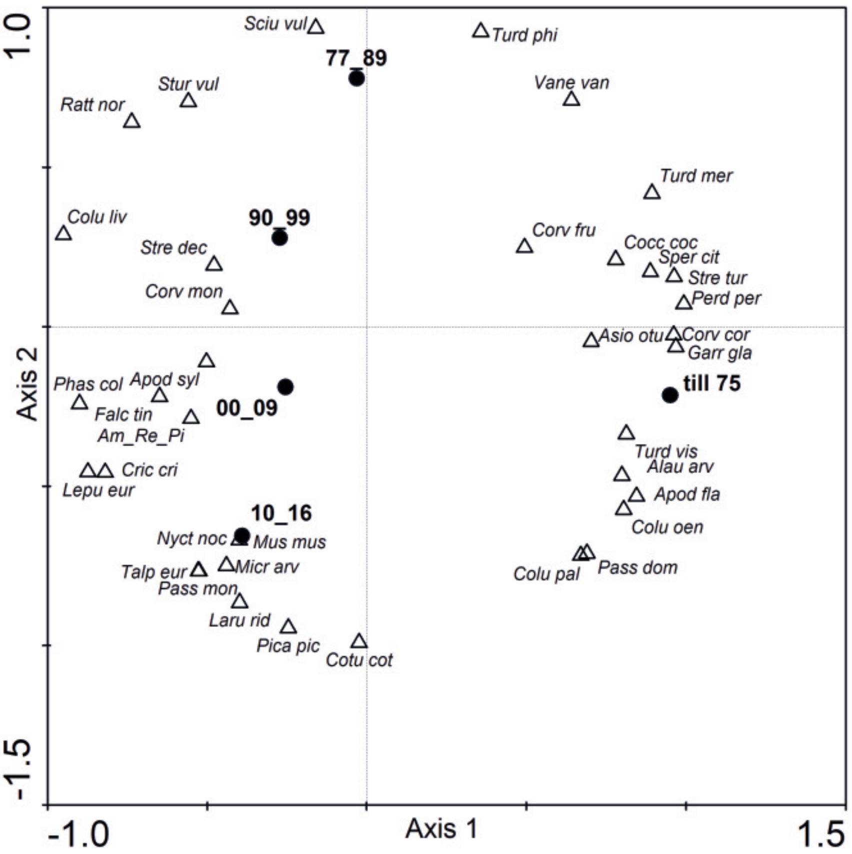
Tab. 2. Časové zmeny v zastúpení koristi sokola rároha na západnom Slovensku. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku).

taxa / taxón // years / roky		<1975		77–89		90–99		00–09		10–16	∑	%
Columba oenas	2+	68	2-	4	2-	11		151		242	476	2.97
Columba palumbus	1+	25	2-	4	1-	8		98		179	314	1.96
Streptopelia turtur	3+	60	2+	34	1-	2	1-	25	2-	17	138	0.86
Perdix perdix	3+	106	1+	49	1-	18		106	1-	83	362	2.26
Vanellus vanellus	1+	12	2+	26	1+	15	1-	19	1-	37	109	0.68
Spermophilus citellus	2+	84	1+	38	1+	78		167	2-	81	448	2.80
Sciurus vulgaris			1+	8		2			1-	0	10	0.06
Turdus philomelos		2	1+	7		4		11	1-	8	32	0.20
Sturnus vulgaris	1-	22	1+	149		114	1-	313		755	1353	8.45
Coloelus monedula					1+	5				4	9	0.06
Phasianus colchicus	2-	0	1-	10	1-	14	1+	177		260	461	2.88
Microtus arvalis	2-	6	3-	6	2-	19	2-	74	1+	1080	1185	7.40
Nyctalus noctula							2-	0	1+	50	50	0.31
Talpa europaea							1-	3	1+	28	31	0.19
Lepus europaeus	2-	0	2-	2	1-	8		76	1+	175	261	1.63
Coccothraustes coccothr.		2		1		2		8	1-	1	14	0.09
Streptopelia decaocto				8	1-	0		14		38	60	0.37
Pica pica		1	1-	0		2		18		51	72	0.45
Chroicocephalus ridibundus	1-	1	2-	0	2-	2		58		115	176	1.10
Cricetus cricetus	3-	1	3-	5		51		289		483	829	5.18
Columba livia dom. (n)	2-	89		577		790		2908		4800	9164	57.22
%		16.76		59.79		66.55		63.20		54.97		
Coturnix coturnix		2		1		3		19		46	71	0.44
Alauda arvensis		4		2		1		15		26	48	0.30
Garrulus glandarius		5		3		2		6		19	35	0.22
Turdus merula		4		5		3		8		12	32	0.20
Passer montanus								2		15	17	0.11
Passer domesticus		2						2		11	15	0.09
Corvus frugilegus		1		1		2				6	10	0.06
Mus cf. *musculus*										10	10	0.06
Apodemus flavicollis		3						1		6	10	0.06
Falco tinnunculus						2		1		6	9	0.06
Asio otus		1		1						6	8	0.05
Apodemus sylvaticus						2				5	7	0.04
Rattus norvegicus				1		1		3		2	7	0.04
Corvus cornix		3		1				2		1	7	0.04
Turdus viscivorus		2				1		1		2	6	0.04
Mammalia		**97**	**2-**	**63**	**1-**	**162**	**1-**	**619**	**1+**	**1,934**	**2,875**	**17.95**
Aves		**434**		**902**		**1,024**		**3,982**		**6,792**	**13,134**	**82.01**
Amphibia, Reptilia, Pisces		**0**		**0**		**1**		**0**		**6**	**7**	**0.04**
∑		**531**		**965**		**1,187**		**4,601**		**8,732**	**16,016**	**100.00**
Diversity Index H'		**2.45**		**1.60**		**1.45**		**1.61**		**1.80**	**1.84**	

pigeons than in eastern Slovakia, where their lower share was compensated with higher representation of the common vole (Tab. 3). This difference was confirmed by the results of our PCA analyses, the ordination diagram from which separated the east Slovakian orographic areas from the western ones (Fig. 9: the first two axes explain 90.3% of species variability: first axis 70.3%, second axis 20%). The cluster of species in the right-hand part of the graph along the first ordination axis may be characterized generally as the prey of saker falcons which is typical for its higher representation in eastern Slovakia (Košická kotlina Basin, Východoslovenská rovina Plain). This applies mainly to the common vole, whose diet share rises from west to east from

Fig. 9. Ordination diagram of PCA analyses from monitoring of diet changes relative proportions of species identified in the saker falcon diet and their distribution in the individual nesting periods.

Obr. 9. Ordinačný diagram PCA analýzy sledovania potravných zmien – vzťahy medzi druhmi v potrave sokola rároha a ich distribúciou v jednotlivých hniezdnych obdobiach.



a subdominant share in the Malé Karpaty Mts. and Borská nížina Lowlands to eudominant (Východoslovenská rovina Plain and Košická kotlina Basin). A similar observation applies to the stock dove (*Columba oenas*), which is found with dominant representation in the diet only in the Košická kotlina Basin. Another numerous prey item in eastern Slovakia is the skylark (*Alauda arvensis*). In contrast, a species typical for the western part of the country, but almost completely absent from the falcons' diet in eastern Slovakia, is the black-headed gull (*Chroicocephalus ridibundus*). Relatively large shares in the western diet consist of *Phasianus colchicus*, *Lepus europaeus* and (especially historically) *Spermophilus citellus*. In the area of the Trnavská pahorkatina Uplands the European hamster is so highly represented that it borders on eudominance. Compared with other areas there is also higher incidence here of the common noctule (*Nyctalus noctula*).

Tab. 3. Percentage representation of individual animal prey groups in saker falcon diet in western and eastern Slovakia in 2000–2016.

Tab. 3. Percentuálne zastúpenie jednotlivých skupín živočíchov v potrave sokola rároha na západnom a východnom Slovensku v 2000 – 2016.

birds / vtáky	mammals / cicavce	reptiles / plazy
	western Slovakia / Z Slovensko	
	agro-cenoces / agrocenózy	
81.2	18.76	0.04
	mountains / pohoria	
86.14	13.86	0
	floodplains / luhy	
88.65	10.81	0.54
	eastern Slovakia / V Slovensko	
	agro-cenoces / agrocenózy	
62.32	37.46	0.21

The character of some of the animal remains brought by saker falcons to their nests as food led us to conclude that they could not have been hunted, but found as cadavers (Figs. 10, 11, 12). Body parts from adult hares, hacked off limbs of roe deer (*Capreolus capreolus*), the head of a fox (*Vulpes vulpes*) and remains of pheasants could have been picked up after being killed during mowing or harvesting, or by road traffic. Dead animals might also have been taken from other raptor species.

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Fig. 10–12. Saker falcon female bringing a hacked-up hare killed during mowing of meadows. This way of acquiring prey was relatively frequent among these falcons (10). Part of a severed limb from a roe deer (*Capreolus capreolus*) in a box occupied by saker falcons. Deer remains, most frequently young animal limbs, were always found in the form of hacked-up body parts (11). Head of a fox (*Vulpes vulpes*) found in a box occupied by saker falcons. We may assume that this was another case of brought-in carrion (12).

Obr. 10 – 12. Samica sokola rároha priniesla posekaného zajaca usmrteného pri kosení trávnych porastov. Tento spôsob získavania koristi bol u sokolov rárohov pomerne častý (10). Časť useknutej končatiny srnca (*Capreolus capreolus*) v búdke obsadenej sokolom rárohom. Zbytky srnčej zveri, najčastejšie končatiny mláďat, boli náchádzané vždy v podobe posekaných častí tiel (12). Hlava líšky (*Vulpes vulpes*), nájdená v búdke obsadenej sokolom rárohom. Možno predpokladať, že aj v tomto prípade bol prinesený nález kadáveru (12).

Differences were also found in the composition of the food spectrum of individual pairs (Appendices 3–6). Some pairs in western Slovakia specialized in hunting black-headed gulls. In this part of the country remains of these gulls were found more frequently in the boxes of pairs nesting close to municipal rubbish dumps, where the gulls were regularly concentrated in large numbers. There was also an interesting find of remains from two yellow-legged gulls (*Larus michahellis*) in the box of a west Slovakian pair nesting near a rubbish dump visited by flocks of these gulls.

Discussion

Throughout the period between 1976 and 2016 we monitored the distribution of nesting sites of two saker falcon populations concentrated in upland areas and adjacent lowlands in western and eastern Slovakia. In the former area we recorded nesting by 56 pairs with a total of 516 nestings, and in the latter area we observed nesting by 32 pairs with a total of 246 nestings. The nesting success rates were similar in both regions, the pairs producing an average of 3.2 young in each successful nest. Altogether 1788 young saker falcons were raised in the monitored period as a whole.

We evaluated the results of collections of the falcons' food remains from 49 pairs in the area of western Slovakia in the period 1977 to 2016, and from 12 pairs in eastern Slovakia in the years 2009, 2010, 2015 and 2016. Altogether 17,669 prey items were identified. From 1980 onwards mammals (Mammalia, 19.8%, 24 species) became gradually less represented as a component in the falcons' diet compared with birds (Aves, 79.9%, 58 species). In areas of western Slovakia we found stable and predominant proportions of domestic pigeons ranging from 52% to 62%. The proportion of pigeons was distinctly lower in eastern Slovakia (31.5%), compensated for by larger shares of common vole, starling (*Sturnus vulgaris*), Eurasian magpie (*Pica pica*) and hooded crow (*Corvus cornix*). The common starling (9.5%) was a significant prey species in the lowlands of western and eastern Slovakia alike. Mammals were mostly represented by common voles (9.8%), European hamsters (5.3%), ground squirrels (2.1%) and hares (1.6%) (Tab. 1).

For comparison purposes we also made use of collections from two abandoned nests on rock outcrops in the Malé Karpaty Mts., which were occupied by saker falcons prior to 1975. Through comparison of prey compositions in individual time periods it is possible to track the changes connected with resettlement of the saker falcon population from the hills down into open countryside (Tab. 3). The indirect ordination diagram produced by PCA distinguished the food spectrum found before 1975 from the prey remains collected in later periods (Fig. 9). The period prior to 1975 was characterized by a relatively small share of the domestic pigeon (16.8%) and a higher proportion of wild pigeons *Columba oenas* and *C. palumbus*. Before 1975 there was substantially higher diversity of prey species (H‘ = 2.45) compared with the last 40 years, during which time the diversity index has ranged between 1.45 and 1.80, being indirectly dependent on the proportion of *C. livia* f. *domestica*. Declining from 66.5% to 55.0%. The share of domestic pigeons peaked in the decade 1990–1999, then gradually declined to a minimum in the period 2010–2016 (Tab. 2).

The change in nesting preferences among saker falcons and their shift from upland nesting sites into open agricultural country, where they make use of boxes and platforms on power line pylons for their nesting, may be explained by their high degree of flexibility and adaptation to new conditions. Their survival in the conditions of this country, however, was dependent on support from human management measures such as the creation of new nesting opportunities (Bagyura et al. 2010, Beran et al. 2012, Rahman et al. 2016). Potential areas were identified in lowland regions all around Slovakia, and altogether 350 nesting boxes were installed on electricity pylons where all pairs in both populations progressively resettled, and a new distribution of nesting sites and feeding territories was established. The upland areas of south-western and south-eastern Slovakia in fact belong among the historically familiar nesting areas of the saker falcon, where the first specific nest finds date from the second half of the 19th century. The core area in western Slovakia was the Malé Karpaty Mts. range, where nesting was first confirmed back in 1931 (Janda 1932) and further information about nest finds or observations of young flying from nests date from 1946, 1949, 1953, 1951 and 1954 (Brtek 1956, Matoušek 1956). Ferianc (1964) estimated the number of saker falcons in the Malé Karpaty Mts. during the 1950s and 60s at six pairs. The first nest in western Slovakia though was formally documented in the years 1885 and 1886, on the rock outcrop of Devín Castle near Bratislava. Nests were also found in the Danube wetland forests in 1928, 1933 and 1934 (Kunszt 1929, Matoušek 1933, Csiba 1959), and between 1951–1959 one or two pairs of saker falcons nested in the Šúr nature reserve near Bratislava, where specific nest finds were reported as well (Brtek 1956, Hell 1958a,b, Ferianc 1964). Later nesting was also confirmed in the Považský Inovec range (Hell, 1958a, b, Soviš & Šindár 1964, Varga 1969), the Strážovské vrchy Hills, the Biele Karpaty Mts. and Pohronský Inovec aMts. gain (Soviš & Šindár 1964). The first information about saker falcons nesting in eastern Slovakia (Slovenský kras Karst area) was published between the years 1860 and 1870 (Tschusi 1887). Further known data on nesting in that upland area date from 1931 (Lokcsánsky 1931), and then from 1951 and 1958 (Mošanský 1974). Nesting in eastern Slovakia was comprehensively researched by Mošanský (1974). According to his results, these falcons nested in the Slovenský kras Karst area and the Slanské and Volovské vrchy Mts. In the Slovenský kras Karst they occupied nests on rock outcrops, and in the Slanské vrchy Mts. they nested on rocks and in trees as well.

The great increase in numbers of nests on pylons indicates that lowland biotopes are still trophically attractive for saker falcons, despite the worsening state of diversity among food sources (Karp et al 2012). On the other hand we can state that their original nesting conditions have practically disappeared throughout Slovakia as a result of excessively intensive economic exploitation of their previous home habitats (Chavko & Deutschová 2012). An analogical situation of reduction in trophical and topical conditions, is becoming more and more serious in other European states as well (Donald et al. 2001, Butler et al. 2010, Vermouzek & Zámečník 2017). The installation of boxes on pylons has led to a clear improvement in nesting conditions for saker falcons across the intensively farmed lowlands (Zink & Izquierdo 2012, Chavko et al. 2014). As a result, the availability of food may now be considered as the most significant motivating factor for reproduction and successful nesting, which correlates directly with the range of nesting opportunities and the level of incidence of threats (especially human disturbance and bird-related criminality. The main reason for the falcons' resettlement however was the disappearance of most of the colonies of ground squirrel (Ambros 2008) within range of pairs nesting in the hills. Flying to and fro deep into the lowlands gathering food became too demanding and inefficient in terms of the birds' energy, which naturally led to resettlement closer to their food sources.

Analogical changes have also taken place in the nesting site distribution of the eastern imperial eagle (*Aquila heliaca*) in eastern Slovakia. Since 2016 all of the pairs have moved out of the hills and now nest solely in lowland agricultural areas (Danko 2016). In their case too the principal reason was probably the disappearance of the majority of ground squirrel colonies just below the uplands, so the imperial eagles were also forced to resettle deeper in the lowlands in agricultural country where the population of European hamsters was still preserved and poplar stands (mainly poplar windbreaks planted out in the 1960s) provided them with sufficient and suitable nesting places. Influence of the return and spread of peregrine falcons (*Falco peregrinus*) on the occupancy of original saker falcon nests has not been confirmed, and evidently did not influence the end of their nesting in the uplands either. It has been demonstrated that the first known pair of peregrine falcons took over a nest on a rock outcrop in the Malé Karpaty Mts. (after the last known nesting in 1977) as late as 1994 (Chavko 2008). In that year there were still six saker falcon pairs using tree nests in that range, and no interspecies territorial conflicts were observed. A similar situation also developed in the Slanské vrchy Hills and in the Slovak Karst, where several saker falcon nests on outcrops were occupied by peregrine falcons, but this happened at a time when the saker falcons were already using nesting boxes on pylons in the lowlands.

The success rate levels of 2.4 young per nest on average for all nests and 3.2 young per successful nest recorded in Slovakia are very similar to the levels reported in the surrounding countries (Bagyura et al. 2004, Beran et al. 2012). Differing parameters of the prey spectrum apparently do not significantly influence the nesting success rates, and it has been shown that nesting pair numbers and size of area of nesting distribution are influenced to a decisive degree by the sufficiency and range of prey during the reproduction season (Dixon 2009).

One of the significant negative factors which reduced saker falcons' nesting success rates in the past was nest robbery. The first information about nest robberies in the Malé Karpaty Mts. was published by Ferianc back in 1977, who stated that the impact of falconry and commercial interests had already led to stagnation in progress of the species, and that saker falcons had stopped nesting in the Malé Karpaty Mts. in 1973. During monitoring of the population studied in western Slovakia between the years 1976 and 2006 there were 28 recorded instances of suspected nest robbery (Appendix 7). The number of cases included only those involving pairs which had evidently nested, but the nests were later found empty with marks of climbing on the tree trunks. The real number of robberies was probably higher, because some nests may have been robbed early, just at the time of egg-laying, and we would not necessarily have discovered such cases. Our estimate is that between 1965 and 1999 as many as 175 nests were robbed (Chavko 2002a). The greatest threat due to nest robbery appeared after 1988, putting the survival of the saker falcon population itself at risk, as at that time it consisted of just 7–11 pairs. For this reason from 1991 till 1994 all occupied nests in the Malé Karpaty Mts. were physically guarded round the clock. This guarding was performed on shifts by hundreds of trained volunteers, mostly Czech and Slovak students. We recorded several attempts at robbery even of the guarded nests, but thanks to the well-organized nest protection the robbers did not succeed in taking anything at all. In the years immediately following the attempts stopped completely, and later there were only occasional cases. The last suspected robbery was recorded in 2006. We assume that this robbery ceased here mainly because after the dissolution of the Soviet Union, falconers' interest in young taken from the wild became focused on countries with populations of falcon species with greater body weight, for example Kazachstan (for more see Kovács et al., 2014), and moreover saker falcons were superseded in falconers' collections above all by peregrine falcons and gyrfalcons (*Falco rusticolus*) and cross-breeds of these. Large falcons (*Falco rusticolus*, *Falco peregrinus*, *Falco cherrug*) living in the wild are threatened mainly due to megalomaniac breeding by Arab falconers and the resulting commerce with birds, and by the involvement of raptor collectors from other countries (Levin 2000, 2008).

The most significant current threats to the maintenance of stability and nesting success rates within the saker falcon population in Slovakia may be considered as the environmentally inappropriate manner of intensive agricultural and forestry exploitation of the countryside, and then certain other kinds of bird-focused criminality, primarily illegal culling by shooting and poisoning. The problem is considerably exacerbated by the insufficient level of law enforcement and by the ignoring or lack of application of international conventions dealing with the protection of biotopes and endangered species.

The original biotopes of the saker falcon were grassland steppes, which have progressively given way to agricultural land-use, and practically disappeared in Slovakia after the 1950s and 60s with the exception of small areas of meadows and pasture land (Chavko 2002a). One of the consequences of the post-war changes in political orientation was a significant reform of the strategy of agricultural land-use. Political decisions on consolidation and collectivization produced large blocks of land adapted for mechanized farming, but resulting in unsuitable changes to biotopes, the effects of which persist to the present-day. We can state, therefore, that the saker falcon now nests and acquires its food in secondary, non-original and altered biotopes. These factors have also had significant impact on the diversity and numbers of the dominant prey species, causing a drop in both. The first species to disappear from the countryside was the ground squirrel, and recent years have also seen a decline in the common hamster. There has been considerable reduction in the small animal count as well, especially partridges, pheasants and hares (Bro et al. 2000, Newton 2004). The influence of chemical elimination of small, ground-based mammals has been particularly negative, above all of the common vole. It was not possible to precisely quantify the impact of poisoning in our research framework, but we definitely recorded the end of nesting by a specific pair of falcons in the Trnavská pahorkatina Uplands (western Slovakia) which had been nesting in the vicinity of around 200 hectares of lucerne fields with large numbers of common voles. We observed them hunting here, the male primarily hunting voles and taking them back to the young. In the very course of their nesting pesticide was applied against the voles, and nesting by this pair of falcons ceased in 2016. There has been particular impact on biodiversity and consequently also on quantity and range of prey due to extensive agriculture (Vermouzek 2017).

There is a persistent threat to the falcons from the dogma of the harmful influence or raptors on small animal species. There is a rising trend in finds of illegally killed raptors, which only intensifies the problem of growing vulnerability in the population of these birds. In all parts of Slovakia, with the exception of the built-up areas of towns and villages, people are intensively pursuing their hunting rights. In our monitored period between 1976 and 2016, above all in the lowlands, every year there were numerous instances of birds of prey being killed predominantly by illegal means, whether shooting, poisoning or trapping. Apart from serious injury, the use of lead shot also causes secondary poisoning, but illegal prey poisoning represents a more serious threat to the saker falcon (Kovács et al. 2014). All of the falcons' nesting areas in the lowlands are intensively used by hunters, and in most cases we encountered their incomprehension with regard to the importance and irreplaceability of raptors in our ecosystems (Deutschová et al. 2018). One case of poisoning, serious but by no means unique, was recorded in the Trnavská pahorkatina Uplands (south-western Slovakia) in March 2009, when in just one hunting ground 22 common buzzards (*Buteo buteo*), 4 saker falcons and 5 magpies were found poisoned. Domestic pigeons and hares were used as bait (Figs. 13, 14) contaminated with carbofuran. Additionally, several instances of harmed saker falcon individuals were recorded in western Slov-

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Figs. 13, 14. Finds of killed saker falcons and common buzzards (*Buteo buteo*). Veterinary examination confirmed the cause of death as carbofuran pesticide poisoning.

Obr. 13, 14. Nálezy usmrtených sokolov rárohov a myšiakov hôrnych (*Buteo buteo*). Veterinárnym vyšetrením bola potvrdená príčina úmrtia – otrávenie carbofuranom.

akia in which the use of poison was suspected, but it was not possible to specify the source or the cause of the poisoning. Our assumption is that poisoning and illegal shooting represent an essential threat to the stability of the west Slovakian saker falcon population and other mainly carrion-eating species of raptor. Furthermore, the large proportion of domestic pigeons in the saker falcon diet is establishing in them an increasingly dangerous dependence on this kind of prey, evoking unfriendly reactions among pigeon fanciers which may in future become a definite threat to sakers, similarly as for peregrine falcons already (Chavko 2002b).

During the course of the monitored period we recorded three deaths resulting from collisions with electric power lines. Lightning strikes on pylons caused the deaths of four young in one nesting box in western Slovakia, and a total of nine young in three boxes in the eastern part of the country. The greatest threat in this context however may be seen in short-circuits on the cross-bars of poles on 22 kV overground power lines, on which we recorded the deaths of 14 individuals altogether. These medium-voltage lines threaten the falcon population throughout Europe, with thousands of kilometres of power lines crossing all of their nesting and migrating territories (Chavko 2002a, Beran et al. 2012, Kovács et al. 2014). It may be assumed namely that the said finds are only an indication of the extent of bird injuries on power lines, and that the real mortality rate will be substantially higher. A considerable majority of killed individuals fails to be recorded, mainly because a large proportion of them tends to be removed by predators (*Vulpes vulpes*, *Meles meles*), so only a fraction of the true number of bird deaths is registered. Increased attention is being paid to this problem in Slovakia at the present time, as a result of which 62,000 power line pylons have been ecologized, around one third of which (18,000) stand in the home territories of the saker falcon (Gális et al. 2018, 2019).

Initial growth in the number of saker falcon nesting sites in Slovakia in the late 1980s later gave way to stagnation in the numbers of nesting pairs, which was probably linked with changes in the range and availability of prey. The greatest share of prey now consists of domestic pigeons, while species such as ground squirrel, hamster, vole, partridge and lapwing, which might compensate for seasonal or local lack of pigeons, are reduced to minimum availability as a result of environmentally inappropriate agricultural practices. The distinct drop in numbers of these species most likely underlies their reduced share in the falcons' diet during the first monitored nesting periods 1977–1989 and 1990–1999. This is probably a manifestation of the effect of the ongoing decline in biodiversity, and thus also of the decline in density of other species which are potential prey for the saker falcon. In eastern Slovakia the low number of nesting sites persists, which for a long time has not exceeded the annual frequency of 12 nesting pairs. Domestic pigeons are represented with a share of just 31.5% in the saker falcon diet in eastern Slovakia, i.e. one half of their share in the western part of the country. The availability of dominant prey species has also dropped considerably in eastern Slovakia, and the lack of small mammals is now equally serious, particularly the growing lack of ground squirrels as well as of common hamsters. Currectly prospering saker falcon pairs probably occupy only those biotopes which are viable from the points of view of prey availability and relative safety from predator threats, in this case mainly kleptoparasitism by the numerous population of imperial eagles in eastern Slovakia. The lack of suitable food meant that in nests of the east Slovakian population we found remains of small prey species apart from voles, for example also lizards (*Lacerta agilis*) and beetles (Coleoptera). The numbers of finds of small, land-based mammals, songbirds and other small creatures must be considered as clearly underestimated, however. After feeding there were only very small amounts of their remains left in the nests, and this also influenced the counts recorded. Very small prey was often totally consumed, and was then digested without remains in the birds' guts.

Similarly as in our study, higher incidence of birds in the falcons' diet is also found in certain other areas around Europe, for example in France, Croatia, the Czech Republic and Hungary (Kovács et al. 2014), but also in the Middle East (Izrael), or in China (Wu 2011), where the proportion of birds was found to be 52% (44% when recalculated as biomass). On the other hand, mammals are still a dominant diet component in Romania and Bulgaria (Baumgart 1971), and mainly in Asia. In central Kazachstan the red-cheeked ground squirrel (*Spermophilus erythrogenys*) and great gerbil (*Rhombomys opimus*) form the dominant component (together almost 50%) in the saker falcons' diet (Nedyalkov et al. 2014) These are medium-sized mammals like those which used to form the dominant diet component in Slovakia in the past (Chavko et al. 2014). Similar incidence of mammals (together up to 70%) is reported in Mongolia (Gombobaatar et al. 2006), of which the dominant prey is Brandt's vole (*Lasi-*

opodomys brandtii; equivalent to common vole in the conditions of central Europe). These data suggest that the saker falcon is a species which focuses primarily on hunting mammals, and it is a form of secondary feeding opportunism which has made it adapt to the local availability of prey, which in central European conditions means mainly pigeons (Balázs 2008, Papp & Balázs, 2010, Chavko & Deutschová 2012). Pigeons are otherwise known as the preferred prey during the winter months, when in the case of insufficient food in their nesting areas the falcons move to their wintering grounds where there are higher concentrations of prey (Baumgart 1991, Snow and Perrins 1998, Ferguson-Lees & Christie 2001), especially pigeons in the vicinity of larger towns and farms.

In western Slovakia we recorded specialization in hunting seagulls among some saker pairs, especially the black-headed gull (Chavko et al. 2014). Similar specialization was found by Horák (1998) in southern Moravia. The latter observed that the saker falcon hunted gulls in the fields, not in their nesting colonies. Moreover, food analysis results clearly indicated that some pairs acquired their food by picking up dead animals they had found, or by stealing them from other raptor species. These were above all animals which had been killed as a result of human activity, during mowing or harvesting, or by road traffic, but also by illegal poisoning, for example by deliberate poisoning of small, ground-based mammals as bait (Figs. 13, 14). It may be stated, therefore, that the saker falcon is to some extent a cadaverivorous species.

Kleptoparasitism was commonly observed in the monitored population as a way for the falcons to acquire food, similarly as is known in other areas where they occur (Braun & Lederer 1996, Kovács et al. 2014). In the course of nesting we saw individual parents take prey from common kestrels (*Falco tinnunculus*), western marsh harriers (*Circus aeruginosus*), common buzzards and other raptors. Young saker falcons having flown their nests also commonly attacked other raptor species, trying to take the prey they had hunted. On the other hand, we also recorded numerous instances of eastern imperial eagles, common buzzards, rough-legged buzzards (*Buteo lagopus*), northern goshawks (*Accipiter gentilis*) and white-tailed sea-eagles (*Haliaeetus albicilla*) snatching prey from saker falcons.

Moreover, we recorded one case of a common kestrel itself being hunted down, but without being consumed as food. In early May 2016 a male saker falcon was sitting by his nesting box with one of his young and noticed a kestrel fly up to its own box two pylons away. The falcon immediately took off and flew in attacking mode towards the rear of the kestrel's box, so as not to be observed. Then he made a sudden turn and managed to force the kestrel into the box (Fig. 15). After a moment he flew out of the box again carrying the lifeless kestrel in his claws, but after about 30 metres he dropped the corpse on the ground and paid no more attention to it. It is interesting that the falcon did not take his catch back to his young. This was most likely a case of territorial behaviour, as kestrels often nastily harass saker falcons during the course of their nesting, and this may have given rise to the falcon's interest in ridding his brood of the kestrel's presence.

During the period 1976–2016 in western Slovakia and the period 1979–2016 in the eastern part of the country, we recorded nesting by a great majority of all the monitored pairs of saker falcons (we estimate that we checked practically all the pairs, in any case roughly 95–97% of nestings in the whole population). In western Slovakia we monitored nesting by 56 pairs, and between the years 1976 and 2016 we recorded a total of 514 nestings. In eastern Slovakia between the years 1979 and 2016 we recorded nesting by 32 pairs, and in the monitored period we recorded altogether 245 nestings there.

In conclusion we can briefly state the following: we have described the process and course of changes in the saker falcons' preferred nesting habitats in two geographical areas within Slovakia, and the move of the


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Fig. 15. Attack by a male saker falcon on a common kestrel in which the death of the kestrel was recorded, although the attack was not associated with prey-hunting behaviour.

Obr. 15. Útok samca sokola rároha na sokola myšiara. Zdokumentované bolo usmrtenie sokola myšiara, pričom lov nesúvisel s potravovým správaním.

nesting population from the hills and wetlands into agricultural countryside. We have compared the reproductive success rate among pairs nesting in trees and on rock outcrops with that achieved by pairs nesting in boxes and on platforms on power line pylons amidst farmland. We found significantly higher success rates among saker falcons nesting in agricultural country compared to those nesting in the uplands, with similar results in both monitored geographical areas (western and eastern Slovakia). In agricultural country an average of 81.1% of all nests were successful, producing on average 2.7 young per nest overall, or 3.3 young per successful nest. In the uplands on average 1.7 young flew from each nest overall, or 2.9 young per successful nest, with an overall success rate of just 57.1% nests.

We have compared the spectrum of prey hunted by saker falcons going back over the past 40 years and more within the monitored nesting areas of the Slovakian saker population, and also compared the range of prey with regard to the different orographic areas within Slovakia. We found that from 1980 onwards mammals (Mammalia) as a component of the falcons' diet became progressively less important than birds. The most frequently hunted prey species was the domestic pigeon, the incidence of which in the food spectrum amounted to 57% on average during the monitored period as a whole. There were also relatively frequent catches of starlings, common voles and hamsters. Together with the move of nesting pairs into the agricultural lowlands there occurred a change in the falcons' preference for certain species of mammal, with others assuming higher proportions in the falcons' diet. We also found differences in the diet composition of nesting falcons between the eight orographic areas studied in western and eastern Slovakia, as well as between the five subdivided time spans making up the whole monitored period when comparing the individual orographic areas. Whereas the common pigeon was clearly the highest represented prey species in the falcons' diet in all types of nesting biotope, in western Slovakia they hunted approximately double the number of pigeons compared with eastern Slovakia, where their lower share was compensated for with a higher incidence of the common vole. From all the pairs of saker falcon in the monitored period as a whole we gathered 17,669 samples of prey from 56 pairs (40 nesting in lowland agricultural country, and 16 in upland and wetland forest areas).

The results of our identification of the range of threats faced by saker falcons demonstrate that in the interests of sustainability of the population it is necessary to accept that they are dependent on human management measures, especially the creation, restitution and maintenance of sufficient numbers of nesting boxes, as well as restoration of the former diversity among the falcons' original sources of prey, and diminution of the impact of human criminality.

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Appendix 1. Survey of development parameters for the west Slovakian population of saker falcon; the distribution of pairs based on codes is presented on the map in Fig. 6.

Príloha 1. Prehľad parametrov vývoja západoslovenskej populácie sokola rároha, distribúcia párov podľa kódov je uvedená na mape na obr. 6. Biotop: mountains = pohoria, agrocenosis = agrocenóza, floodplain forest = lužný les.

pair No. / pár č.	**orographic unit / orografický celok**	**biotope / biotop**	**No.of breeding attempts / n všetkých hniezdení**	**No. of successful nesting / n úspešných hniezdení**	**No. of juveniles / n vyvedených mláďat**	**avg. No. of juveniles per successful breeding / priemerný n mláďat na úspešné hniezdenie**	**avg. No. of juveniles per all breeding attempts / priemerný n mláďat na všetky hniezdenia**	**breeding period / zaznamenané obdobie hniezdenia**	**number of collections / počet sezón zberov vzoriek**
1	Malé Karpaty	mountains	13	6	15	2.5	1.2	1976–1987	9
1	Podunajská rovina	floodplain forest	4	1	2	2.0	0.5	1988–1990, 1993	2
2	Malé Karpaty	mountains	17	7	21	3.0	1.2	1977–1980, 1982, 1983, 1985–1991, 1994, 1995	10
2	Borská nížina	agrocenosis	11	9	28	3.1	2.5	2003–2013	9
3	Malé Karpaty	mountains	5	3	8	2.7	1.6	1978, 1979, 1981, 1982, 1991	3
4	Malé Karpaty	mountains	4	0	0	0.0	0.0	1978–1981	1
5	Malé Karpaty	mountains	25	19	56	2.9	2.2	1978–1996, 1998–2002	16
5	Trnavská pahorkatina	agrocenosis	6	3	11	3.7	1.8	2004, 2006, 2008–2011	4
6	Malé Karpaty	mountains	18	12	37	3.1	2.1	1979–1984, 1988, 1989, 1991–2000	9
7	Malé Karpaty	mountains	14	10	25	2.5	1.8	1979, 1981–1983, 1985–1991, 1993–1995	6
8	Malé Karpaty	mountains	25	14	49	3.5	2.0	1980, 1982–1990, 1994, 1995, 1997–2005, 2007, 2008	17
8	Podunajská rovina	agrocenosis	6	5	15	3.0	2.5	2006, 2009–2012, 2016	3
9	Malé Karpaty	mountains	17	11	28	2.5	1.6	1980, 1983, 1984, 1986, 1991–1995, 1997–2002, 2006, 2007	10
10	Malé Karpaty	mountains	6	6	23	3.8	3.8	1981–1983, 1990, 1998, 1999	4
10	Trnavská pahorkatina	agrocenosis	18	16	57	3.6	3.2	1997, 2000–2016	14
11	Malé Karpaty	mountains	10	7	20	2.9	2.0	1982, 1983, 1985–1987, 1989, 2000–2003	6
12	Burda	mountains	7	5	16	2.8	2.3	1992–1994, 1996–2001	4
13	Strážovské vrchy	mountains	15	8	24	3.0	1.6	1979, 1981–1994	0
14	Borská nížina	floodplain forest	6	1	2	2.0	0.3	1991, 1993, 1998–2001	1
15	Borská nížina	floodplain forest	5	3	10	3.3	2.0	1991–1995	3
16	Borská nížina	floodplain forest	3	2	7	3.5	2.3	1992, 1993, 1997	1
17	Borská nížina	agrocenosis	16	15	46	3.1	2.9	1988, 1993–2007	13
18	Dolnomoravský úval	floodplain forest	1	1	3	3.0	3.0	1993	0
19	Podunajská rovina	agrocenosis	4	3	7	2.3	1.8	1994–1997	3
20	Podunajská rovina	agrocenosis	13	13	49	3.8	3.8	1999–2011, 2016	9
21	Podunajská rovina	agrocenosis	18	16	54	3.4	3.0	1999–2016	14
22	Podunajská rovina	agrocenosis	15	15	56	3.7	3.7	2001–2004, 2006–2016	12
23	Trnavská pahorkatina	agrocenosis	4	4	14	3.5	3.5	2001, 2010, 2014	3
24	Trnavská pahorkatina	agrocenosis	13	13	43	3.4	3.3	2002, 2003, 2006–2016	11
25	Nitrianska pahorkatina	agrocenosis	6	4	14	3.5	2.3	2002, 2008, 2009, 2011–2013	3
26	Podunajská rovina	agrocenosis	8	7	19	2.7	2.4	2003, 2005, 2008, 2012–2016	6

Appendix 1. Continuation.
Príloha 1. Pokračovanie.

pair No. / pár č.	orographic unit / orografický celok	biotope / biotop	No.of breeding attempts / n všetkých hniezdení	No. of successful nesting / n úspešných hniezdení	No. of juveniles / n vyvedených mláďat	avg. No. of juveniles per successful breeding / priemerný n mláďat na úspešné hniezdenie	avg. No. of juveniles per all breeding attempts / priemerný n mláďat na všetky hniezdenia	breeding period / zaznamenané obdobie hniezdenia	number of collections / počet sezón zberov vzoriek
27	Trnavská pahorkatina	agrocenosis	13	8	27	3.4	2.1	2003–2011, 2013–2016	8
28	Trnavská pahorkatina	agrocenosis	12	9	38	4.2	3.2	2004, 2005, 2007–2016	7
29	Nitrianska pahorkatina	agrocenosis	10	8	33	4.1	3.3	2004, 2008–2016	7
30	Podunajská rovina	agrocenosis	5	3	9	3.0	1.8	2003, 2011–2013, 2015	1
31	Trnavská pahorkatina	agrocenosis	13	10	27	2.7	2.1	2005–2016	8
32	Ipeľská pahorkatina	agrocenosis	2	1	2	2.0	1.0	2005, 2006	0
33	Trnavská pahorkatina	agrocenosis	2	0	0	0.0	0.0	2005, 2006	0
34	Trnavská pahorkatina	agrocenosis	9	7	28	4.0	3.1	2008–2016	7
35	Borská nížina	agrocenosis	7	5	11	2.2	1.6	2007–2013	3
36	Nitrianska pahorkatina	agrocenosis	10	9	30	3.3	3.0	2007–2016	8
37	Podunajská rovina	agrocenosis	9	9	32	3.6	3.6	2008–2016	7
38	Trnavská pahorkatina	agrocenosis	8	7	21	3.0	2.6	2009–2016	4
39	Trnavská pahorkatina	agrocenosis	3	2	8	4.0	2.7	2009–2011	2
40	Trnavská pahorkatina	agrocenosis	7	6	18	3.0	2.6	2009–2012, 2015, 2016	5
41	Borská nížina	agrocenosis	8	7	23	3.3	2.9	2009–2016	5
42	Borská nížina	agrocenosis	1	0	0	0.0	0.0	2009	0
43	Podunajská rovina	agrocenosis	7	4	14	3.5	2.0	1997, 2007, 2010, 2011, 2013–2015	1
44	Podunajská rovina	agrocenosis	7	6	20	3.3	2.9	2010–2016	5
45	Podunajská rovina	agrocenosis	7	7	20	2.9	2.9	2010–2016	6
46	Trnavská pahorkatina	agrocenosis	6	4	15	3.8	2.5	2010–2015	6
47	Borská nížina	agrocenosis	1	0	0	0.0	0.0	2010	0
48	Podunajská rovina	agrocenosis	10	8	35	4.4	3.5	2004–2012, 2016	6
49	Nitrianska pahorkatina	agrocenosis	7	7	21	3.0	3.0	2007, 2010–2012, 2014–2016	6
50	Trnavská pahorkatina	agrocenosis	4	2	6	3.0	1.5	2011–2014	2
51	Podunajská rovina	agrocenosis	2	0	0	0.0	0.0	2011, 2014	0
52	Nitrianska pahorkatina	agrocenosis	5	2	5	2.5	1.0	2011–2015	2
53	Borská nížina	agrocenosis	1	0	0	0.0	0.0	2012	0
54	Podunajská rovina	agrocenosis	3	2	7	3.5	2.3	2011, 2015, 2016	1
55	Podunajská rovina	agrocenosis	1	1	2	2.0	2.0	2016	1
56	Trnavská pahorkatina	agrocenosis	1	0	0	0.0	0.0	2015	0
∑			514	373	1211	3.2	2.4		314

Appendix 2. Survey of development parameters for the east Slovakian population of saker falcon; the distribution of pairs based on codes is presented on the map in Fig. 7.
Príloha 2. Prehľad parametrov vývoja východoslovenskej populácie sokola rároha, distribúcia párov podľa kódov je uvedená na mape na obr. 7. Biotop: mountains = pohoria, agrocenosis = agrocenóza, floodplain forest = lužný les.

pair No. / pár č.	**orographic unit / orografický celok**	**biotope / biotop**	**No.of breeding attempts / n všetkých hniezdení**	**No. of successful nesting / n úspešných hniezdení**	**No. of juveniles / n vyvedených mláďat**	**avg. No. of juveniles per successful breeding / priemerný n mláďat na úspešné hniezdenie**	**avg. No. of juveniles per all breeding attempts / priemerný n mláďat na všetky hniezdenia**	**breeding period / zaznamenané obdobie hniezdenia**	**number of collections / počet sezón zberov vzoriek**
1	Slovenské rudohorie	mountains	1	0	0	0.0	0.0	1979	0
2	Slánske vrchy	mountains	3	1	1	1.0	0.3	1979–1981	0
3	Slovenské rudohorie	mountains	1	2	1	2.0	2.0	1979	0
4	Slovenský kras	mountains	9	3	1	3.0	0.3	1980, 1984–1986, 1988, 1990–1992, 1995	0
5	Slovenské rudohorie	mountains	1	0	0	0.0	0.0	1981	0
6	Slovenský raj	mountains	1	4	1	4.0	4.0	1982	0
7	Slovenský kras	mountains	1	2	1	2.0	2.0	1986	0
8	Slovenský kras	mountains	9	11	6	1.8	1.2	1986–1990, 1992–1995	0
9	Košická kotlina	agrocenosis	14	43	12	3.6	3.0	1986–1999	0
10	Košická kotlina	agrocenosis	26	84	22	3.9	3.2	1991–2016	2
11	Košická kotlina	agrocenosis	25	77	21	3.7	3.0	1992–2016	1
12	Košická kotlina	agrocenosis	7	12	4	3.0	1.7	2006, 2008–2013	0
13	Košická kotlina	agrocenosis	21	68	19	3.6	3.2	1996–2016	0
14	Košická kotlina	agrocenosis	16	26	10	1.3	0.8	1996, 1998–2012	0
15	Slanské vrchy	mountains	1	0	0	0.0	0.0	1996	0
16	Východoslovenska rovina	agrocenosis	20	51	17	3.0	2.5	1997–2016	2
17	Východoslovenska rovina	agrocenosis	19	37	13	2.8	1.9	1997–2006, 2008–2016	2
18	Východoslovenska rovina	agrocenosis	4	10	3	3.3	2.5	1998, 2004, 2014–2015	1
19	Košická kotlina	agrocenosis	16	36	10	3.2	2.0	1998–2013	0
20	Slovenský kras	agrocenosis	3	3	1	3.0	1.0	1999, 2001–2002	0
21	Východoslovenska rovina	agrocenosis	2	2	2	1.0	1.0	2002, 2013	0
22	Slanské vrchy	agrocenosis	1	4	1	4.0	4.0	2003	0
23	Východoslovenska rovina	agrocenosis	11	25	9	2.8	2.3	2003–2010, 2014–2016	3
24	Východoslovenska rovina	agrocenosis	5	12	4	3.0	2.4	2006–2007, 2009, 2011–2012	1
25	Východoslovenska rovina	agrocenosis	11	33	9	3.7	3.0	2005, 2007–2016	2
26	Východoslovenska rovina	agrocenosis	1	0	0	0.0	0.0	2008	0
27	Východoslovenska rovina	agrocenosis	3	1	1	1.0	0.3	2008–2010	0
28	Východoslovenska rovina	agrocenosis	1	4	1	4.0	4.0	2016	1
29	Košická kotlina	agrocenosis	6	12	4	2.5	1.7	2009–2014	0
30	Východoslovenska rovina	agrocenosis	1	3	1	3.0	3.0	2010	0
31	Východoslovenska rovina	agrocenosis	3	7	3	2.3	2.3	2011–2013	0
32	Košická kotlina	agrocenosis	2	1	1	1.0	0.5	2015–2016	0
∑			245	574	179	3.2	2.3		15

Appendix 3. Saker falcon diet diet in the Malé Karpaty Mts. and Burda Mts. Pairs no. 1, 2, 5, 6, 7, 8, 9, 10 and 11. Malé Karpaty Mts.; pair no. 12. Burda Mts. Mts. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g. 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods).

Príloha 3. Potrava sokola rároha v pohoriach Malé Karpaty a Burda. Páry č. 1, 2, 5, 6, 7, 8, 9, 10 a 11: Malé Karpaty, pár č. 12: Burda. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku).

years / roky	**78–11**	**81–16**	**80–16**	**78–93**	**77–13**	**82–03**	**79–95**	**92–01**	**80–07**	**79–00**		
No. of seasons / N sezón	**27**	**20**	**22**	**10**	**21**	**8**	**7**	**9**	**15**	**10**		
taxa / taxón // pair no. / pár č.	**5**	**10**	**8**	**1**	**2**	**11**	**7**	**12**	**9**	**6**	∑	**%**
Sciurus vulgaris	1+ 8							1	1		10	0.25
Cricetus cricetus	1+ 46	1+ 51	23	1- 0	2- 2	8	4	1- 1	6	3	144	3.60
Streptopelia turtur	1+ 14	1- 2	6	2	9		1	1	1+ 8	3	46	1.15
Microtus arvalis	20	1+ 98	2- 5	1- 0	18	1- 1	1- 0	1- 1	7	1- 1	151	3.77
Spermophilus citellus	2- 10	3- 9	2+ 132	1+ 16	1+ 47	1- 2	4	8	1- 4	1- 3	235	5.87
Columba oenas	14	1- 10	1+ 40		7	5		1	7	3	87	2.17
Perdix perdix	10	20	1- 5	2+ 22	13		4	1	5	3	83	2.70
Phasianus colchicus	1- 1	1- 5	1- 4	3	2+ 30		3	1	2		49	1.22
Vanellus vanellus	10	1- 2	1- 1	3	1+ 13	1+ 7	5	1		1	43	1.70
Sturnus vulgaris	66	87	2- 32	14	1+ 91	18	1+ 22	1+ 23	1+ 48	21	422	10.54
Coccothraustes coccothr.			1		2				1+ 7		10	0.25
Columba livia dom. (n)	443	664	527	1- 61	1- 273	125	56	95	1- 107	135	2,486	62.10
%	65.63	65.61	64.74	48.80	50.09	69.83	51.38	64.19	50.00	74.18		
Columba palumbus	4	8	8		5			3		1	29	0.72
Lepus europaeus	5	11	3	1	7				1		28	0.70
Chroicocephalus ridibundus	4	10	1		5			1	1		22	0.55
Turdus philomelos	1	1	2		5	4	3		2		18	0.45
Coturnix coturnix	2	4	5		1		1		1		14	0.35
Alauda arvensis	2	3	3		4					1	13	0.32
Streptopelia decaocto	3	1	1		3			1	1	1	11	0.27
Turdus merula	1		1		3		4	2			11	0.27
Garrulus glandarius	3	4			1				1		9	0.22
Pica pica		1	3			2			1		7	0.17
Corvus frugilegus			3		1	1				2	7	0.17
Mammalia	**92**	**174**	**1+ 164**	**17**	**74**	**1- 11**	**1- 9**	**1- 13**	**1- 20**	**1- 9**	**583**	**14.56**
Aves	**583**	**838**	**650**	**108**	**471**	**168**	**100**	**135**	**194**	**173**	**3,420**	**85.44**
∑	**675**	**1012**	**814**	**125**	**545**	**179**	**109**	**148**	**214**	**182**	**4,003**	**100.00**
Diversity Index H'	1.48	1.42	1.36	1.56	1.84	1.23	1.66	1.42	1.76	1.10	1.64	

Appendix 4. Saker falcon diet in the Podunajská rovina Plain. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g. 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods).

Príloha 4. Potrava sokola rároha v Podunajskej rovine. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku).

years / roky	**10–16**	**11–16**	**78–16**	**10–16**	**04–16**	**99–16**	**01–16**	**03–16**	**99–16**	**08–16**		
No. of seasons / N sezón	**6**	**3**	**14**	**7**	**7**	**16**	**14**	**7**	**10**	**8**		
taxa / taxón // pair no. / pár č.	**44**	**54**	**others**	**45**	**48**	**21**	**22**	**26**	**20**	**37**	**∑**	**%**
Columba livia dom. (n)	1+ 281	72	159	1- 179	1- 211	621	484	1- 158	200	319	2,684	60.13
%	84.89	56.25	58.67	49.18	43.87	66.99	61.11	44.76	68.26	60.88		
Sturnus vulgaris	22	1+ 17	1+ 27	1+ 38	1- 19	54	50	27	15	31	300	6.72
Streptopelia turtur			1+ 6		4	2	3	4	1	1	21	0.47
Chroicocephalus ridibundus	1- 1		1+ 14	2+ 35	2+ 38	3- 1	2- 2	1- 2	1- 0	8	101	2.26
Microtus arvalis	2- 3	4	18	2+ 72	2- 7	50	1- 31	17	17	25	244	5.47
Phasianus colchicus	1- 5	4	1- 4	1- 5	1+ 47	38	42	10	8	20	183	4.10
Vanellus vanellus	3		4	3	1+ 8	1- 1	1- 1	1	1	8	30	0.67
Perdix perdix	1- 1	1	4	1- 0	2+ 28	1+ 30	1- 7	1- 0	3	1- 3	77	1.72
Lepus europaeus	6	3	5	1- 1	1+ 18	1+ 25	1- 7	3	4	7	79	1.77
Columba palumbus	2- 0	6	1- 1	1- 3	2+ 46	1- 18	1+ 40	9	5	12	140	3.14
Columba oenas	1- 3	9	9	1- 4	25	30	1+ 51	1+ 24	8	15	178	3.99
Spermophilus citellus	1- 0		1- 2	2- 0	2- 1	2- 4	23	3+ 76	1- 0	2- 0	106	2.37
Cricetus cricetus	1- 2	8	1- 3	1- 5	16	1- 25	30	1- 4	1+ 18	2+ 56	167	3.74
Coturnix coturnix	1	1		3	4	6	9	1		2	27	0.60
Streptopelia decaocto		1	1	1	1	1	2	2		5	14	0.31
Alauda arvensis	1		4		2	5					12	0.27
Nyctalus noctula	1		1	3				3		2	10	0.22
Pica pica					1	3	1			3	8	0.18
Talpa europaea			1	1	1		1	2			6	0.13
Passer montanus			1	1			1	1	1	1	6	0.13
Falco tinnunculus			3						2		5	0.11
Mammalia	**2- 12**	**15**	**33**	**1+ 86**	**1- 44**	**109**	**93**	**1+ 106**	**42**	**91**	**629**	**14.13**
Aves	**319**	**113**	**240**	**278**	**437**	**818**	**698**	**1- 247**	**250**	**432**	**3,832**	**85.84**
Reptilia	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**3**	**0.07**
∑	**331**	**128**	**273**	**364**	**481**	**927**	**792**	**353**	**293**	**524**	**4,466**	**100.00**
Diversity Index H'	0.72	1.59	1.71	1.68	2.3	1.44	1.59	1.87	1.39	1.59	1.74	

Appendix 5. Saker falcon diet in the Trnavská pahorkatina Uplands. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g. 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods).

Príloha 5. Potrava sokola rároha v Trnavskej pahorkatine. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku).

years / roky	**11–14**	**09–16**	**01–14**	**10–15**	**05–16**	**09–11**	**04–16**	**08–16**	**09–16**	**02–16**	**03–16**		
No. of seasons / N sezón	**3**	**6**	**3**	**4**	**10**	**2**	**8**	**9**	**5**	**13**	**9**		
taxa / taxón // pair no. / pár č.	**50**	**40**	**23**	**46**	**31**	**39**	**28**	**34**	**38**	**24**	**27**	∑	%
Columba livia dom. (n)	1+ 117	1+ 339	1+ 238	196	187	1- 52	292	397	1- 82	1- 280	198	2,378	56.48
%	82.98	76.18	74.14	61.64	55.00	36.88	55.20	66.28	34.02	38.10	55.00		
Columba palumbus	1	16	1+ 22	1+ 15	12	5	1- 6	15	5	1- 5	8	110	2.61
Columba oenas	1	1+ 15	7	5	1+ 17	4	7	1- 4	5	1- 8	5	78	1.85
Phasianus colchicus	1	20	2- 0	7	1+ 27	1+ 12	20	25	5	1- 6	1- 5	128	3.04
Perdix perdix	1	2- 0	1- 1	2	1+ 14	1+ 13	1+ 20	1- 2	1	17	2	73	1.73
Chroicocephalus ridibundus			4	1			1+ 8	1+ 8		1- 0	2	23	0.55
Streptopelia decaocto		1		2	2	1		1+ 11		1	1	19	0.45
Cricetus cricetus	10	44	1- 21	23	1- 15	1+ 37	1- 24	1+ 79	1+ 59	64	28	404	9.60
Nyctalus noctula				3	1		1		2+ 13	4	2	24	0.57
Lepus europaeus	2	13	4	9	5	7	12	9	1+ 10	1- 5	10	86	2.04
Sturnus vulgaris	3	1- 6	1- 4	11	16	1- 0	1- 15	22	1+ 19	1+ 49	1+ 31	176	4.18
Microtus arvalis	2- 3	1- 23	1- 19	1- 25	1- 22	1- 5	1+ 118	2- 15	31	1+ 227	60	548	13.02
Pica pica		1- 0		3	1- 0	2	1- 0	1- 0		2+ 46	1- 0	51	1.21
Garrulus glandarius				1	2			1		1+ 8		12	0.29
Coturnix coturnix				4	3		1	5		3	2	18	0.43
Vanellus vanellus	1	1		2	5		1			2		12	0.29
Alauda arvensis		2			1		1	2	2	1	1	10	0.24
Talpa europaea				1			1	1	4			7	0.17
Streptopelia turtur				2	2				2	1		7	0.17
Turdus merula					2			1	2			5	0.12
Mammalia	**1- 15**	**1- 81**	**1- 44**	**1- 62**	**1- 43**	**1+ 50**	**156**	**1- 104**	**1+ 117**	**1+ 304**	**101**	**1,077**	**25.58**
Aves	**126**	**404**	**277**	**256**	**297**	**91**	**373**	**494**	**1- 124**	**1- 431**	**259**	**3,132**	**74.39**
Amphibia	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0.02**
∑	**141**	**485**	**321**	**318**	**340**	**141**	**529**	**599**	**241**	**735**	**360**	**4,210**	**100.00**
Diversity Index H'	0.78	1,23	1,03	1,62	1,82	1,84	1,49	1,34	1,94	1,75	1,56	1,68	

Appendix 6. Saker falcon in the Borská nížina Lowlands and Nitrianska pahorkatina Uplands. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g. 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods).

Príloha 6. Potrava sokola rároha v Borskej nížine a Nitrianskej pahorkatine. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku).

years / roky	**07–13**	**09–16**	**92–00**	**88–07**	**11+15**	**07–16**	**04–16**	**07–16**	**02–13**		
No. of seasons / N sezón	**5**	**7**	**8**	**15**	**2**	**9**	**8**	**7**	**4**		
taxa / taxón // pair no. / pár č.	**35**	**41**	**14–16**	**17**	**52**	**36**	**29**	**49**	**25**	∑	%
Chroicocephalus ridibundus	3+ 31			1- 0		2	1- 0	1- 0		33	1.11
Spermophilus citellus		1+ 13	1+ 6			4	1- 0			23	0.78
Sturnus vulgaris	33	1+ 56	1+ 36	1- 41	28	1- 34	100	82	27	437	14.73
Phasianus colchicus	6	8	1+ 15	1+ 28	1- 1	2- 3	20	12	8	101	3.41
Perdix perdix	1			1+ 12	1	3	2	4	1	24	0.81
Columba palumbus		2		1+ 9	1+ 10	3	4	1		29	0.98
Columba oenas	2	3	2	1+ 18	2+ 19	16	1- 6	1- 4	1- 0	70	2.36
Lepus europaeus	1	5	6	1- 1	9	1+ 21	12	11	6	72	2.43
Cricetus cricetus	1- 0	1- 3	1- 1	2- 0	10	1+ 45	1+ 42	14	6	121	4.08
Talpa europaea		1				3	1+ 11	1	1	17	0.57
Microtus arvalis	2- 2	24	1- 4	2- 10	12	39	1+ 62	1+ 84	18	255	8.60
Columba livia dom. (n)	115	162	80	252	1- 64	360	248	1- 200	147	1,628	54.89
%	59.90	55.67	48.78	65.28	37.21	65.57	45.50	44.94	66.52		
Streptopelia decaocto				3	3	3	4	3		16	0.54
Vanellus vanellus		1	3		1		2	6		13	0.44
Nyctalus noctula		1				2	6	3	1	13	0.44
Turdus philomelos		2	2	2			1	2	2	11	0.37
Coturnix coturnix		2	2	1		1	1	2	1	10	0.34
Alauda arvensis		2			1	1	1	2	2	9	0.30
Turdus merula		1	2	1	2	1	1			8	0.27
Garrulus glandarius					4		4			8	0.27
Mus cf. musculus						1	3	3		7	0.24
Passer montanus					1		2	2		5	0.17
Pica pica					2		3			5	0.17
Mammalia	**3- 3**	**49**	**1- 17**	**2- 13**	**31**	**116**	**1+ 139**	**1+ 117**	**32**	**517**	**17.40**
Aves	**189**	**241**	**151**	**373**	**141**	**432**	**406**	**329**	**189**	**2,446**	**82.50**
Reptilia, Pisces	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**3**	**0.10**
∑	**192**	**291**	**169**	**386**	**172**	**549**	**545**	**446**	**221**	**2,966**	**100.00**
Diversity Index H'	1.19	1.56	1.71	1.36	2.10	1.42	1.88	1.78	1.26	1.77	

Appendix 7. Survey of suspected saker falcon nest robberies in western Slovakia 1976–2006.
Príloha 7. Prehľad podozrení vykrádania hniezd sokola rároha na západnom Slovensku v 1976 – 2006.

year / rok	No. of breeding pairs / n hniezdiacich párov /	No. of successfull breeding pairs / úspešne vyhniezdilo /	No. of robbed nests / n vykradnutých hniezd	pair no. / pár č.
1976	1	0	1	1
1977	2	1	0	
1978	5	2	0	
1979	8	5	1	13
1980	7	1	1	1
1981	8	6	1	13
1982	10	9	0	
1983	11	8	2	6, 8
1984	7	3	1	13
1985	8	4	2	1, 8
1986	8	5	1	1
1987	7	3	0	
1988	9	5	3	2, 8, 13
1989	9	3	4	1, 2, 5, 13
1990	7	2	4	1, 5, 7, 13
1991	9	3	1	13
1992	8	7	0	
1993	12	6	1	14
1994	12	6	0	
1995	9	7	0	
1996	5	4	0	
1997	9	6	0	
1998	8	7	0	
1999	10	9	0	
2000	12	11	0	
2001	12	8	2	12, 21
2002	11	9	0	
2003	12	10	0	
2004	12	9	1	5
2005	13	11	0	
2006	15	11	2	5, 21
∑	276	181	28	

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Long-eared owls roosted in the forest, still hunted in open land

Myšiarky ušaté zimovali v lese, stále lovili v otvorenej krajine

Filip TULIS, Michal ŠEVČÍK & Ján OBUCH

Abstract: Long-eared owls' winter roosts located within forest, compared to their winter roosts in human settlements, often escape human attention. Only minimum information has been published about winter roosts located deep in the forest. During the years 2005 to 2016, we collected long-eared owl pellets at irregularly occupied forest winter roosts. Compared to the diet at winter roosts in human settlements, the long-eared owls roosting in the forest surprisingly significantly more frequently hunted the common vole. Moreover, we did not record higher consumption of forest mammal species in the diet of owls at forest winter roosts. Long-eared owls roosting in human settlements hunted significantly more birds. The results show that, despite the location of deep forest winter roosts, long-eared owls preferred hunting the common vole, i.e. hunting in open agricultural land. The study also points out the lack of knowledge about winter roosts located deep in the forest.

Abstrakt: Zimoviská myšiarok ušatých situované v lesoch v porovnaní so zimoviskami v blízkosti ľudských obydlí často unikajú ľudskej pozornosti. O zimoviskách hlboko v lese bolo dodnes publikovaných minimum informácií. V priebehu rokov 2005 až 2016 sme na nepravidelne obsadených lesných zimoviskách zbierali vývržky myšiarok ušatých. V porovnaní s potravou zo zimovísk v blízkosti ľudských obydlí, myšiarky zimujúce v lese lovili preukazne viac hraboša poľného. V potrave v lesných zimoviskách sme však nezaznamenali vyššiu konzumáciu lesných druhov cicavcov. Myšiarky zimujúce v blízkosti ľudských obydlí naopak lovili preukazne viac vtáky. Výsledky poukazujú, že aj napriek situovaniu zimovísk hlboko v lese, myšiarky preferovali lov hraboša poľného, teda lov v otvorenej poľnohospodárskej krajine. Práca tiež poukazuje na nedostatok informácii o zimovískách situovaných hlboko v lesných porastoch.

Key word: *Asio otus*, pellets, diet, winter roost, forest

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Introduction

Food availability and weather conditions are factors which affect over-wintering birds' survival (Lahti et al. 1998, Robinson et al. 2007). The selection of roosting-place plays an important role in protection against predators (Sunde et al. 2003) and minimisation of thermoregulation cost (Körtner & Geiser 1999). The localisation of birds' roosting-places does not strictly predict the localisation of their feeding sites (Caccamise & Morrison1988, Hill & Frederick1997).

Aggregation to communal winter roosts is a typical phenomenon for long-eared owls during the non-breeding season. The process of winter roost creation is still not quite clear. According to Wijnands (1984), in the beginning the roosts are formed by adult pairs and their juveniles. However molecular analyses have revealed that only some individuals in the wintering flock are closely related (Galeotti et al. 1997a). The number of wintering owls varies from several to dozens of individuals (Winjands 1984, Škorpíková et al. 2005, Noga 2007, Makarova & Sharikov 2015, a.o.). The largest winter roost of approximately 750 owls was recorded in 2009 in Serbia (Radišić 2010). The number of wintering owls in the conditions of central Europe is affected by the abundance of common vole *Microtus arvalis* (Grzędzicka 2014, Tulis et al. 2015a), the most frequently preyed species in this area (reviewed by Birrer 2009). The common vole is a typical inhabitant of open agricultural areas (Baláž 2010), and its abundance in central Europe changes irregularly in three to five-year fluctuations (Jacob & Tkadlec 2010, Jacob et al. 2013). These fluctuations lead to a functional response in the long-eared owl diet (Korpimäki & Norrdahl 1991, Tome 2003). The composition of their diet is also affected by land use or by quantitative relations of small mammals, which may vary regionally. Particular regions thus offer different prey availability, which on a small scale affects the proportion of prey species and diversity of the long-eared owl diet (Tome 2000, Noga 2007). On a larger scale it can affect regional-specific patterns, where for example the long-eared owl is considered as a specialist predator in northern Europe, but in southern Europe as a generalist predator (Kontogeorgos et al. 2019). Our study sites were localized in two regions where the diet of long-eared owls has been studied in the long term (Obuch 1982, Obuch 1989, Šotnár & Obuch 1998, Tulis et al. 2012, Benešová 2013, Tulis et al. 2015a). Comparison of these two different regions reveals long-term differences in the proportion of particular prey species and diet diversity. Occupation of human settlements by long-eared owls for roosting in the breeding season is common (e.g. Kiat et al. 2008, Riegert et al. 2009), and relatively common in forest. Several studies have also presented information about the diet of long-eared owls roosting in forest areas (Gawlik & Banz 1982, Bull et al. 1989, De Wavrin et al. 1991, Bodbijl 1997).

Similarly, during the non-breeding season long-eared owls´ winter roosts have regularly been recorded within human settlements (Škorpíková et al. 2005, Noga 2007, Zaňát et al. 2007, Ružič et al. 2010), where the proportion of synanthropic species in their diet increases with the rising level of urbanisation, but the common vole still represents these owls’ main prey (Riegert et al. 2009, Sharikov & Makarova 2014, Mori & Bertolino 2015, Szép et al. 2018). However, several studies deal with winter roosts located in rural zones such as windbreaks and bushes within agricultural land or forest edges (Czarnecki 1956, Enriquez-Rocha et al. 1993, Smith & Devine 1993, Škorpíková et al. 2005, Zaňát et al. 2007) and some of them also deal with diet composition (Holt & Childs 1991, Cecere et al. 2013). Studies which deal with winter roosts located deeper inside compact forest (more than 500 m from the forest’s edge) can be found only rarely (Armstrong 1958 in Holt (1997), Enriquez-Rocha et al. 1993, Škorpíková et al. 2005, Zaňat et al. 2007). Škorpíková & Křivan (2013) described one winter roost of long-eared owls in a patch of young spruces (5–8 m high) which was part of a larger coniferous forest complex. This winter roost was used for at least 17 years, and the owls moved several times from older and denser stands to younger and thinner ones. The nearest clear cut was 200 m away, and the edge of the forest was 500 m from this winter roost. The roost was occupied by 4–6 individual long-eared owls, and also at least two individual short-eared owls (*Asio flammeus*). Despite several studies mentioned above, data about the diet of long-eared owls wintering in the forest are still completely lacking.

This study presents the first data about the diet of long-eared owls from winter roosts situated within forest areas. The aims of this study were to: (i) investigate the diet ecology of long-eared owls from winter roosts located in the forest and (ii) compare the diet spectrum of these owls with the diet of long-eared owls from the nearest winter roosts situated within human settlements. We hypothesized that long-eared owls wintering in the forest hunted more forest small mammal species than those wintering within human settlements.

Material and methods

Study sites

All our study sites are located in the central part of Slovakia. Pellets were collected at two types of winter roosts (Fig. 1): (i) winter roosts situated within forest, and (ii) winter roosts situated within human settlements, which were used as control sites (Tab. 1).

Winter roosts situated within forest

Three forest winter roosts were situated in 20–30 year-old spruce or pine monoculture patches situated in mixed forest at various distances (≥ 800 m) from the edge of the forest (Tab. 1). Two winter roosts (nos. 1 and 2) were discovered accidentally. Winter roost no. 3 was discovered during telemetry study of long-eared owls, while tracking one individual which was caught and marked with a radio transmitter in the vicinity of winter roost no. 4 within human settlement, 1.5 km away from each other (Fig. 1). Next day after catching, the marked individual was found at a winter roost with another eight owls (Tulis 2013). The proportion of forest in a 3 km buffer zone around all forest winter roosts was greater than 35% (Fig. 2). Winter roost no. 1 (48°50'56.86" N, 18°44'44.30" E) was situated at Žiar Mts., winter roost

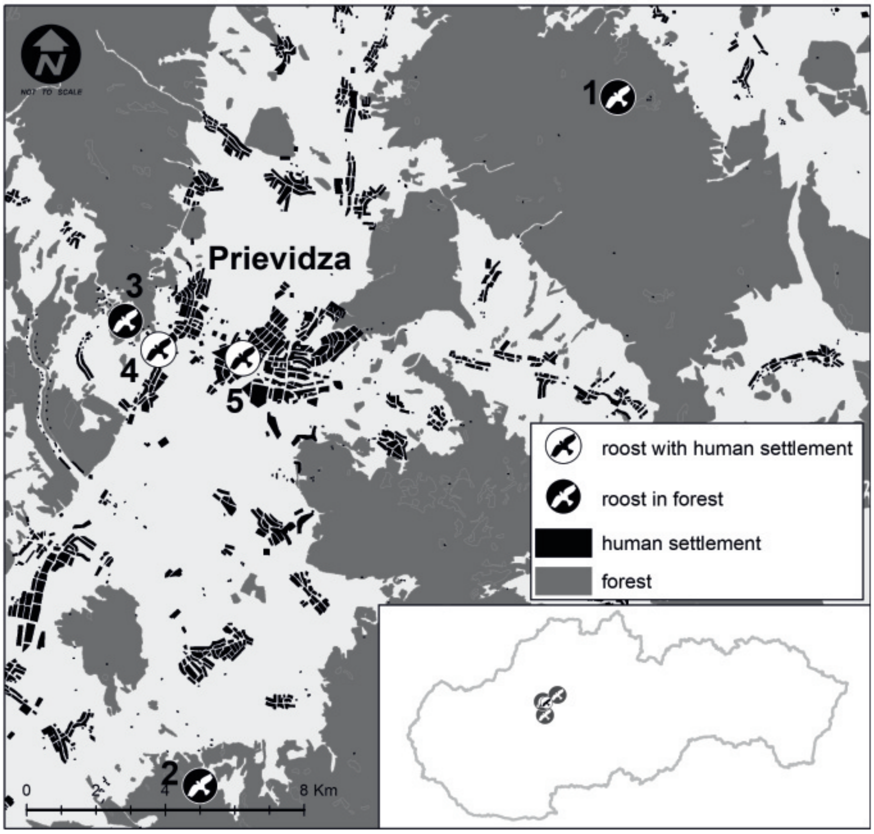

Fig. 1. Location of winter roosts (1 – Budiš, 2 – Lehota p. Vtáčnikom, 3 – Viglaš, 4 – Bojnice, 5 – Prievidza).
Obr. 1. Lokalizácia sledovaných zimovísk (1– Budiš, 2 – Lehota p. Vtáčnikom, 3 – Viglaš, 4 – Bojnice, 5 – Prievidza).

no. 2 (48°39'43.59" N, 18°36'14.61" E) was situated in the Vtáčnik Mts., and roost no. 3 (48°46'51.01" N, 18°33'36.09" E) was located in the Strážov Mts.

Winter roosts situated within human settlement

Two winter roosts no. 4 (48°46'26.80" N, 18°34'25.97" E) and no. 5 (48°46'25.53" N, 18°36'25.53" E) situated within human settlements were used as control sites in this study (Fig. 1). The diet data used for winter roost no. 4 were published in Tulis et al. (2015a). Winter roost no. 4 has not been used since 2014. Winter roost no. 5 was formed in winter 2016. For selection of control sites (winter roosts), two options were taken into consideration: (i) distance from the forest winter roost, using the nearest known winter roost; (ii) the same year of pellet collection as for the forest winter roosts. In this way we avoided the possible influence of different prey abundance.

Tab. 1. Studied winter roosts of long-eared owls (compared pairs of roosts are in the same row).
Tab 1. Sledované zimoviská myšiarky ušatej (dvojice porovnávaných zimovísk sú v rovnakom riadku).

ID	forest / les	winter / zima	DFE (km)	ID	settlement / sídlo	winter / zima	DBW (km)
1	Budiš	2005	1.6	-	-	-	-
2	Lehota p. Vtáčnikom	2007	1.3	4	Bojnice	2007	12.4
	Lehota p. Vtáčnikom	2009	1.3		Bojnice	2009	12.4
	Lehota p. Vtáčnikom	2013	1.3		Bojnice	2013	12.4
3	Viglaš	2011	0.8		Bojnice	2011	1.5
	Viglaš	2012	0.8		Bojnice	2012	1.5
	Viglaš	2016	0.8	5	Prievidza	2016	3.4

DFE – distance from forest edge / vzdialenosť od okraja lesa; DBW – distance between roosts / vzdialenosť medzi zimoviskami

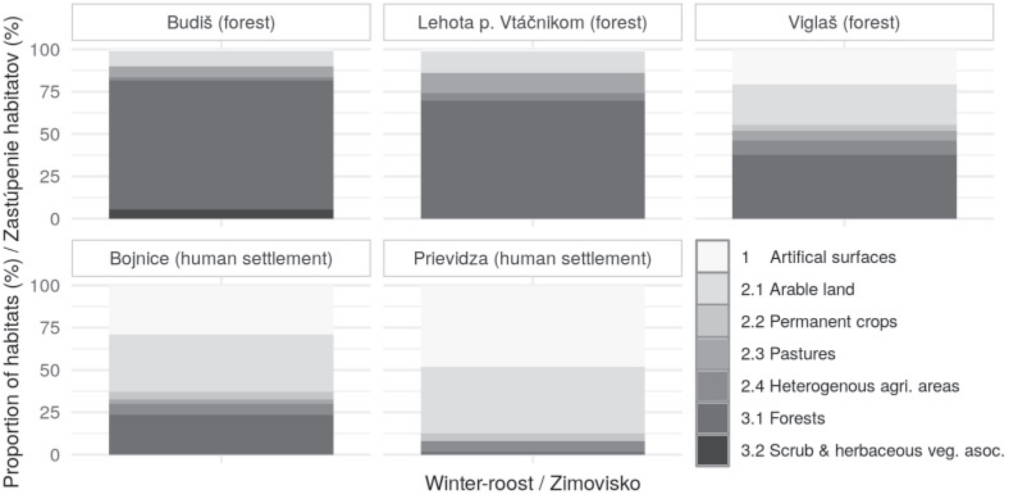

Fig. 2. Land cover in a 3 km buffer around winter roosts, (numbers before legend items represent their position in the hierarchy of land use according to the Corine legend; Heterogeneous agri. Areas = Heterogeneous agricultural areas, Scrub and herbaceous veg. association = Scrub and herbaceous vegetation association; parentheses after the names of winter roosts indicate their location: forest or human settlement).

Obr. 2. Krajinná pokrývka v 3 km rádiuse od zimovísk, (1 – zastavané územie, 2.1 – orná pôda, 2.2 – trvalé plodiny, 2.3 – pasienky, 2.4 – heterogénne poľnohospodárske plochy, 3.1 – lesy, 3.2 – kroviny a bylinná vegetácia; v zátvorkách za názvom zimoviska uvádzame jeho lokalizáciu: les alebo ľudské obydlie).

A circle of 3 km around the long-eared owls' roosting site was used to simulate the habitat use of the potential hunting area utilized by long-eared owls (Tulis 2013). The CORINE map from 2006 and 2012 was used as the background. As the legend for land use we used the proportion of: 1. Artificial surfaces (level 1), 2. Agricultural areas in detailed level 2, e.g. 2.1 Arable land, 2.2 Permanent crops, 2.3 Pastures, 2.4 Heterogenous agricultural areas and 3 Forest and seminatural areas in detailed level 2, e.g. 3.1 Forests, 3.2 Scrub and herbaceous vegetation association. In cases where pellets were collected over a longer period, we visualized both available time periods. The proportion of forest in a 3 km buffer zone around all forest winter roosts was greater than 35%, and the proportion of forest around winter roosts within human settlement was less than 20%, but the proportion of open land was greater than around forest roosts (Fig. 2).

Diet analyses

Pellets were collected at the end of the wintering period during March and April and were put into 5% solution of sodium hydroxide (NaOH), which dissolves all the undigested parts of prey except the bones. Mammals were identified by skull (maxilla) and jaw (mandibula) according to Anděra & Horáček (2005) and Baláž et al. (2013). Bird bones were identified using a reference collection. The identification of birds was based on beaks (rostrum), metatarsal (tarsometatarsus), humeral (humerus) and metacarpal bones (metacarpus). The number of individuals of identified prey was estimated as the least number of individuals which we were able to identify according to the same anatomical parts of bones (Klein & Cruz-Uribe 1984). Data for mammal and bird prey biomass were taken from Baláž & Ambros (2006), Baláž et al. (2013) and Hudec & Štastný (2005).

Data analyses

The breadth of food niches (FNB) was estimated using the formula proposed by Levins (1968): $B = 1/\Sigma p^2_i$, where p_i is the proportion of the prey category in the total biomass of the owl's diet. Trophic niche overlap was measured with Pianka's index, using the percentage of biomass consumed of particular food items ($O_{jk} = \sum p_{ij}\, p_{ik} / \sqrt{\sum p_{ij}^2 \sum p_{ik}^2}$, where p_i is the percentage of prey item "i" in the diet of species "j" and "k") (Pianka 1973). Pianka's index varies between 0 (total separation) and 1 (total overlap). Diet diversity was evaluated with the Shannon diversity index. Overall diet diversity was compared by means of the Hutcheson t-test, which was developed as a method to compare the diversity of two community samples using the Shannon diversity index (Hutcheson 1970).

For comparison of the food spectrum from forest roosts with roosts within human settlement, we grouped the components of the diet into five prey categories: common vole, other Cricetidae (including all voles except the common vole), Muridae, Soricidae and Aves. The yellow-necked mouse (*Apodemus flavicollis*) and bank vole (*Myodes glareolus*) were considered as typical forest species of small mammals. For forest winter roost no. 1 we did not find any winter roosts meeting the above-defined conditions for control site. For this reason we did not include this winter roost in the analysis.

For eliminating bias caused by different sample sizes (sampling effort), i.e. different numbers of analysed pellets, we used two approaches: in the first (proportional) approach, we used the ratio between the number of prey items of each species and the total number of identified prey items for each particular collection (roost). The relative proportions of diet items were arcsin transformed. This approach was justified by several studies (Varuzza et al. 2001, Charter et al. 2007, Sergio et al. 2008, Kross et al. 2018). Secondly, we used a control for sampling effort (Morand et al. 2015, McElreath 2016), where we regressed the number of long-eared owl prey items found against a number of pellets examined in logarithmic space. A number of diet components were affected by sampling effort (r^2 = 0.095, F = 7.19, P = 0.009). Original values of diet abundance were then replaced with their residual deviations from the regressions in log space and used in subsequent analyses. Differences in transformed diet items between the two kinds of roosts (from both approaches) were analysed by means of Monte Carlo permutation testing for paired individuals with 9999 permutations, for each prey category using the surveillance package (Meyer et al. 2017). All statistical analyses were performed using R software v. 3.2.5 (R Core Team 2018).

Regional comparison of diet was evaluated using the calculations of marked differences from the mean (MDFM, Obuch 2001) with comparison of published data from winter roosts within human settlements in the Hornonitrianska kotlina Basin (Tulis et al. 2015a) and Turčianska kotlina Basin regions (Benešová 2013). The samples in the adjusted results tables are sorted according to their similarity, and the ordering is adjusted so as to have the determining species with positive MDFM values arranged in columns and blocks. These blocks are enclosed in continuous line borders. Species without MDFM are arranged under a dashed line and ranked down according to total abundance. Calculations of the MDFM and contingency tables were carried out in the ZBER software application (Šipöcz 2004).

Results

Diet of owls in forest winter roosts

Altogether, 4995 prey items (129.7 kg of biomass) consisting of 16 mammal species and 10 bird species were identified in pellets from the forest winter roosts (Appendix 1). The common vole was the most frequent prey species in all forest winter roosts with average proportion of relative abundance (mean ± SD) 92.1 ± 5%, range: 82.1–96.6%. Relative abundance of forest mammal prey species (bank vole and yellow-necked mouse) was minimal (1.5 ± 2.4%, range: 0–9.7%).

Diet of owls in winter roosts situated within human settlements

Based on all pellets from winter roosts within human settlements, we identified 5,757 (151.5 kg of biomass) prey items consisting of 18 mammal and 24 bird species (Appendix 2). The common vole was the most frequent prey species in both winter roosts with average proportion (mean ± SD) 84.2 ± 3.6%, range: 79.6–88.9%. The proportion of forest mammal prey species was also minimal, and similar to the proportion in forest winter roosts (1.9 ± 1.5%, range: 0–4.3%).

Comparing the diets between winter roosts situated in forest and in human settlements

Comparing the diets, we recorded a statistically significant higher amount of common vole in the diet of long-eared owls wintering in the forest (Tab. 2). In contrast, the presence of birds was significantly higher in the diet of owls wintering in human settlements. Differences in the presence of other diet groups were not significant (Fig. 3). The results of both applied methods (proportional approach and CFC) were the same (Tab. 2).

Overall food diversity was higher in long-eared owls wintering in human settlements (Shannon index: forest roosts H´= 0.41, human settlements H´= 0.8, Hutcheson t-test: t = 12.7, P < 0.001). The differences in breadth of the food niche between the two winter roosts were minimal: (mean FNB in human settlements ± SD: 1.2 ± 0.2, range: 1.1–1.5; mean FNB in forest roost: 1.4 ± 0.3, range: 1.2–1.9). Pianka's overlap index then showed

Tab. 2. The comparison of prey categories proportion in diet of long-eared owls wintering in the forest and in human settlements using two methods (proportional approach and control for sampling effort approach).

Tab. 2. Porovnanie zastúpenia jednotlivých kategórii koristi myšiarok ušatých zimujúcich v lese a v blízkosti ľudských obydlí použitím dvoch metód (proporčný prístup – proportional approach a prístup kompenzujúci skreslenie, vplyvom rozličného úsilia zberu dát – control for sampling effort approach).

diet / method **potrava / metóda**	**proportional**		**control for sampling effort**	
	t	**P**	**t**	**P**
Microtus arvalis	0.007	0.016	0.009	0.014
other Cricetidae	0.113	0.074	0.177	0.204
Muridae	0.131	0.119	0.093	0.111
Soricidae	0.350	0.278	0.232	0.255
Aves	0.002	0.016	0.005	0.016

high match in the food spectrum between compared pairs of winter roosts (mean ± SD = 0.99 ± 0.003).

Regional differences in diets

Comparing the diets of long-eared owls using the MDFM method, we found regional differences between the diets in the Horná Nitra and Turiec areas. While the proportion of common vole in the diet in forest winter roosts was still higher than in human settlements in both regions, in the Turiec area the abundance of common vole in human settlements was higher (> 95%). In the region of Horná Nitra, the proportion of common vole was lower in human settlements due to higher consumption of various rodent species (Rodentia) and songbirds (Passeriformes). Long-eared owls had become specialized in hunting the common noctule (*Nyctalus noctula*) wintering in adjacent human settlements. Consequently, the diet diversity of winter roosts in the Horná Nitra region was higher in human settlements than in forest winter roosts. The lowest value of diet diversity was in the forest winter roosts in the Turiec region (Tab. 3).

Discussion

A higher proportion of common vole has been recorded in the diet of long-eared owls wintering in the forests. The preferred habitat of the common vole is open agricultural land (Tkadlec & Stenseth 2001, Baláž 2010). During the population peak the common vole sporadically penetrates more deeply into the forest habitat, but it is still linked only with small, open meadows and clear cuts (Zejda et al. 2002), where it survives only until other small mammals expel it as part of the succession process (Tichý 1978). In the Vtáčnik Mountains (where winter roost no. 2 is located), small isolated populations of common vole were confirmed, which survived in small, open areas at an altitude of 1,200 to 1,346 m a.s.l.

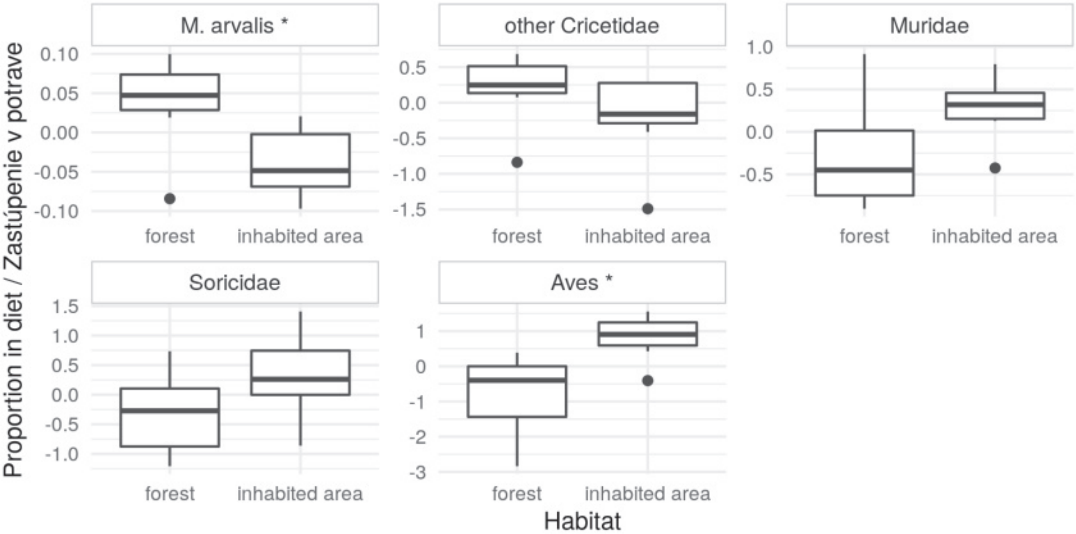

Fig. 3. Results of diet comparison between winter roosts in forest and within human settlements evaluated using the control for sampling effort approach (* = statisticaly significant difference; median, upper and lower quartiles, min–max (whisker) are presented).

Obr. 3. Porovnanie zloženia potravy medzi zimoviskami v lese (forest) a v ľudských obydliach (inhabited area) pomocou prístupu transformácie dát kompenzujúcich skreslenie, vplyvom rozličného úsilia zberu dát (* predstavuje štatisticky preukazný rozdiel; medián, horný a dolný kvartil, min–max sú prezentované v grafoch).

Tab. 3. Comparison of regional differences in long-eared owl diets between the regions of Horná Nitra and Turiec. Numerical data in the table are given in absolute values, and positive and negative deviations (e.g 1+, 2+, 1-, 2-) are marked deviations from the mean (MDFM, Obuch 2001) for the species in these samples (see Methods). H' – diversity index.

Tab. 3. Porovnanie regionálnych rozdielov v potrave myšiarky ušatej medzi regiónmi Horná Nitra a Turiec. Číselné hodnoty v tabuľke sú uvedené v absolútnych hodnotách, kladné a záporné odchýlky (1+, 2+, 1-, 2- a podobne) sú výrazné odchýlky od priemeru (MDFM, Obuch 2001) druhov vo vzorkách (pozri Metodiku). H' – index diverzity.

region / región	**Horná Nitra**			**Turiec**			
years / roky	**2007–14**	**2010–12**	**2007–14**	**2006–18**	**2004–05**		
roost / zimovisko	**setl. / sídlo**	**forest / les**	**forest / les**	**setl. / sídlo**	**forest / les**		
species/ locality	**1**	**2**	**3**	**4**	**5**	**∑**	**%**
Microtus arvalis (n)	8352	1352	2111	6150	1181	19,146	89.59
%	83.99	90.74	92.43	95.63	96.72		
Apodemus sylvaticus	1+ 410	39	1- 23	2- 51	1- 12	535	2.50
Apodemus microps	1+ 12		1	1- 0	1	14	0.07
Mus cf. *musculus*	1+ 30	5	1	1- 7		43	0.20
Terricola subterraneus	1+ 96	14	20	3- 2	1- 0	132	0.62
Nyctalus noctula	1+ 57		1- 0	3- 0		57	0.27
Crocidura suaveolens	1+ 29	4	2	1- 3		38	0.18
Passer domesticus	1+ 189	2- 0	1- 10	2- 14	2- 1	214	1.00
Passer montanus	1+ 40		4	1- 3		47	0.22
Parus major	1+ 78	3	10	2- 9	1- 1	101	0.47
Cyanistes caeruleus	1+ 29		3	1- 1	1	34	0.16
Carduelis chloris	1+ 20	1	3	1- 3		27	0.13
Turdus merula	1+ 20		1	4		25	0.12
Micromys minutus	1+ 231	1+ 37	2- 8	1- 41	1- 9	326	1.53
Apodemus flavicollis	1+ 216	22	1+ 64	2- 40	1- 9	351	1.64
Apodemus agrarius	2- 0			1+ 18		18	0.08
Myodes glareolus	37	11	11	39	4	102	0.48
Muscardinus avellanarius	12		3	2	1	18	0.08
Erithacus rubecula	9			6		15	0.07
Arvicola amphibius	3		2	8	1	14	0.07
Carduelis carduelis	9			1		10	0.05
Sitta europaea	7			1		8	0.04
Sorex araneus	5			2		7	0.03
Sorex minutus	3		1	3		7	0.03
Emberiza citrinella	3		2	2		7	0.03
Fringilla coelebs	6			1		7	0.03
Mammalia	**9501**	**1484**	**2250**	**6369**	**1218**	**20,822**	**97.44**
Aves	**1+ 443**	**2- 6**	**1- 34**	**2- 62**	**3- 3**	**548**	**2.56**
∑	**9944**	**1490**	**2284**	**6431**	**1221**	**21,370**	**100**
H'	**0.84**	**0.48**	**0.44**	**0.30**	**0.20**	**0.60**	

setl. – settlement; Locality / lokalita: 1 – Bojnice (Tulis et al. 2015a), 2 – Vigľaš (our study / naša práca), 3 – Lehota pod Vtáčnikom (our study / naša práca), 4 – Turiec (Benešová 2013), 5 – Budiš (our study / naša práca)

as a consequence of deforestation and grazing in the past (Ambros et al. 1994). These small, open areas represent only refugiums of its occurrence, in comparison to open agricultural land. These habitats are also covered with a compact snow layer during winter, and without snow cover these places can partially represent suitable hunting habitats for long-eared owls, mainly because of their closeness. However, the distance of hunting places from the winter roost does not strictly affect the owls´ preferences. During telemetry study, several individuals occupying winter roost no. 4 hunted every tracked night in a range from several hundreds to several thousand meters, but one individual preferred hunting places 5 km away from the winter roost (Tulis 2013). Long-eared owls search for prey during active flight at low levels (Voous & Cameron 1988), predominantly in open habitats with forest edges and network habitats such as edge banks and treelines (Galeotti et al 1997b, Henrioux 2000, Lövy & Riegert 2013). In our case, clear cuts and fallows can also play the role of open habitats with forest edges. In winter 2012, moreover, an individual from winter roost no. 3 similarly tracked by telemetry was seen avoiding contiguous forest immediately after leaving its winter roost, preferring hunting in open agricultural land and its along edges bordering the forest (Tulis 2013). Our results show a low proportion of forest mammal species in the diet of forest-roosting owls, which indicates that they did not go hunting in forest areas. All these findings point to the conclusion that despite the location of winter roosts in deep forest, the long-eared owls went hunting in the forest only minimally and preferred hunting in open agricultural landscape.

On the other hand, we noticed a significantly higher proportion of birds in the diet of long-eared owls wintering in human settlements. Flocks of songbirds wintering in human settlements are a suitable source of prey for long-eared owls (Moučka 1966, Ginter 1971, Bezzel 1972, Laiu & Murariu 1998, Mori & Bertolino 2015). In larger settlements we can even see an increase in the proportion of synanthropic species of prey for wintering long-eared owls, e.g. brown rat (*Rattus norvegicus*) (Laiu & Murariu 1998, Pirovano et al. 2000, Mori & Bertolino 2015). The incidence of common vole in the diet of both types of winter roosts was over 85%. This result fully correspondends to the diet ecology of the long-eared owl in this European region (reviewed by Birrer 2009). Korpimäki (1992) explains the overall preference for the common vole by the fact that the hunting habitats of long-eared owls are precisely the areas where common voles are numerous, and also due to the voles´ gregarious way of life. Colonies of common voles are thus subjected to greater predation risk than other solitary-living species of voles and mice. The high abundance of common voles, the food niche breadth and the low food diversity at all monitored winter roosts show that there was no decline in the availability of common voles during the monitored period. Data from winter roost no. 4 (but at a different time) confirm that the decrease in the availability of common voles led to a decrease in their diet proportion to under 60% (Tulis et al. 2015a). The natural extension of the food spectrum thus represents a functional response by long-eared owls to the long-term unavailability of common voles caused by fluctuation in their population (Jacob & Tkadlec 2010) or by cycles in their abundance (Lambin et al. 2006), or by short-term unavailability due to meteorological factors (Canova 1989, Tome 2000, Rubolini et al 2003, Romanowski & Zmihorski 2008, Sharikov & Makarova 2014). Extension of the food niche as a response to the decline in the main component of prey is known in several owl species, such as the barn owl (*Tyto alba*) (Horváth et al. 2018) or boreal owl (*Aegolius funereus*) (Korpimäki & Hakkarainen 2012). Our results also suggest regional differences in diets between the compared regions. Spatial heterogenity is often observed in the long-eared owl diet (Tome 2000, Noga 2007, Escala et al. 2009) and also in the diets of other owl species, such as the barn owl (Horváth et al. 2018), tawny owl (*Strix aluco*) (Żmihorski et al. 2008, Obuch 2011), or eagle owl (*Bubo bubo*) (Obuch 2014). This is a consequence of differing land use and regional differences in the quantitative relations of small mammals, which are then reflected in the dietary composition of owls (Horváth et al. 2005, Szűcs et al. 2014).

To date only a few data about the wintering of long-eared owls in deep forests have been published (Armstrong 1958 in Holt 1997, Enriquez-Rocha et al. 1993, Škorpíková et al. 2005, Zaňat et al. 2007). Czarnecki (1956), making reference also to the experience of other researchers in the first half of the 20th century, indicates that wintering colonies of long-eared owls can be found in forests no deeper than 60 to 80 m from their edges. In contrast, winter roosts in human settlements are a relatively common phenomenon nowadays. Škorpíková et al. (2005), moreover, identified the aggregation of long-eared owls in winter roosts in human settlements in this region as a less common phenomenon in the past. The possibility of overlooking a large number of pellets and a high number of owls in the immediate vicinity of human dwellings is hardly likely. The oldest found published information about winter roosts situated within human settlements began appearing at the end of the 19th (1884 in Ružič 2011) and beginning of the 20th century (Bread 1906, Knežourek 1910, Fischer 1919, Spiker 1933). According to Volkov et al. (2005), in the past long-eared owls tended to roost in forest or its margins. Saunders (1919) observed a group of long-eared owls occupying clumps of fir trees near a mountain meadow. Škorpíková et al. (2005) further contend that urban development has also played a major role in the last few decades. Potential reasons why long-eared owls utilize human settlements for their wintering may be the better microclimate and smaller predation risk (Noga 2007, Zvážal & Sviečka 2009, Sharikov et al. 2010). From this point of view, use of human settlements by long-eared owls for wintering, similarly as for nesting (Sharikov et al. 2010), appears to be a feature of synanthropisation, as previously described in the case of other birds of prey and owls (reviewed by Kettel et al. 2018).

After their discovery, all three monitored winter roosts were inspected yearly, but their occupancy was not repeated annually. Winter-roost no. 3 was even abandoned during one winter from December 20, 2011 to January 14, 2012 (Tulis et al. 2015b). From the discovery of winter roost no. 3 (November 22) to its abandonment on December 19, 2011), the average temperature was 1.5 °C, without presence of snow cover (www.ogimet.com). During the absence of the wintering group from December 20, 2011 to January 12, 2012, the average temperature was -2.3 °C and the average snow cover reached 4.9 cm. We do not know where the owls were during this interval. After this time, the weather became warmer and the snow cover melted away. On February 14, 2012, the wintering flock reappeared at the monitored winter roost, and was recorded again during every subsequent inspection until March 2012. Long-eared owls are also typical for their aggregation response to unavailability of prey, whereby during a decline in the vole population they are able to relocate into more plentiful prey areas (Village 1981, Korpimäki 1992, Norrdahl & Korpimäki 1996).

The application of two evaluation methods in our study revealed identical results. However, performing standardization based upon the number of pellets collected by several persons may be partially subjective. In future, it would be advisable to standardize the material based on the weight of analyzed dried pellets, which would seem to be more explicit.

To conclude, our study indicates a preference among long-eared owls for hunting in an open agricultural landscape, regardless of where the winter roost is located. The location of a winter roost in the forest did not lead to increased consumption of forest mammals. While relatively more is known about the winter roosts of long-eared owls situated in human settlements, we have minimal information about their winter roosts located deep in the forest. In any case, with regard to the difficulty involved in discovering them, we cannot say that winter roosts located deep in the forest are less common than those in human settlements. This lack of data points to the need for more intensive study of long-eared owls' winter roosts in forests.

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Appendix1. Diet of long-eared owl within roosts situated in forest.
Príloha 1. Potrava myšiarky ušatej na zimoviskách situovaných v lesnom poraste.

locality / lokalita	**1**			**2**			**2**			**2**			**3**			**3**			**3**			**∑**			
winter / zima	**2005/2006**			**2007/2008**			**2009/2010**			**2013/2014**			**2011/2012**			**2012/2013**			**2016/17**						
	items / kusy		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	
species / druh	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**b(kg)**	**%**
M. arvalis	1181	96.6	96.9	1379	94.1	93.4	471	93.6	94.0	261	82.1	80.9	878	89.2	92.3	132	96.4	97.2	342	92.7	94.1	4644	92.6	122.2	85.2
M. subterraneus				11	0.8	0.5	6	1.2	0.8	3	0.9	0.7	12	1.2	0.9	2	1.5	1.0				34	0.7	0.6	0.5
M. glareolus	4	0.3	0.3	6	0.4	0.4	1	0.2	0.2	4	1.3	1.1	7	0.7	0.6				4	1.1	1.0	26	0.5	0.6	0.5
A. amphibius	1	0.1	0.6	2	0.1	0.9																3	0.1	0.5	0.4
M. minutus	9	0.7	0.1	3	0.2	0.1	3	0.6	0.1	2	0.6	0.1	35	3.6	0.6	1	0.7	0.1	1	0.3	0.1	54	1.1	0.2	0.2
A. flavicollis	9	0.7	0.9	30	2.0	2.5	3	0.6	0.8	31	9.7	12.1	15	1.5	2.0	1	0.7	0.9	6	1.6	2.1	95	1.9	3.1	2.4
A. sylvaticus	12	1.0	0.9	11	0.8	0.7	6	1.2	1.1	6	1.9	1.8	33	3.4	3.3	1	0.7	0.7	5	1.4	1.3	74	1.5	1.8	1.4
A. microps	1	0.1	0.1							1	0.3	0.2										2	0.1	0.04	0.1
M. cf. *musculus*							1	0.2	0.2				4	0.4	0.4				1	0.3	0.3	6	0.1	0.2	0.1
M. avellanarius	1	0.1	0.1	2	0.1	0.1	1	0.2	0.2													4	0.1	0.1	0.1
T. europaea				1	0.1	0.3	1	0.2	0.8													2	0.01	0.2	0.1
C. leucodon										1	0.3	0.1										1	0.01	0.01	0.1
C. suaveolens				2	0.1	0.1													4	1.1	0.2	6	0.1	0.03	0.1
S. minutus				1	0.1	0.1																1	0.01	0.01	0.1
T. merula				1	0.1	0.3																1	0.3	0.1	0.1
P. major	1	0.1	0.1	3	0.2	0.1	6	1.2	0.9	1	0.3	0.2							3	0.8	0.6	14	0.3	0.26	0.2
C. caeruleus	1	0.1	0.1	2	0.1	0.1	1	0.2	0.1													4	0.1	0.04	0.1
P. ater																			1	0.3	0.1	1	0.01	0.01	0.1
C. chloris				1	0.1	0.1	1	0.2	0.2	1	0.3	0.4							1	0.3	0.3	4	0.1	0.1	0.1
P. domesticus	1	0.1	0.1	4	0.3	0.3				6	1.9	2.3										11	0.2	0.3	0.2
P. montanus				3	0.2	0.2				1	0.3	0.3										4	0.1	0.09	0.1
P. pyrhulla																			1	0.3	0.3	1	0.01	0.02	0.1
E. citrinella				1	0.1	0.1	1	0.2	0.2													2	0.01	0.06	0.1
C. cinclus							1	0.2	0.5													1	0.01	0.06	0.1
Mammalia	**1218**	**99.7**	**99.8**	**1448**	**98.8**	**98.9**	**493**	**98.0**	**98.1**	**309**	**97.2**	**96.9**	**984**	**100**	**100**	**137**	**100**	**100**	**363**	**98.4**	**99.0**	**4952**	**99.1**	**129.7**	**99.2**
Aves	**3**	**0.2**	**0.2**	**15**	**1.0**	**1.1**	**10**	**2.0**	**1.9**	**9**	**2.8**	**3.1**							**6**	**1.6**	**1.0**	**43**	**0.9**	**1.1**	**0.8**
∑	**1221**			**1463**			**503**			**318**			**984**			**137**			**369**			**4995**		**130.8**	
Diversity (H´)		0.21			0.36			0.38			0.76			0.51			0.21			0.41			0.41		
FNB		1.06			1.15			1.13			1.49			1.25			1.17			1.05			1.14		

B(kg) – biomass (mass) in kilograms / biomasa v kilogramoch; **Localities / Lokality**: 1 – Budiš, Lehota p. Vtáčnikom, 3 - Viglaš; also in a case when the item proportion of mass (%) was less than 0.1 we used value 0.1 /aj v prípade ak proporcia položky potravy (%) bola menšia ako 0.1 použili sme hodnotu 0.1

Appendix 2. Diet of long-eared owl within roost situated within human settlements.
Príloha 2. Potrava myšiarky ušatej na zimoviskách v ľudských obydliach.

locality / lokalita								**4**									**5**			**∑**		
winter / zima	**2007/2008**			**2009/2010**			**2011/2012**			**2012/2013**			**2013/2014**			**2016/2017**						
	items / kusy		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	**items / kusy**		**mass / hmotn.**	
species / druh	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**%**	**n**	**%**	**B (kg)**	**%**
M. arvalis	759	84.2	86.1	2278	83.2	83.4	435	87.7	89.6	336	88.9	91.5	739	81.4	81.1	285	79.6	71.4	4832	83.6	127.2	83.7
M. subterraneus	4	0.4	0.3	33	1.2	0.9	7	1.4	1.0	2	0.5	0.4	4	0.4	0.3				50	0.9	0.9	0.6
M. glareolus	1	0.1	0.1	3	0.1	0.1				1	0.3	0.2	7	0.8	0.7				12	0.2	0.3	0.2
A. amphibius				1		0.2							2	0.2	1.5				3	0.05	0.5	0.4
M. minutus	29	3.2	0.5	42	1.5	0.2	4	0.8	0.1	7	1.9	0.3	13	1.4	0.2	16	4.5	0.6	111	1.9	0.4	0.3
A. flavicollis	38	4.2	5.4	67	2.4	3.1	6	1.2	1.6	5	1.3	1.7	13	1.4	1.8				129	2.2	4.2	2.8
A. sylvaticus	21	2.3	2.3	194	7.1	6.7	19	3.8	3.7	9	2.4	2.3	46	5.1	4.8	13	3.6	3.1	302	5.2	7.5	4.9
A. microps					0.3	0.2										1	0.3	0.2	8	0.1	0.2	0.1
M. cf. *musculus*				12	7	0.4	1	0.2	0.2	2	0.5	0.5	5	0.6	0.5	4	1.1	1.0	24	0.4	0.6	0.4
R. norvegicus																6	1.7	14.7	6	0.1	1.6	1.0
M. avellanarius	1	0.1	0.1	1						1	0.3	0.3	5	0.6	0.6				8	0.1	0.2	0.1
C. leucodon										3	0.8	0.2							3	0.05	0.02	0.01
C. suaveolens	3	0.3	0.1	5	0.2	0.1	1	0.2	0.1				2	0.2	0.1				11	0.1	0.1	0.1
N. noctula	1	0.1	0.1	6	0.2	0.2							1	0.1	0.1				8	0.1	0.2	0.1
T. merula	1	0.1	0.5	7	0.3	1.0							3	0.3	1.3	2	0.6	2.0	13	0.2	1.4	0.9
T. philomelos				1		0.1										2	0.6	1.3	3	0.1	0.2	0.1
P. major	11	1.2	0.9	9	0.3	0.2	15	3.0	2.2	4	1.1	0.8	21	2.3	1.6	8	2.2	1.4	68	0.1	1.3	0.8
C. caeruleus	3	0.3	0.1	9	0.3	0.1				2	0.5	0.2	5	0.6	0.2	3	0.8	0.3	22	0.1	0.3	0.2
P. palustris	1	0.1		2	0.1	0.1													3	0.05	0.03	0.02
C. chloris	1	0.1	0.1	5	0.2	0.2							3	0.3	0.4	1	0.3	0.3	10	0.1	0.3	0.2
P. domesticus	19	2.1	2.6	29	1.1	1.3	3	0.6	0.8	3	0.8	1.0	32	3.5	4.3	6	1.7	1.8	92	0.2	2.9	1.9
P. montanus	2	0.2	0.2	11	0.4	0.4	1	0.2	0.2				3	0.3	0.3	1	0.3	0.2	18	0.3	0.4	0.3
S. vulgaris				3	0.1	0.3													3	0.05	0.2	0.1
E. rubecula				1									2	0.2	0.1	3	0.8	0.5	6	0.1	0.1	0.1
G. cristata				1		0.1							1	0.1	0.2	1	0.3	0.4	3	0.1	0.1	0.07
Regulus sp.				2	0.1	0.1	1	0.2	0.1							1	0.3	0.1	4	0.07	0.01	0.01
S. europaea	2	0.2	0.2							2	0.5	0.5				1	0.3	0.2	5	0.09	0.1	0.08
Mammalia	**858**	**95.2**	**95.1**	**2653**	**96.9**	**96.0**	**473**	**95.4**	**96.2**	**367**	**97.1**	**97.5**	**838**	**92.3**	**91.5**	**325**	**90.8**	**90.9**	**5514**	**95.4**	**144.2**	**95.0**
Aves	**43**	**4.8**	**4.9**	**84**	**3.1**	**4.0**	**23**	**4.6**	**3.8**	**11**	**2.9**	**2.5**	**70**	**7.7**	**8.5**	**33**	**9.2**	**9.1**	**264**	**4.6**	**7.8**	**5.0**
Σ	**901**			**2737**			**496**			**378**			**908**			**358**			**5757**		**151.5**	
Diversity (H´)		0.78			0.81			0.61			0.61			1.06			0.93			0.8		
FNB		1.34			1.42			1.24			1.19			1.51			1.9			1.42		

B (kg) – biomass (mass) in kilograms; **Localities / lokality:** 4 – Bojnice, 5. Prievidza; Prey species occurred 1 time (species, locality, year) / Druh koristi s 1 výskytom(druh, lokalita, rok): *E. roumanicus* 4, 2009; *T. torquatus* 4, 2009; *C. cannabina* 4, 2007; *E. citrinella* 4, 2007, *T. troglodytes* 4, 2009; *Sylvia* sp. 4, 2009; *F. coelebs* 4, 2011; *C. coccothraustes* 5, 2017; Prey species occurred 2 times (species, locality, year) / Druh koristi s 2 výskytmi (druh, lokalita, rok): *M. agrestis* 4, 2007, 2009; *S. araneus* 4, 2009, 2012; *S. minutus* 4, 2009, 2013; *P. ater* 4, 2007, 2009; *P. pyrrhula* 4, 2011; *C. carduelis* 5, 2017; *C. spinus* 5, 2017; also in a case when the item proportion of mass (%) was less than 0.01 we used value 0.01 /aj v prípade ak proporcia položky potravy (%) bola menšia ako 0,01 použili sme hodnotu 0,01

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Riding the storm out: select demographics of a breeding population of Cooper's hawks (*Accipiter cooperii*) following a severe spring snowstorm

Prežiť búrku: vybrané charakteristiky hniezdnej populácie jastraba čiapočkatého (*Accipiter cooperii*) po silnej jarnej snehovej búrke

Robert N. ROSENFIELD

Abstract: The demographic responses to severe weather by top-level predators, including birds of prey, are underreported and/or unknown. Severe storms are predicted by climate change models to increase globally and in frequency into the 22nd century. In April 2018, a population of breeding Cooper's hawks (*Accipiter cooperii*) in central Wisconsin, USA, experienced three days of heavy snowfall in the most severe storm, in pre-incubation-stage, for 39 years (1980–2018). Here I report select demographic outcomes of this nesting population following this intense weather. The median hatching date of 10 June in 2018 was the sixth latest such metric in those 39 years (and the latest in 22 years since 1996) for this population, which has advanced its breeding schedule about 1.3 days/decade due to climate change or warming. Survival of a total of 16 color-marked breeding adults, 15 males and 1 female, observed pre-storm in the nesting areas, was 100% up through the late nestling stage in the same nesting areas where these birds were initially detected in 2018. Average clutch size (4.4 eggs/nest) and average brood size (4.0 young/nest) were similar to the overall average annual metrics of these demographics for this population in the earlier 38 study years. Nest success, whereby 95% of 21 nests with eggs produced advanced-aged young, was higher in 2018 than the overall average of 77% nest success rate during the earlier years. The later timing of hatching in 2018, likely due to the severe spring snowstorm, appeared to have no deleterious effects either on survival of the breeding adults or on the reproductive output of this healthy study population. Tree-canopy prey may have served as important alternative food for this typically ground-foraging raptor in 2018.

Abstrakt: Demografické reakcie na nepriaznivé počasie vrcholovými predátormi, dravce nevynímajúc, sú nepublikované a/alebo neznáme. Klimatické modely predpovedajú celkový nárast výskytu búrok aj ich frekvencie do 22. storočia. V apríli 2018 zažila hniezdna populácia jastraba čiapočkatého (*Accipiter cooperii*) v centrálnom Wisconsine, USA, tri dni silného sneženia v najsilnejšej búrke v predinkubačnom období za posledných 39 rokov (1980 – 2018). V tomto príspevku uvádzam vybrané demografické charakteristiky tejto hniezdnej populácie po tomto silne nepriaznivom počasí. Stredný dátum liahnutia – 10. júna v roku 2018 – bol šiestym najneskorším počas posledných 39 rokov (a najneskorší počas 22 rokov od roku 1996) pre túto populáciu, ktorá v dôsledku klimatických zmien alebo otepľovania urýchlila termín hniezdenia o 1,3 dňa/desaťročie. Prežitie celkovo 16 farebne označených hniezdiacich dospelých jedincov, 15 samcov a 1 samice, pozorovaných pred búrkou v hniezdiskách bolo 100 % do posledných fáz hniezdenia v rovnakých hniezdiskách, kde boli tieto vtáky prvykrát zistené v roku 2018. Priemerná veľkosť znášky (4,4 vajec/hniezdo) a priemerný počet mláďat (4,0 mladé/hniezdo) boli podobné celkovým priemerným ročným hodnotám charakteristík tejto populácie v predchádzajúcich 38 študovaných rokoch. Hniezda úspešnosť, keď v 95 % z 21 hniezd so znáškou boli odrastené mláďatá, bola v roku 2018 vyššia než 77 % celková priemerná hniezda úspešnosť v predchádzajúcich rokoch. Neskoršie načasovanie liahnutia v roku 2018, pravdepodobne v dôsledku silnej jarnej snehovej búrky, nemalo žiaden škodlivý účinok ani na prežitie hniezdiacich dospelých jedincov, ani na reprodukciu tejto životaschopnej populácie. Korisť viazaná na koruny stromov mohla slúžiť ako dôležitá alternatívna potrava pre tohto na zemi loviaceho dravca v roku 2018.

Key words: demographic response, severe weather, hatching date, survival, climate change, Wisconsin, USA

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Introduction

Future climate-change scenarios predict that storm events, including low temperatures, tornados, hail, and high amounts of precipitation will increase in severity and globally in many areas, including the western Great Lakes region of North America (Serbin & Kucharik 2009, Wellicome et al. 2014, USGCRP 2017). Our knowledge of the consequences of recent climate change including adverse weather on wildlife are limited (Hunter et al. 2010, Franke et al. 2013, Anctil et al. 2014), although some information is available for some well-studied Arctic species (e.g., geese [Dickey et al. 2008], seabirds [Gaston et al. 2005], and polar bears [*Ursus maritumus*; Stirling & Derocher 2012]). Moreover, some bird groups such as raptors have received much less attention than others regarding their response to adverse weather (Møller et al. 2010). Similarly, discussions of conservation of raptor species in two recent review papers (Newton et al. 2016, McClure et al. 2018) did not address the threat of climate change and/or adverse weather to raptor populations.

Precipitation, usually in the form of rain, is an important, if not primary component of severe weather which often adversely influences breeding success of avian species (Lõhmus 2003). Periods of intense and/or prolonged rain or snow, especially early in the breeding season, increase the risk of egg loss and hypothermia for the young, and degrade hunting conditions for adults in part by reducing food availability (e.g, prey species are often inactive during stormy weather and thus difficult to detect; Krüger 2004, Whelan et al. 2017). Intense poor weather also increases the risk of predation and starvation for stressed adults (Rodriguez & Bustamante 2003, Krüger 2004, Franke et al. 2013, Whelan et al. 2017). Poor spring weather can cause nest abandonment and reduce overall reproductive success of birds, including birds of prey (Whelan et al. 2017).

In response to recent and rapid climate change, especially warming spring temperatures, Wisconsin Cooper's hawks in the Great Lakes region have advanced their egg-laying on average by about 4–5 days during 1980–2015, concordant with advanced spring phenologies of 55 Wisconsin species of plants and migratory songbirds (Rosenfield et al 2016). Notably, some of these birds, including particularly the ground-foraging American robin (*Turdus migratorius*), are primary prey of this raptor especially during the pre-incubation period (Bradley et al. 1999, Rosenfield et al. 2016). It is conceivable that some of these phenological advancements may create a mismatch between the timing of (reduced) availability of prey and optimal brood-rearing time for Cooper's hawks with consequential deleterious effects on their production and other demographics (Wellicome et al. 2014, Whelan et al. 2017). However, there have been no adverse effects on the average, relatively high and stable reproductive indices of this population of Cooper's hawks during the 36-year period (Rosenfield et al. 2016).

That said, the study area experienced a severe spring storm during 14–16 April 2018 (defined as ≥ 3 days of consecutive heavy precipitation [sensu Anctil et al. 2014]), which included 508 mm of snowfall (including 76 mm of rain), with about 381 mm of snow on the ground for four days during 15–18 April (National Climatic Data Center website; see Fig. 1). Cooper's hawks are a partially migratory species in Wisconsin (i.e. some birds are present year-round, even at nesting sites), and most breeding birds are at their nesting sites for about 1–3 weeks prior to mid-April. Earliest nesting pairs in many years will begin laying eggs around 20 April (Rosenfield 2018). Combined snow and rainfall during 14–16 April 2018 averaged about 10× higher (range = 3–62×) than any other 3-day maximum amount of combined snow and rainfall in April during the preceding 38 study years. The average number of days with ground snow cover in April during 1980–2017 was 1.2 days (there were 20 days of snow cover in April 2018); and the average amount of daily snow depth on the ground in April during 1980–2017 was ≤ 25 mm (National Climatic Data Center website).

Wisconsin Cooper's hawks are principally ground-foraging predators, and snow cover may limit access to ground-dwelling prey, which includes songbirds, the mourning dove (*Zenaida macroura*), and small mammals (especially eastern chipmunks, *Tamias striatus*). Availability of such prey may trigger egg-laying in Wisconsin Cooper's hawks (Rosenfield et al. 2016). The intense spring storm in 2018 precluded for the first time in 39 years my travel to my Cooper's hawk study nests because virtually all roads (and landscapes) became impassable with deep, wet snow for four days following the storm in and around Stevens Point, Wisconsin (Fig. 1). This city is my residence and the geographic center of my mid-Wisconsin study area. Notably, during about two weeks following this storm, unsolicited communication with the general public about their detections of 'high numbers' of dead birds in my study area demonstrated local concern about the possible population effects of this 'historic' storm.

Fig. 1. Heavy snowfall during a severe, mid-April 2018 storm in Stevens Point, Wisconsin, near the center of our Cooper's Hawk study area.

Obr. 1. Silné sneženie počas prudkej búrky v polovici apríla 2018 v Stevens Point, Wisconsin, blízko stredu študijnej plochy jastraba čiapočkatého.

My objective was to document the breeding phenology and reproductive success of the study population in the storm's aftermath, in addition to the nesting season survival of marked adults observed at their breeding sites 5–15 days prior to this severe April weather. Although I place some of my results in the ecological context based on analyses of similar, long-term demographics from this study population (Rosenfield et al. 2016, R.N. Rosenfield, unpubl. data), I highlight that this study population had never experienced in the previous 38 years spring weather as severe as that in April 2018, and so I was hesitant to predict what, demographically, to expect post-storm. Regardless, my findings are relevant to depicting how a breeding raptor population contends with severe weather, as stochastic events are projected by climate change models to be a more frequent phenomenon into the 22nd century (USGCRP 2017).

Methods

I studied breeding Cooper's hawks during 1980–2018 in central Wisconsin, as described in Rosenfield (2018) and Rosenfield et al. (1995). My study area included the rural environments of Portage County and within the same county the abutting municipalities of Stevens Point, Whiting and Plover, with a predominately urban population of about 38,000, and a human density of about 600/km^2 (US Census Bureau 2000).

Each year I find > 90% of nests before egg-laying by listening for dawn vocalizations or by searching for partially constructed nests during the pre-incubation stage, about mid-March through late April (Rosenfield 2018); all nests analyzed for 2018 were found prior to the April storm. I am thus able to examine productivity without adjusting for the biases that might have resulted from excluding breeding attempts that failed prior to discovery (Rosenfield et al. 2000).

I made at least two visits to nests to assess reproduction. One visit included climbing to nests during the mid-incubation period (about mid-May) to obtain completed clutch counts, and another climb about mid-June when nestlings were about 18 days of age, or about 70% of fledgling age, to ascertain brood size and nestling age, and band the young in the nests. This schedule avoided the criterion of 80% fledgling age suggested for other raptor species, an age at which visits could result in premature fledging of some nestlings and/or inaccurate brood counts of Cooper's hawk young (Rosenfield et al. 2007). I report average brood counts (± standard error) for successful nests in 2018, which are defined as those in which at least one young reached ≥ 18 days of age (Rosenfield et al. 2016). Hatching dates per nest were determined by backdating from estimated nestling ages of the oldest chicks based on plumage development (Rosenfield et al. 2016). I report the median hatching date for successful nests in 2018; I use the median because it is less sensitive to outliers which could skew results (Rosenfield et al. 2016). Nest success was the proportion of occupied nests that were successful (an occupied nest is one in which eggs were laid).

I identified 15 males and 1 female (she was paired with one of the 15 males) in the nesting areas before the 14–16 April storm by sighting their colored, unique alpha-numeric coded leg bands using binoculars or a spotting scope. I defined a nesting area as a nest-centered plot of 800 m in diameter which was occupied by a breeding adult in one or more years (this metric is the median inter-nest distance between breeding pairs in our Wisconsin study areas; Rosenfield et al. 2016). Survival of marked individuals after the storm was verified by re-sightings or re-captures in nesting areas during the nestling stage. Breeding adults are initially marked (and re-trapped in later years) when captured in mist nets with use of a live, decoy great horned owl (*Bubo virginianus*; see details of trapping techniques in Rosenfield (2018).

Results and discussion

I found 21 occupied nests, of which one failed at the egg stage in 2018; no adults were observed incubating eggs at any of these 21 nests prior to the April storm. The median hatch date for the remaining 20 successful Cooper's hawk nests was 10 June (range: 27 May–19 June), which was the sixth latest median hatch date in a breeding season for 39 years (1980–2018). The five later median hatch dates (of which 14 June 1982 was the latest) occurred during the first 17 years of the 39-year study, and thus 2018 was the latest median hatch date in the 22 years since 1996. During this period the average median hatch date was 5 June. Accentuating the later timing of hatching in 2018, the median hatching date for the study population advanced an average of 1.3 days/decade since 1980 in accord with climate warming in Wisconsin (Rosenfield et al. 2016, RNR, unpublished data). The ~3-week period between the earliest (27 May) and latest hatching date (19 June) of young at nests in 2018 is similar to the annual average 20-day range between earliest and latest calendric timing of hatching at nests in the previous 38 years for the study population of Wisconsin Cooper's hawks (Rosenfield et al. 2016, RNR, unpublished data).

Survival was complete for a total of 16 uniquely color-marked adult Cooper's hawks (15 males and 1 female, which includes one mated pair) identified in 15 nesting areas 5–15 days prior to the 14–16 April 2018 storm. All 16 birds were present until their young had reached at least 19 days of age in the nesting area where each adult was initially observed that year.

Reproductive output of Cooper's hawks in 2018 was on average similar to Wisconsin metrics for our study species in the previous 38 years (1980–2017; Rosenfield et al. 2016, RNR, unpublished data). In 2018, average clutch size at 21 nests was 4.4 ± 0.13 eggs (range 3–5), and average brood size at 20 successful nests was 4.0 ± 0.24 nestlings (range = 3–5). During 1980-2017, the overall average clutch count was 4.3 eggs/nest (range of annual averages = 3.9–4.8 eggs; n = 648 nests), and the average brood size per successful nest was 3.7 young (range of annual averages = 3.1–4.1 nestlings; n = 776 nests). Average clutch and brood sizes per successful nest have remained stable during these 38 years (Rosenfield et al. 2016, R.N. Rosenfield, unpubl. data). Furthermore, these long-term metrics are among the highest such measures for any population of Cooper's hawks in North America (Rosenfield 2018). Thus the later timing of hatching in 2018, most likely influenced by the severe spring storm, appeared to have no apparent deleterious effects on the productivity of our study population. Accentuating this conclusion, nest success during 2018 was 95%, which was higher than the overall average 77% (range = 57–93%) nest success rate in the previous 38 years (Rosenfield et al. 2000, RNR, unpublished data). Moreover, the three-week nesting period in 2018 was similar to the annual duration of three weeks for the nesting season in earlier decades (Rosenfield et al. 2016). Notably, I have been unable to show in my multi-decade studies that habitat (rural or urban, conifer plantation or non-plantation, presumptive site quality as indexed by consistency of nest area use, and high breeding density) is related to size of clutch or brood counts, nesting phenology, annual adult survival, and production of recruits, or fitness in Wisconsin Cooper's hawks (Rosenfield & Bielefeldt 1999, Rosenfield et al. 2000, 2009, 2016). Conceivably, the apparent high quality of various Wisconsin habitats for breeding Cooper's hawks could be related to a lessening of the impacts of severe weather.

Adequate amounts of prey were probably available to support in part the survival of adults and the high reproduction in our Wisconsin nesting areas despite the severe weather early in the 2018 breeding season. It is possible that alternative, non-ground prey may have been important for the Cooper's hawks during the pre-incubation period (they typically use shrub- and ground-dwelling prey). Indeed, I documented numerous feathers of pine siskins (*Spinus pinus*) at plucking posts (substrates where avian prey are delivered and plucked by adults) in 11 of the 21 nesting areas visited in April 2018. I had rarely detected feathers of pine siskins at plucking posts during the entire nesting season at Wisconsin-wide nest sites prior to 2018 (Rosenfield 2018). This songbird is a tree canopy species, but, unlike the American robin (a predominant prey species of Wisconsin Cooper's hawks especially during the pre-incubation period), the siskin will also use feeder stations (Dawson 1997). Thus, the siskin's use of above-ground habitat may have provided an alternative prey resource for Cooper's hawks, given the ground snow cover in April 2018. Similarly, researchers in Florida reported a heavy reliance' by breeding male Cooper's hawks on nestling songbirds taken from tree canopy nests apparently due to low levels of ground prey (Millsap et al. 2013).

Climate change models predict greater frequency of severe storms into the 22nd century (USGCRP 2017), and so I urge raptor researchers to document in detail how birds of prey contend behaviorally and demographically with severe weather, as such responses by this group of birds are globally underreported and/or unknown (Anctil et al. 2014). My study population of Wisconsin Cooper's hawks contended favorably in one breeding season to a single severe weather event, with high nest success and average indices for clutch and brood sizes, including high adult survival. However, these results stem from one population responding to a severe weather event in a single year. If climate projections are correct, similar breeding demographics across larger temporal and spatial scales could provide more insights into the population effects of future erratic weather on raptor species.

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Migration pattern and wintering population of the Eurasian marsh harrier (*Circus aeruginosus*) in the Central Marshes, a wetland of international importance in southern Iraq

Charakter migrácie a zimujúca populácia kane močiarnej (*Circus aeruginosus*) v Centrálnych močiaroch, mokradi medzinárodného významu v južnom Iraku

Omar F. AL-SHEIKHLY & Ahmad J. AL-AZAWI

Abstract: There is scarce information on the migration patterns and population size of the Eurasian marsh harrier (*Circus aeruginosus*) in Iraq in general and in the southern Mesopotamian wetlands in particular. From February 2018–April 2019, a total of 11 field expeditions were conducted in the Central Marshes (219,700 ha), one of the major Mesopotamian wetlands and Iraq's National Park, a RAMSAR and UNESCO site. Two of the field survey objectives were to determine the spatial and temporal distribution and estimate the population size of the migratory/wintering Eurasian marsh harrier in the Central Marshes. Distance sampling on three line-transects covering a study plot of 40,000 ha was conducted. Among other wintering *Circus* harriers, the Eurasian marsh harrier was the most abundant species with a total of 93 individuals recorded. The estimated species densities were 0.0042–0.035 individuals/ha, and the estimated size of the Eurasian marsh harrier migratory population in the Central Marshes was 922.7–7,689.5 individuals. Moreover, the migration phenology and breeding status of the Eurasian marsh harrier in the Central Marshes were investigated. Our efforts did not confirm the breeding of this species during recent years, or since the inundation of the Mesopotamian wetlands in 2003. Furthermore, hunting and trapping were identified as major threats affecting the species which need urgent conservation action.

Abstrakt: O charaktere migrácie a veľkosti populácie kane močiarnej (*Circus aeruginosus*) všeobecne v Iraku a obzvlášť v mokradiach južnej Mezopotámie je málo informácií. Od februára 2018 do apríla 2019 sa v Centrálnych močiaroch (219 700 ha), jednej z najvýznamnejších mokradí Mezopotámie, Ramsarskej lokalite a lokalite Svetového dedičstva UNESCO, uskutočnilo 11 expedícií. Jedným z cieľov terénneho prieskumu bolo určiť priestorovú a časovú distribúciu a veľkosť populácie migrujúcej/zimujúcej kane močiarnej v Centrálnych močiaroch. Distančné vzorkovanie sa uskutočnilo na troch transektoch pokrývajúcich plochu 40 000 ha. Kaňa močiarna s 93 zaznamenanými jedincami bola najpočetnejšou zo zimujúcich kaní (*Circus*). Hustota druhu bola odhadnutá na 0,0042 – 0,035 jedincov/ha a veľkosť migrujúcej populácie kane močiarnej v Centrálnych močiaroch bola odhadnutá na 922,7 – 7689,5 jedincov. V príspevku tiež diskutujeme migračnú fenológiu a hniezdny status kane močiarnej na študovanom území. Náš výskum nepotvrdil súčasné hniezdenie tohto druhu na území a ani od zaplavenia mezopotámskych mokradí v roku 2003. Ako najväčšie hrozby pre druh tu boli identifikované lov a chytanie do pascí, čo vyžaduje neodkladné ochranárske opatrenia.

Key words: avifauna, Mesopotamian wetlands, population, protected areas, raptor, density.

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Introduction

The Eurasian marsh harrier (*Circus aeruginosus*) is a long-distance migrant raptor, moving on a broad front and using a leap-frog migration pattern (Bildstein 2006, Panuccio et al. 2013a, Polakowski et al. 2014). Its zoogeographical range extends from western Europe

(Fennoscandia south to the Iberian Peninsula), east to Central Asia (Baikal), Asia Minor and Mongolia, and into northern Africa. It winters in southern Europe, sub-Saharan Africa (few cross the equator), and in the Indian subcontinent (GRIN 2019).

In the western Palearctic there are two main known routes for migratory raptors (Bildstein & Zalles 2005, Bildstein 2006). These are the Western European-West African (Atlantic) flyway, where raptors migrate from Scandinavia through western Europe to Spain, and the West African and Eurasian-East African (western Black Sea) flyway, which leads from north-eastern Europe and western Siberia, passes through the Middle East and ends in sub-Saharan Africa (Shirihai & Christie 1992, Shirihai et al. 2000, Bildstein 2006, Meyburg et al. 2017, Fülöp et al. 2018). However, Marsh harriers originating from north-eastern European populations and migrating south-west along the southern Baltic Sea coastline are assumed to make a strong contribution to the Western European-West African flyway (Panuccio et al. 2013b, Polakowski et al. 2014).

During autumn and spring, large numbers of migratory raptors pass along the major flyways, avoiding large water bodies or high mountain chains, and become concentrated at just a few bottleneck sites around the Mediterranean Sea, Black Sea and Red Sea (Verhelst et al. 2011). The main bottleneck sites on the Western European-West African flyway are situated in Sweden, Spain, and Italy (Porter & Beaman 1985, Kjellén 1992, Kjellén & Roos 2000, Bildstein 2006, Polakowski et al. 2014), while those on the Eurasian-East African flyway are in Romania, Bulgaria, Greece, Georgia, Turkey, and Israel (Porter and Beaman 1985, Shirihai & Christie 1992, Shirihai et al. 2000, Bildstein 2006, Ullman & Ullman 2010, Michev et al. 2011, Panuccio et al. 2011, Verhelst et al. 2011, Fülöp et al. 2018, Panuccio et al. 2018).

In autumn, raptors originating from the eastern part of the western Palearctic arrive in the Middle East via two major routes. The first follows both sides of the Black Sea and northern Caspian Sea area, bypassing the eastern Mediterranean Sea and the northern Red Sea, and move through Levant/Israel using the North Negev and Dead Sea-Kfar Kasem-Eliat-Suez route towards Sinai (Porter & Beaman 1985, Shirihai & Christie 1992, Shirihai et al. 2000, Verhelst et al. 2011, Fülöp et al. 2018). The second major route involves mostly the eastern and some western populations following the south-eastern side of the Caspian Sea and crossing the north-eastern Arabian Peninsula, the Arabian Gulf via the Hormuz Straits, and the southern Red Sea via the Bab-el-Mandeb Straits between Yemen and Djibouti (Shirihai & Christie 1992, Shirihai et al. 2000, Ullman & Ullman 2010, Panuccio et al. 2018).

The Mesopotamian marshes (Ahwar) are large open freshwater wetlands occupying the Tigris and Euphrates river basin. The estimated total area of the Iraqi marshes is 900,000–2,000,000 ha covering the alluvial plain of the Arabian Gulf delta in southern Iraq (Haba et al. 2017). The Mesopotamian marshes consist of three major core wetlands, which are the Central Marshes, Hammar Marsh (Haur Al-Hammar), and Hawizeh Marsh (Haur Al-Hawizeh) (Al-Mansori 2008). In the 1990s the Mesopotamian wetlands of southern Iraq faced massive habitat destruction after they were almost drained following the uprisings in Iraq in 1991, although they were subsequently re-flooded in 2003–2004 (Richardson et al. 2005, Al-Sheikhly & Nader 2013).

One of the major Mesopotamian wetlands is the Central Marshes, a vast complex of permanent freshwater wetlands extending along the geographical zone (30°50' N–31°30' N and 46°45' E–47°25' E) between ThiQar (Nassiriyah), Mayssan (Emara), and Basra provinces, and covering a total area of 219,700 ha (Evans 1994, RSIS 2019). The Abu Zirig marshes (Haur Abu Zirig) form the north-western part of the Central Marshes, the Al-Chebaeish (Al-Chabaish, Al-Chibaish) marshes make up the central part, while Lake Zichri occupies the eastern part. The Central Marshes have been identified as an Important Bird Area (IBA038), a wetland of International Importance, and as a Key Biodiversity Area (KBA) site (Carp 1980, Evans 1994, Nature Iraq 2017). Due to their ecological significance, the Central Marshes were declared Iraq's first National Park (Mesopotamian National Park MNP), a RAMSAR site, and a United Nations Educational, Scientific and Cultural Organization (UNESCO) site (IMOE 2014, Pearce 2014, UNESCO 2016, RSIS 2019).

Iraq is one of the range countries for many migratory raptors en route to their wintering grounds in Arabia and Africa, however, raptor migration in the Mesopotamian wetlands of southern Iraq has not been fully investigated (Al-Sheikhly et al. 2017). Besides other hen (*C. cyaneus*), pallid (*C. macrourus*), and Montagu's (*C. pygargus*) harriers wintering in the Mesopotamian wetlands, the Eurasian marsh harrier is the most abundant and predominant raptor species (Scott 1995, Abed 2007, Fazaa et al. 2017). It is a Least Concern species (Birdlife International 2019) which has been regarded as a local breeding resident in the southern marshes and possibly in the wetlands of central Iraq as well, it is also a passage migrant and winter visitor (Salim et al. 2012). In the past, it was abundant in the Euphrates marshes, at Hammr Lake, and in the marshes near Basra, where it bred (Ticehurst et al. 1922). It was common to the Suweicha marsh in Kut and in the plains between Suweida and Chabbab on the north bank of the Tigris River (Allouse 1960, Moor & Boswell 1965). It was the most abundant raptor in Haur Al-Hammar and adjacent areas and at Haur Uwainah and along the Nasiriya-Kut road, where a total of 286 harriers were observed during a mid-winter survey in 1979 (Scott & Carp 1982). The Eurasian marsh harrier has been recorded at many sites around the geographical zone of the Mesopotamian marshes. A total of 73 marsh harriers were recorded during very incomplete surveys in January 1968, December 1972 and January 1979 (Scott 1995). However, information on the breeding and wintering populations of the Eurasian marsh harrier in the Mesopotamian wetlands was particularly scarce after the marshes were inundated in 2003. It was listed among the avifauna of the southern Iraqi marshes recorded from 2005 to 2008 (Salim et al. 2009). The Eurasian marsh harrier was the most abundant raptor species recorded in three restored Mesopotamian wetlands in southern Iraq during May 2004–May 2005 (Abed 2007). Moreover, it was recently recorded in the Central Marshes where a total of 28 marsh harriers were observed during October 2013–June 2014 (Fazaa et al. 2017). Given the lack of information concerning their current spatial and temporal distribution, migration patterns and estimated population size of migratory (wintering/passage migrant) Eurasian marsh harriers in the Central Marshes, this study was conducted to fill this gap.

Materials and methods

Study area

The study area (study plot) is situated within the Central Marshes geographical zone (Fig. 1). This is a vast complex of permanent freshwater wetlands, semi-desert aridlands and scrublands which encompasses an area of 40,000 ha (400 km^2) and occupies the Tigris-Euphrates Alluvial Salt Marsh (PA0906) Ecoregion with altitudes of less than 6 m. The study area is fed with water from the Tigris and Euphrates rivers and their tributaries. The general landscape is dominated by freshwater open lakes lined with dense common reed (*Phragmites australis*) beds and *Typha* sp. vegetation.

Field techniques

A line-transect survey with a distance sampling field method was performed (Sutherland 2006, Hardey et al. 2013). A total of three distanced longitudinal water tran-

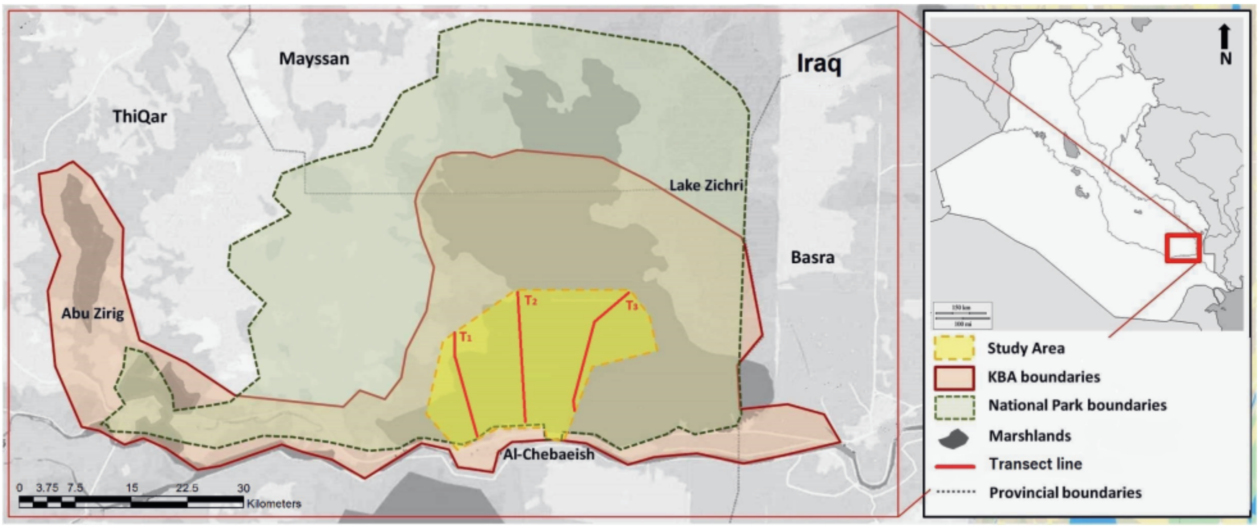
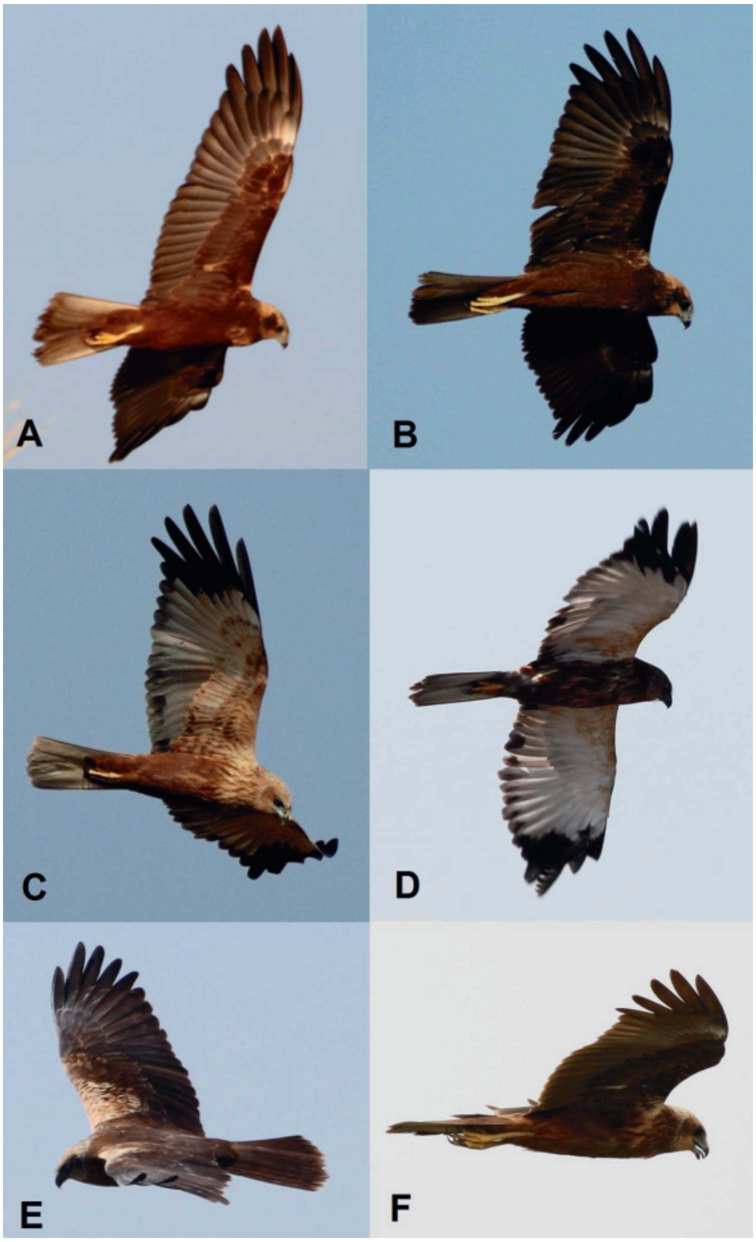


Fig. 1. The Central Marshes area in Southern Iraq, showing the boundaries of the study area, Key Biodiversity Area (KBA), and National Park boundaries.

Obr. 1. Územie Centrálnych močiarov v južnom Iraku, zobrazené sú hranice študovaného územia, Kľúčové územie biodiverzity (KBA) a hranice národného parku. Study area = skúmané územie, KBA boundaries = hranice Kľúčového územia biodiverzity, National Park boundaries = hranice národného parku, Marshlands = močiare, Transect line = transekt, Provincial boundaries = hranice provincie.



OF Al-Sheikhly

Fig. 2. Age classes of the Eurasian marsh harrier (*Circus aeruginosus*) in the Central Marshes, Southern Iraq. A & B: Juvenile (1st y), overall dark-brown body, fresh flying feathers, dark underside of primaries with pale crescent at base, underwing coverts and tail lack rufous tint, head with pale yellowish crown and dark eyes. C: Sub-adult/Immature (3rd y) male, streaked upper-breast, pale secondaries with dark subterminal band, dark rufous underwing coverts, and brown eyes. D: Adult male, body retains younger plumage, whitish underwing coverts with light rufous wash, and yellow eyes. E: Adult female, creamy patches on upperwing coverts contrasting with darker secondaries, rufous cast on tail and uppertail coverts, and yellowish eyes. F: Older juveniles/immature (circa 2nd y) probably a young male, fresh flight feathers retain juvenile plumage, streaked upperbreast, clear facial disk, and pale tail feathers.

Obr. 2. Vekové triedy kaní močianych (*Circus aeruginosus*) z Centrálnych močiarov, južný Irak. A a B: juvenil (1. rok), celkovo tmavohnedé sfarbenie, nové letky, tmavý spodok ručných letiek so svetlým "polmesiacom" na báze, spodným lakťovým krovkám a chvostu chýba červenohnedý nádych, hlava so svetložltým temenom a tmavými očami. C: subadultný (3. rok) samec, prúžkovaná horná časť hrude, svetlé lakťové letky, s tmavý pásom na okraji, tmavé červenohnedé spodné lakťové krovky, hnedé oči. D: Dospelý samec, telo si zachováva perie mladšieho vtáka, belavé spodné krovky s ľahkým červenohnedým nádychom, žlté oči. E: Dospelá samica, krémové škvrny na horných lakťových krovkách kontrastujúce s tmavšími lakťovými letkami, červenohnedý nádych na chvoste a horných chvostových krovkách, žltkasté oči. F: Starší juvenilný/nedospelý jedinec (asi 2. rok), pravdepodobne mladý samec, nové letky si zachovávajú juvenilný charakter, prúžkovaná horná časť hrude, svetlá tvárová časť a bledé chvostové perá.

sects (length 10 km each) covering a study plot of 40,000 ha were randomly identified and followed by motor canoe. Transect (T1) started from the first channel in Al-Hamrawia (Al Moajed Village) and covered the western part of the Central Marshes; (T2) started from the Abo Sobat Channel in Al-Chebaeish district and covered the central part of the Central Marshes; (T3) started from Kinziri Village towards Zichri Lake and covered the eastern part of the Central Marshes. Transects were carefully surveyed at a slow-moving rate (20–30 km/hour) in order to increase detection probability and accurate identification of species, and reduce the possibility of double counting. Transects were randomly followed from south to north and north to south alternately, and flying/perching raptors within a fixed observation/detection distance (500 m) were counted. Stopping points were applied at fixed intervals (15–20 minutes) along each surveying transect; a 30 to 40-

minute time period was spent at each stop. Counting of raptors stopped at the end of each survey transect, and raptors observed on the way back were ignored.

A total of 11 field surveys were conducted in the Central Marshes from February 2018 to April 2019. Three days were spent in the study area during each survey period (one day/transect), and six to eight hours per day were spent moving along each transect. The field observations were made using a ‘double-observer’ approach by three field observers (primary observer, secondary observer, and recorder). The starting time of the field surveys varied. A Canon EOS/SLR 7D Canon camera body attached to 100×400 mm and Canon image stabilizer zoom lens and 8×42 mm Swarovski binocular were used to observe/document species/habitats. A Garmin GPS device was used to digitally position the three transect way-points on the map.

The age state of the observed harriers was classified into two classes: (i) juvenile/immature (year y1–2) and (ii) adult (≥y3) birds (Fig. 2). Their breeding was assessed using the British Trust for Ornithology (BTO) breeding evidence (BTO 2019) and interviews with Marsh Arabs (indigenous inhabitants of the Mesopotamian Marshes) were performed when possible. The species field identification remarks followed (Clark 1999).

Data analysis

The species density was interpreted as the number of individuals recorded in one hectare of the study area. The species density was calculated in each survey using distance sampling (Sutherland 2006). The estimated species density (D) was calculated in each survey using the formula: $D = n\sqrt{(2n/\pi\sum_i(x^2_i))}/(2L)$ where n = total number of birds detected, L = length of transect, and x_i = perpendicular distance from the transect line of the ith bird detected. Perpendicular distance x_i was calculated using the formula $x_i = Z \sin\Theta$, where Z = distance from observer to the bird in meters (m), and Θ = measured observation angle. The Z distance was estimated using the mean of three observers’ estimations. The observation angle was measured using a measuring protractor. The species migratory/wintering population size in the Central Marshes was estimated by extrapolating the species density to the total area size of the Central Marshes (219,700 ha) (Fazaa et al. 2015). In order to determine significant differences between age/sex classes, the chi-square (χ^2) test of goodness-of-fit was performed (McDonald 2014). Our null hypothesis suggests no differential migration between age/sex classes ($H_0 = P_{juvenile/immature} = P_{adult\ male} = P_{adult\ female}$).

Results

Population size

During the 2018–2019 field surveys, a total of 93 marsh harriers were recorded in the Central Marshes. The species was observed in all surveyed transects and periods, except May and June 2018 and April 2019. The recorded age classes were 53 juveniles/immature, 16 adult males and 24 adult females (Tab. 1).

In February 2018 a total of five harriers (two juveniles; one adult male; two adult females) were carefully observed at an estimated 30–300 m distance range with 22–42° observation angles. The estimated density for this species in the study area was 0.013 individual/ha, and the estimated population migrating across the Central Marshes was 2,856.1 individuals.

In March 2018 a total of three harriers (two adult females and one juvenile) were carefully observed at an estimated 50–200 m distance range with 30–45° observation angles. The estimated species density was 0.0055 individual/ha, and the estimated migratory population was 1,208.35 individuals.

In April 2018 two adult males were carefully observed at estimated 70 m and 90 m distances with 30° and 22° observation angles. The estimated species density was 0.0077 individual/ha, and the estimated migratory population was 1,691.69 individuals.

In September 2018 a total of eight harriers (seven juveniles; one adult male) were carefully observed at an estimated 20–400 m distance range with 25–70° observation angles. The estimated species density was 0.0066 individual/ha, and the estimated migratory population was 1,450.02 individuals.

In November 2018 a total of 15 harriers (11 juveniles; 3 adult females; 1 adult male) were carefully observed at an estimated 50–300 m distance range with 30–75° observation angles. The estimated species density was 0.019 individual/ha, and the estimated migratory population was 4,174.3 individuals.

In December 2018 four harriers (one juvenile; two adult females; one adult male) were carefully observed at an estimated 100–200 m distance range with 40–70° observation angles. The estimated species density was 0.0042 individual/ha, and the migratory population was 922.74 individuals, which represents the lowest estimated value.

Tab. 1. Total number of age classes of the Eurasian marsh harrier (*Circus aeruginosus*) with estimated species densities, migratory/wintering population size, and differences among age/sex groups in Central Marshes-Southern Iraq (February 2018–April 2019). y = year; Z = range of distance from observer to the detected bird; Ɵ = range of observation angles.

Tab. 1. Početnosť vekových tried kaní močiarnych (*Circus aeruginosus*), odhadovaná hustota, veľkosť migrujúcej/zimujúcej populácie, rozdiely medzi vekovými triedami a pohlaviami v Centrálnych močiaroch, južný Irak (február 2018 – apríl 2019). y = rok; Z = rozsah vzdialeností medzi pororovateľom a pozorovaným jedincom; Ɵ = rozsah pozorovaných uhlov.

	2018								**2019**			
age/month / vek/mesiac	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Sep**	**Nov**	**Dec**	**Jan**	**Mar**	**Apr**	**∑**
juvenile/immature (y1-2) /juvenil/nedospelý	2	1	0	0	0	7	11	1	21	10	0	53
adult male (≥y3) / dospelý samec	1	0	2	0	0	1	1	1	6	4	0	16
adult female (≥y3) / dospelá samica	2	2	0	0	0	0	3	2	8	7	0	24
∑	5	3	2	0	0	8	15	4	35	21	0	93
Z (m)	30–300	50–200	70–90	0	0	20–400	50–300	100–200	20–400	60–400	0	-
Ɵ (o)	22–42	30–45	22–30	0	0	25–70	30–75	40–70	10–70	20–70	0	-
estimated density (ind/ha) / odhadovaná hustota	0.013	0.0055	0.0077	0	0	0.0066	0.019	0.0042	0.035	0.02	0	-
estimated migratory/wintering population / odhadovaná veľkosť migrujúcej/zimujúcej populácie	2,856.1	1,208.35	1,691.69	0	0	1,450.02	4,174.3	922.74	7,689.5	4,394	0	24,386.7

The highest count of Eurasian marsh harriers was made in January 2019, when a total of 35 harriers (21 juveniles; eight adult females; six adult males) were carefully observed at an estimated 20–400 m distance range with 10–70° observation angles. The estimated species density in this case was 0.035 individual/ha, and the estimated migratory population was 7689.5 individuals.

In March 2019 a total of 21 harriers (10 juveniles; seven adult females; four adult males) were carefully observed at an estimated 60–400 m distance range with 20–70° observation angles. The estimated species density was 0.02 individual/ha, and the estimated migratory population in the Central Marshes was 4394 individuals (Tab. 1).

Migration

Our field surveys focused on the period when large numbers of passage migrant and wintering Eurasian marsh harriers can be observed, mainly during autumn (September–November), winter (December–January), and spring (February–April) each year. The Eurasian marsh harrier migration in the Central Marshes starts in September, when migrant individuals emerge and are then followed by a noticeable increase in numbers of migrants in November–January. The peak of the Eurasian marsh harrier winter migration is in January, when a total of 35 migratory/wintering individuals were counted. The winter count possibly represents the actual migratory/wintering populations of Eurasian marsh harrier in the Central Marshes; this assumption however needs further investigation. Afterwards the numbers of migrant individuals fade during the subsequent months (March–April) (Tab. 1).

Breeding

Furthermore, summer surveys (May–July) which focused on observing late migrant and/or breeding pairs in the Central Marshes were conducted. Despite our intensive field surveys, no harriers were detected. Moreover, large proportions of the study area which appear to be suitable breeding habitats (dense reed beds) for the Eurasian marsh harrier were surveyed. Breeding evidence such as adult harriers in pairs or in courtship/display, occupied breeding territories or nesting sites were not detected during the survey period, and the area seems to be abandoned (Tab. 1).

Discussion

The Eurasian marsh harrier is a common raptor widely spread over the Mesopotamian wetlands. It has been regularly recorded since the 1920s, but its wintering population trends were enigmatic. Besides the migration pattern, this study represents an initial attempt to quantify the Eurasian marsh harrier population size in the Central Marshes, a wetland of international importance in southern Iraq. Knowing population trends of migratory species might be useful to predict ecological changes in the Mesopotamian wetlands in the future.

Historically, the species was abundant in the Mesopotamian wetlands prior to the 1990s, when extensive hydrological drainage was carried out (Scott 1995, Hussain 2014). Large numbers of marsh harriers (286 individuals) wintered here in 1979 (Scott & Carp 1982). The drainage of the Mesopotamian wetlands had an adverse effect on the populations of about 40 avian species occurring in the marshes in internationally significant numbers, and it might have caused a major decline (> 10%) in Eurasian marsh harrier regional populations (Evans 1994, Scott 1995). However, the species continues to visit the Mesopotamian marshes, but in lower numbers (Abed 2007, Fazaa et al. 2017).

When estimating the current population size of the migratory Eurasian marsh harrier in the Central Marshes, we reduced bias probabilities through standardized field methodologies and arithmetical estimations, even so, a number of caveats should be taken in consideration. The scarcity of available data related to habitat classification in the Central Marshes made the identification of the surveying sites and suitable applied methodologies rather difficult. We assumed the species made use of the whole geographical zone of the Central Marshes, and also that the habitat classification within the study area was homogenous, of course this is a simplification. The detection distances were estimated rather than being measured using digital range-finders, such devices are prohibited due to the security situation in Iraq. Fazaa et al. (2017) indicated that the numbers of migratory Eurasian marsh harriers in the Central Marshes increased during December 2013. However, our low count in December (n = 4) is explained by low detection probability due to very brief (one day) survey efforts influenced by security and logistical circumstances. Current results suggest that the migratory/wintering population of the Eurasian marsh harrier in the Central Marshes is estimated at between 923–7690 individuals (mean ± SD = 2,216.9 ± 2,392.3), however, cumulative results from subsequent years suggest the need for further estimations.

There is a scarcity of information concerning raptor migration in Iraq and the Middle East generally (Shirihai & Christie 1992, Shirihai et al. 2000, Al-Sheikhly et al. 2017). Our results suggest that the autumn migration of the Eurasian marsh harrier in the Central Marshes starts in early September, when increasing numbers of migrants emerge, similar to those migrating from western and eastern Europe across sub-Saharan Africa (Strandberg et al. 2008, Agostini and Panuccio 2010, Agostini et al. 2017). The pre-migration movement strategies adopted by the genus *Circus* are used to reduce intraspecific competition, ensuring sufficient resources for moulting or recovering from breeding efforts, and for preparing for migration (Limiñana et al. 2008, Triewieler et al. 2008). The timing of Eurasian marsh harrier differential migration in the Central Marshes has not been fully explored. Juvenile/immature marsh harriers (n = 53, 57%) dominated the migratory population in the Central Marshes, followed by adult females (n = 24, 26%) and then by adult males (n = 16, 17%), with significant differences between age classes ($\chi^2_{(2)} = 25.452$, $P < 0.05$). Our results are in agreement with those for marsh harriers migrating across the Falsterbo Peninsula in Sweden (western Europe) in autumn, where juveniles (n = 1594, 78%) outnumbered adult females (n = 273, 13%) and adult males (n = 216, 9%) (Kjellén1992). In contrast, adult marsh harriers were observed in greater numbers than juveniles along the Central Mediterranean flyway (Agostini et al. 2017). Furthermore, our observations suggest that migrating juveniles arrive in the Central Marshes earlier than adults, as their numbers gradually increased from September–January (7–21) respectively. Juveniles tend to migrate over shorter distances, and their migration speed is lower than for adults (Strandberg et al. 2008). Adults may be less inclined to follow major flyways during migration, however, the differential timing between juveniles and adult females ($P < 0.05$) and that between adult females and males ($P < 0.001$) migrating over the Falsterbo Peninsula is significant (Kjellén1992). Conversely, marsh harriers from western and eastern Europe need to refuel at several stopover sites before crossing the Mediterranean Sea in a long-distance energy consuming migration (Agostini et al. 2017). Ring recoveries show that adult marsh harriers tend to engage in autumn migration slightly earlier than juveniles (Strandberg et al. 2008), similarly to those crossing on the Central Mediterranean flyway (e.g. Agostini et al. 2017). However, marsh harriers from western Europe migrating across the Sahara Desert showed no distinct differences between sexes, timing, duration or speed of autumn and spring migrations, except that adult females tended to migrate faster than males in spring (Strandberg et al. 2008, Panuccio et al. 2013a).

The autumn movement of satellite-tagged marsh harriers from western Europe towards their wintering grounds in western Africa showed that adult females arrived earlier (early October) than adult males, which arrived in mid-October (Strandberg et al. 2008). However, the timing of autumn migration of adult marsh harriers in the Central Marshes is rather different from that of harriers from western Europe. Our results show that adult males seem to arrive earlier (mid-September) than adult females (mid-November), but in lower numbers. This is in accordance with the "body size hypothesis" about smaller and lighter males migrating over longer distances (Agostini et al. 2003). The males' tendency towards long-distance movements has been attributed to the higher proportion of males' flapping flight (Spaar & Bruderer 1997), or their avoidance of intraspecific sex competition with larger females, which are capable of capturing larger prey, tolerating cold climates, and enduring starvation (Agostini et al. 2017). However, our conclusion was based on a single observation of an adult male in September with no further records in October, which is rather scarce data to support our claim and requires further investigation.

In the Middle East, several resident breeding populations of Eurasian marsh harriers exist in the northern Mediterranean Sea, southern Black Sea, southern Caspian Sea, and northern Arabian Gulf (Porter & Aspinall 2010). Based on our results, the Central Marshes seems important as a wintering/stopover site for migratory marsh harriers, as 7,690 individuals were estimated (Tab. 1), however, their origin is still unknown. Birds originating from eastern Europe and the central Asian breeding populations probably reach the Central Marshes via the eastern Black Sea and southern Caspian Sea routes (see: Shirihai & Christie 1992, Fülöp et al. 2018), however, this claim requires further verification. On the eastern Black Sea route, at the Batumi bottleneck in south-west Georgia, a total of 4,234 marsh harriers were recorded between August and October in 2008–2009 (Verhelst et al. 2011), a few of which may have drifted away on route to the Central Marshes. On the southern Caspian Sea route, at the Alborz Mountains in north-eastern Iran, a total of 101 marsh harriers were recorded during autumn migration in October 2017 (Panuccio et al. 2018). This route crosses the northern Arabian Gulf region on the way to eastern Africa, and seems to make a significant contribution to the Eurasian marsh harrier migratory/wintering population in the Central Marshes. Moreover, in autumn, marsh harriers (especially juveniles) originating from the Caspian Sea and northern Arabian Gulf breeding populations might arrive in the Central Marshes earlier than those from eastern Europe and Central Asia. This may be attributed to a short-distance movement (e.g. Strandberg et al. 2008) or adapting leap-frog and flapping flight migration strategies (e.g. Spaar & Bruderer 1997). Besides wintering populations, the fate of marsh harriers migrating through the Central Marshes in autumn is unclear. They might migrate across the northern Arabian Peninsula, bypassing the Al-Fao Peninsula in southern Iraq/northern Kuwait to reach eastern Africa via the Bab-el-Mandeb straits, or move through western Iraq towards Sinai via the North Negev and Dead Sea-Kfar Kasem-Eilat route (see: Shirihai & Christie 1992).

Data on raptor migration through the Middle East in spring are deficient, however, the bulk of the spring movement of raptors appears to follow the northern route, bypassing the eastern Mediterranean and northern Red Sea (Shirihai and Christie 1992). In spring, immature marsh harriers were extremely abundant in the marshy areas of southern Iraq up to mid-April, but less so thereafter (Moor & Boswell 1956). This corresponds with our current field observations, as numbers of marsh harriers are notably decreased during April–May.

The current breeding status of the Eurasian marsh harrier in the Central Marshes and adjacent marshy regions is unknown. Previously, their breeding in the Mesopotamian wetlands started in late March-late May, and nests with eggs/young were found in early June (Ticehurst et al. 1922). Breeding records outside the Mesopotamian wetlands geographical zone were lacking for June–July, which was attributed to the impact of extreme heat on bird-watchers (Moor and Boswell 1956). The most recent surveys, especially those preformed after the Mesopotamian wetlands inundation in 2004, did not confirm the breeding of this species (Abed 2007). In addition, marsh harriers left the Central Marshes in April and June 2014 and breeding was not detected (Fazaa et al. 2017). Besides our field observations, extensive interviews with Marsh Arabs have ruled out the breeding of this species in the Central Marshes during recent years. In our study we did not detect any adults with coition attempts, breeding territories or nesting sites, which suggests that marsh harriers are former breeders in the Central Marshes, further field observations may yet modulate this claim.

In Europe, the Eurasian marsh harrier breeding population faces dramatic decline due to shooting, poisoning by pesticides, and habitat destruction and fragmentation especially in south-eastern Europe between 1990 and 2000 (Clarke 1995, Coleiro et al. 1996, Agostini & Pannuci 2010, BirdLife International 2019). The proliferation of wind farms has been identified as a major threat to the species in southern Italy (Panuccio et al. 2007, Panuccio 2011). Further studies on migration routes have been proposed to identify any threats, such as shooting or trapping of migrant raptors, which could lead to conservation measures being set up in the future (Porter & Beaman 1985). Hunting and trapping have been highlighted as major threats to migratory raptors in Iraq (Al-Sheikhly et al. 2017). During our surveys, species persecution has been observed as a serious threat to migratory raptors in the Central Marshes. Several migratory raptors including the Eurasian marsh harrier are persecuted whenever and wherever possible by local hunters/trappers without known motivations. Live trapped harriers are presented in the local animal markets to be sold as domesticated pets or mummified as trophies in hunters' residences or hunting shops. The Iraqi legislation on the protection wild animals (law no. 17 issued on February15, 2010) bans illegal hunting practices in Iraq affecting 34 avian species, unfortunately, the Eurasian marsh harrier is not included. The absence of full enforcement of existing legislation might cause regional declines in certain raptor species (Al-Sheikhly 2011). Moreover, the weak enforcement of the hunting legislation encourages the illegal persecution of many raptor species in Iraq. Indeed, the conservation of the indigenous biota of the Mesopotamian wetlands is an environmental responsibility which urgently needs to be actively acknowledged by the Iraqi authorities.

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Different alternative diets within two subgroups in a winter roost of long-eared owls

Rozdielna alternatívna potrava myšiarok ušatých v rámci dvoch častí zimoviska

Filip TULIS, Tomáš VESELOVSKÝ & Simon BIRRER

Abstract: In winter 2013/2014 a roost of long-eared owls in Bojnice Spa (central Slovakia) was formed by two subgroups situated 12 meters apart from each other. The diets of both subgroups and the direction of the owls' departure from the roost were studied at monthly intervals. Owls of the *Pinus*-subgroup left the roost in a significantly different direction compared with the owls in the *Picea*-subgroup. The common vole was the most hunted prey in both subgroups. However, comparing the alternative prey of the two subgroups, the wood mouse and other mammals were found significantly more often in pellets of the *Picea*-subgroup, whereas birds were more frequent in pellets of the *Pinus*-subgroup. Our results suggest that the different prey hunted by the two subgroups may be a consequence of diverging hunting areas with different availability of alternative prey species.

Abstrakt: V priebehu zimy 2013/2014 bolo zimovisko myšiarok ušatých na lokalite Bojnice kúpele (stredné Slovensko) rozdelené na dve časti, situované 12 metrov od seba. Potrava z oboch častí zimoviska a smer opúšťania zimovísk boli sledované v mesačných intervaloch. Myšiarky z časti zimoviska *Pinus* opúšťali zimovisko preukazne odlišným smerom ako myšiarky z časti zimoviska *Picea*. Hraboš poľný bol najčastejšie loveným druhom koristi v oboch častiachzimoviska. Každopádne porovnanie alternatívnej koristi medzi jednotlivými časťami zimoviska ukázalo, že ryšavka krovinná a ostatné cicavce boli preukazne viac lovené v časti *Picea*, kým vtáky boli preukazne častejšie zastúpene v potrave z časti *Pinus*. Naše výsledky naznačujú, že rozdielne zloženie koristi medzi dvoma sledovanými časťami zimoviska je prejavom využívania odlišných lovných habitatov s odlišnou dostupnosťou alternatívnych druhov koristi.

Key words: *Asio otus*, winter diet, alternative prey, pellet analysis

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Introduction

The long-eared owl (*Asio otus*) is an opportunistic predator (Tome 1991, Bertolino et al. 2001) which prefers open areas (Lövy & Riegert 2013) with forest edges (Henrioux 2000) and network habitats such as hedges and treelines (Galeotti et al. 1997). Its most frequent prey in Central Europe is the common vole (*Microtus arvalis*), but alternative prey is consumed in varying amounts depending on factors such as time, weather and habitat (Birrer 2009). Despite extensive knowledge about the long-eared owl's diet, there is nearly no information about differences in prey use by subgroups of owls living in one roosting-place at the same time.

We studied the foraging behaviour of two subgroups of owls in a roost in winter 2013/2014. This winter roost consisted of two parts, i.e. two different trees, which we labelled as two subgroups. In this article we present: (i) the departure behaviour of the two subgroups in the evening, (ii) differences between the diets of the two subgroups of long-eared owls during winter.

Material and methods

The study was conducted in the western part of the Prievidzská kotlina basin in central Slovakia during the winter of 2013/2014. The long-eared owls' winter roost was situated in the Bojnice Spa park area (48°46´25.16 N, 18°34´18.51 E, 317 m a.s.l.). This roost has been used regularly since 1992 at least (Tulis et al 2015a). The owls roosted in two trees which were 12 m apart and separated by a walkway. The tree to the east was a Norway spruce (*Picea abies*) and the one to the west was Scots pine (*Pinus sylvestris*). The landscape from northwest to southwest of the winter roost is hilly and dominated by extensively-managed grasslands interrupted with hedges and small forest patches. There is a plain with mainly intensively-managed arable fields, some grassland and wetlands along two rivers to the southeast of the roost. A forest and the town of Bojnice border on the roost to the north. The winter climate is characterized by cold weather with average temperatures of 1.3 °C and precipitation of 40.7 mm/month.

The number of owls was counted once a month during their departure in the evening from November 2013 to March 2014, i.e. 5 times. The direction of the owls' departure from the roost was recorded by two persons with the help of a compass with 10° precision at monthly intervals. Pellets were collected also at monthly intervals, separately from both subgroups at the winter roost on the same day when the owls were counted. The pellets were put into 5% solution of sodium hydroxide (NaOH), which dissolves all the undigested parts of prey except the bones. Mammals were identified by the skull – upper jaw (maxilla) and lower jaw (mandibula) according to Baláž et al. (2013). Bird bones were identified using a reference collection based on bills (rostrum), metatarsal (tarsometatarsus), humeral (humerus) and metacarpal (carpometacarpus) bones.

The differences in direction of the owls' departure from the roost were analysed using the Watson-Williams test in Past 3.11 (Hammer & Harper 2006). For statistical analyses four groups of prey were created: 1. *Microtus arvalis*, 2. *Apodemus sylvaticus* 3. birds and 4. other mammals (group consisting of cumulated remaining, less numerous parts of the diet). The minimum number of individuals of each prey species was multiplied with the mean body mass of this species to calculate the total biomass. Data for small mammal weight were taken from Baláž & Ambros (2006) and Baláž et al. (2013) and for birds from Hudec & Šťastný (2005). Trophic niche overlap was measured with Pianka's index, using the percentage of total biomass of particular prey items ($O_{jk} = \sum p_{ij}\ p_{ik} / \sqrt{\sum p_{ij}^2\ \sum p_{ik}^2}$, where p_i is the percentage of prey item "i" in the diet of species "j" and "k") (Pianka 1973).

To study differences in prey use between the two subgroups we built linear mixed models using R-package lme4 (Bates et al. 2015) for each prey group in R (version 3.0.3, R Development Core Team 2011). In these models we used prey-group biomass (arcsinus-squareroot transformed) as dependent variable, subgroup as fixed factor and month as random factor. Bayesian methods were used to assess the significance of the models (Bolker et al. 2008). The function sim from the R-package arm (Gelman & Hill 2007) was used to draw random simulations from the joint posterior distribution of the model parameters. Based on the quantiles of these simulated samples from the posterior distributions, 95% credible intervals (CrI) were obtained for each model parameter. If the difference in proportions between the two subgroups was larger than CrI, a significant effect was assumed.

Results

The number of owls at the winter roost varied minimally (mean ± SD = 5.75 ± 0.50, range 5–6 per month). The *Pinus*-subgroup consisted of two owls at each count, whereas the *Picea*-subgroup contained three owls in November and four individuals in the other months. The mean direction of the owls' departure from the roost was south-west (203.9 ± 10.7°) for the owls of the *Pinus*-subgroup and south-east (116.9 ± 10.5°) for the *Picea*-subgroup (Fig. 1). The difference between the directions

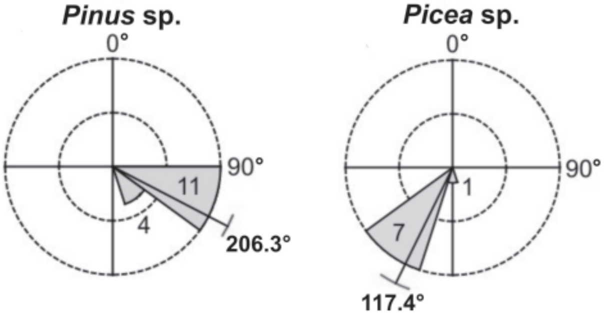


Fig. 1. The direction of long-eared owls' departure from the two parts of the winter roost (grey section = directions of owls' departure with no. of observations, whisker = circular mean of direction).

Obr. 1. Smer odletu myšiarok ušatých z dvoch častí zimoviska (sivá časť = smer odletu myšiarok ušatých zo zimoviska s počtom pozorovaní, línia = kruhový priemer smeru).

Tab. 1. Number and mass of prey species identified in the pellets of long-eared owls from both subgroups at the Bojnice - Spa winter roost, collected monthly over the winter 2013/2014. Mean body mass is taken from the literature (see Study area and Methods section).

Tab. 1. Početnosť a biomasa druhov koristi determinovaná vo vývržkoch myšiarok ušatých z oboch časti zimoviska na lokalite Bojnice-kúpele, zbieraných v mesačných intervaloch v zime 2013/2014. Priemerná hmotnosť tela bola získaná z literatúry (pozri časť Materiál a metodika).

prey species /	***Pinus*-subgroup / časť**						***Picea*-subgroup / časť**					**prey mass / hmotnosť koristi**			
druh koristi	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**∑**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**∑**	**∑∑**	**mean body mass / priem. telesná hmot.**	**% of total biomass / % z celk. biomasy**
Microtus arvalis	27	33	99	41	112	312	37	58	126	75	131	427	739	26	81.3
Microtus subterraneus	1	0	0	2	0	3	0	0	1	0	0	1	4	19	0.3
Arvicola amphibius	0	0	0	0	0	0	0	0	0	1	1	2	2	150	1.3
Myodes glareolus	0	0	0	0	1	1	0	0	1	0	5	6	7	25	0.7
Apodemus sylvaticus	0	1	3	3	1	8	3	4	11	7	13	38	46	25	4.8
Apodemus flavicollis	0	0	0	0	0	0	0	2	0	0	11	13	13	33	1.8
Mus musculus	1	0	0	1	0	2	2	0	0	1	0	3	5	15	0.3
Micromys minutus	1	2	1	0	0	4	3	2	2	1	1	9	13	8	0.4
Crocidura suaveolens	0	0	0	0	0	0	1	0	0	0	1	2	2	5	<0.1
Sorex minutus	0	0	0	0	0	0	0	0	0	0	1	1	1	4	<0.1
Rhinolophus hipposideros	0	0	0	0	0	0	0	0	1	1	0	1	1	5	<0.1
Muscardinus avellanarius	0	1	0	0	0	1	4	0	0	0	0	4	5	27	0.6
∑ Mammalia	**30**	**37**	**103**	**47**	**114**	**331**	**50**	**66**	**142**	**85**	**164**	**507**	**838**		
Passer domesticus	11	6	4	8	1	30	0	1	1	0	0	2	32	32	4.3
Passer montanus	0	0	0	1	2	3	0	0	0	0	0	0	3	23	0.3
Chloris chloris	0	2	0	0	0	2	0	0	1	0	0	1	3	30	0.4
Parus major	1	7	4	7	2	21	0	0	0	0	0	0	21	19	1.7
Cyanistes caeruleus	0	1	1	0	2	4	0	0	0	1	0	1	5	11	0.2
Erithacus rubecula	1	1	0	0	0	2	0	0	0	0	0	0	2	17	0.1
Galerida cristata	0	0	0	1	0	1	0	0	0	0	0	0	1	43	0.2
Turdus merula	0	1	0	0	0	1	0	0	1	0	1	2	3	107	1.4
∑ Aves	**13**	**18**	**9**	**17**	**7**	**64**	**0**	**1**	**3**	**1**	**1**	**6**	**140**		
∑∑	**43**	**55**	**112**	**64**	**121**	**395**	**50**	**67**	**145**	**86**	**165**	**513**	**908**		

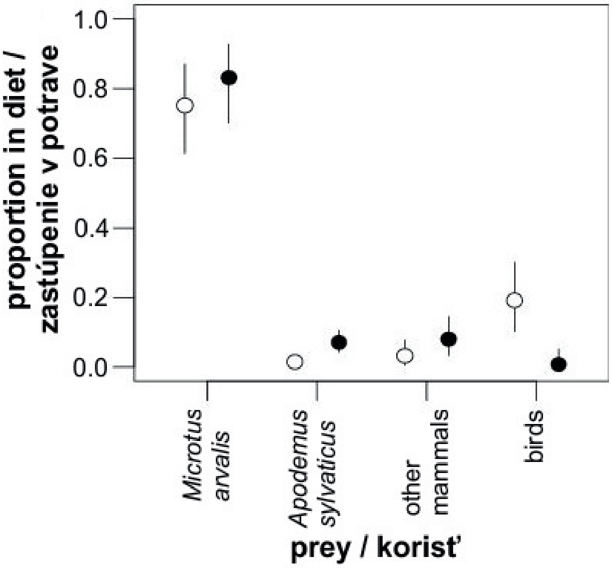
of roost departure was significant (Watson-Williams test, N = 23, F = 25.5, P < 0.001).

In 322 pellets, 908 prey individuals were identified, consisting of twelve mammal and eight bird species (Tab. 1). The common vole was the dominant prey species constituting 81.3% of total biomass (BM) (mean ± SD = 78.4 ± 12.4%, range 59.3–93.9%). Birds were the second most important prey group with 8.6% BM, (11.9 ± 14.6%, range 0–36%) followed by other mammals with 5.5% BM, (5.3 ± 5.11%, range 0.3–14.6%) and wood mouse (*Apodemus sylvaticus*) with 4.8% BM, (4.4 ± 2.9%, range 0–7.6%).

The most hunted prey by the prey number in both subgroups was the common vole, with non-significantly higher proportions in the *Picea*-subgroup (*Pinus* BM mean ± SD = 73.9 ±16.5%; *Picea* BM 82.9 ± 4.5%). Wood mouse (*Pinus* BM 1.9 ± 1.8%; *Picea* BM 6.8 ± 0.8%) and other mammals (*Pinus* BM 2.16 ± 1.5%; Picea BM 8.5 ± 5.6%) were found in significantly lower proportions in the *Pinus*-subgroup diet than in the *Picea*-subgroup. In contrast, birds were found in significantly higher proportions in the *Pinus*-subgroup diet (BM 21.9 ± 15%) than in the *Picea*-subgroup (BM 1.83 ± 1.8%) (Fig. 2). The high proportion of common vole had a strong impact on Pianka's index of trophic niche overlapping (mean ± SD = 0.95 ± 0.03, range 0.86–0.99).

Fig. 2. Proportion of prey groups in diets of long-eared owls in *Pinus*-subgroup (white dots) and *Picea*-subgroup (black dots) (points: fitted value of diet proportion, bars = credible interval (calculated with Bayesian statistic).

Obr. 2. Proporcia skupín koristi v potrave myšiarky ušatej v časti zimoviska na borovici (biele body) a na smreku (čierne body) (body: fitované hodnoty proporcie potravy, čiara = interval spoľahlivosti (vypočítaný pomocou Bayesovskej štatistiky).



Discussion

The prey of the long-eared owls at the Bojnice Spa roost in winter 2013/2014 corresponded to the prey lists of this species found in Central European habitats (Birrer 2009) and at Bojnice in earlier winters (Tulis et al. 2015a), with common vole as the predominant prey species and birds, wood mouse and other mammals as alternative prey.

Individual long-eared owls appear to be very faithful to their sitting spots in the roost over a long period (Bol 2010). But individuals changing their roosting-place during the non-breeding season were observed twice at Bojnice in earlier years (Tulis 2015b). Our data show very small variance in the number of owls in the two subgroups. We assume therefore that membership of the two subgroups stayed constant over time, and that we observed group specific traits.

The main prey of both subgroups of owls was the common vole, whereas alternative prey groups varied significantly between the subgroups. Despite the number of papers dealing with prey differences in time or space, we are aware of only one publication comparing the prey of subgroups in the same place and at the same time: Schnurre (1937) describes a winter roost in Berlin where two long-eared owls sat separated from the rest of the roosting owls. The prey of these two groups of owls was nearly identical. The home ranges of four radio-tracked owls at the Bojnice roost in winter 2010/11 and 2011/12 (Tulis et al. 2015b) were long-shaped with the roost lying acentrically (Tulis 2013). In these years three of the four owls had a home-range directed to the west and one extended to the south. The different directions of roost departure observed in our study combined with the long-shaped home range lead to the assumption that the two subgroups had different hunting areas. In both directions the owls would find open, agricultural landscape. Common voles could be hunted as the main prey there, which was reflected in the high trophic niche overlap in our results Extensively-exploited grassland interspersed with hedges and small woodland patches was found in the southwest, in contrast to the southeast where arable fields were dominant, interrupted with wetlands and grassland. It is probable therefore that the availability of several prey species differed between the two hunting areas, which was reflected in the differing prey the owls of the two subgroups hunted in addition to the common vole. The *Pinus*-subgroup preyed more upon birds, especially on house sparrow (*Passer domesticus*) and great tit (*Parus major*) compared with the *Picea*-subgroup, whereas the latter hunted more on wood mouse and other mammals. Other alternative hypotheses are that the different prey composition was a consequence of different preferences of males and females, of different age classes or of individuals. The probability that the owls of both subgroups were sorted by sex or age is small. In contrast to some other owl species where differences in prey use between sexes are known (Longland 1989, Overskaug et al 1995, Villáran Adanéz 2000, Poulin & Todd 2006, Mikkola et al. 2013, Mikkola & Tornberg 2018), dealing with sex-specific prey use by long-eared owls revealed only minimal differences (Overskaug et al. 2000, Mikkola & Tornberg 2018). Moreover, there is no indication that genetically-related groups or groups from different origins could differ in prey preference, and nothing is known about individual prey use.

However, in accordance with our results we conclude that at the Bojnice roost the two subgroups appeared to use separate hunting areas with different alternative prey availability. This study also indicates that it would be valuable to take a closer look at the structure of long-eared owl roosting groups, to their departure behaviour, and hunting areas.

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