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# Avian-power line interactions in the Gobi Desert of Mongolia: are mitigation actions effective?

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## Abstract

**Background:** Electrocutation and collisions on power lines are among the leading causes of non-natural mortality for birds. Power lines are exponentially increasing, particularly in developing countries, but mitigation strategies to prevent bird mortality are questionable. Mongolia combines a recently increased power line network, an abundant raptor population, a dangerous crossarm configuration and a habitat with no natural perches, producing many bird-power line interactions. Our aim is to assess the bird mortality caused by power lines in the Gobi Desert of Mongolia, to determine the factors increasing the risk of bird electrocutation, and to evaluate the effectiveness of used retrofitting measures.

**Methods:** In July 2019 we covered 132.9 km of 15 kV power lines checking 1092 poles. We also conducted bird transects to record raptor and corvid richness and abundance, to assess species vulnerability to electrocutation.

**Results:** We recorded 76 electrocuted birds of 7 species. Electrocutation rate was 6.96 birds/100 poles. The most affected species were Common Raven (*Corvus corax*) and Upland Buzzard (*Buteo hemilasius*), highlighting the electrocution of 5 endangered Saker Falcons (*Falco cherrug*). By contrast, we only recorded 8 individuals of 5 species colliding with wires, the most affected being Pallas's Sandgrouse (*Syrrhaptes paradoxus*). About 76.1% of sampled poles had some mitigation measure. Of these, 96.6% were brush perch deflectors and 3.4% rotating-mirrors perch deterrents. We found differences in electrocution rates among crossarm configurations, with the strain insulator with one jumper being the most lethal. Additionally, we found no correlation between bird abundance and electrocution rates, suggesting that some species are more sensitive to electrocution. Although no differences in total bird electrocution rates were detected between poles with and without perch deterrents, when bird size is considered, deterrents reduced the mortality rate of small birds, while they were ineffective for medium-sized birds.

**Conclusions:** Despite the widespread use of perch deterrents in the Mongolian power line network, there is still an alarming electrocution rate. This strategy is ineffective and some mechanisms, such as brush perch deflectors, may increase the electrocution rate for some medium-sized birds. Finally, we propose strategies to minimize the avian electrocution rate in the Gobi Desert.

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**Keywords:** Collision, Crossarm configuration, Electrocution, Electric infrastructures, Perch deterrent, Power line network, Raptor

## Background

The development of power line networks is both a consequence and a driver of a country's economic progress (Chaurey et al. 2004), but it is also an important source of environmental impacts (Sánchez-Zapata et al. 2016). Electrocutions and collisions with power lines are among the leading non-natural causes of bird mortality (Bevanger 1998; Haas 2005), drastically reducing the populations of some endangered species (García-del-Rey and Rodríguez-Lorenzo 2011), especially raptors (Meretsky et al. 2000; Real et al. 2001; López-López et al. 2011; Angelov et al. 2013). Three factors have been linked to the increased risk of accidents between birds and power lines. The first one is related to the pole and crossarm configuration or the wire arrangement (e.g. grounded steel and concrete poles and crossarms, or the increase of jumper wires; Tintó et al. 2010; Guil et al. 2011), the second one is associated with the ecology and biology of birds (e.g. size and wingspan, low maneuverability, narrow visual field, hunting behavior; Janss 2000; Lehman et al. 2007; Martin and Shaw 2010; Guil et al. 2015) and the last one is related to the environment (e.g. absence of natural perches, frequency of fogs, location on migratory routes; Harness et al. 2008; Dixon et al. 2018).

Electrocution occurs when a bird simultaneously contacts two differently energized phases or one energized phase and one grounded area (APLIC 2006). Thus, mitigation strategies (from now on "retrofitting") used to prevent bird electrocution can be: (i) by "separation" between potential contacts, which is the most recommended strategy since it is permanent and does not require maintenance; (ii) by "insulation", which requires strategically covering energized or grounded contacts, it is the most used strategy and needs maintenance; and (iii) by "redirection" of birds to perch in safer places, which is the cheapest strategy and also requires maintenance (APLIC 2006). By contrast, bird collisions can be mitigated modifying surrounding habitats, removing overhead shield wires, burying lines, and increasing visibility to birds by marking wires (Eccleston and Harness 2018). Although these mechanisms are considered effective in reducing electrocutions (Tintó et al. 2010) and collisions (Alonso et al. 1994; Barrientos et al. 2011), few studies have evaluated their long-term effectiveness in the field and with different avian populations (Janss and Ferrer 1999).

Asia is undergoing the fastest economic growth and many of its countries are exponentially increasing their

power line network (Hammons 2011). In addition to this sharp increase, most power lines have little or no retrofitting (Dixon et al. 2013a), as most Asian countries are limited in their economic resources. However, avian electrocution and collision studies in this continent are scarce (Lehman et al. 2007; Bernardino et al. 2018; Slater et al. 2020), so there is an urgent need to focus efforts on the continent, especially in important bird areas, to understand the magnitude of these impacts. In the last two decades, Mongolia has sharply increased its power line network (Amartuvshin and Gombobaatar 2012). Studies carried out so far show a severe environmental impact as a result of the interaction between rich and abundant raptor populations, an electrical network with hazardous designs (grounded steel and concrete poles and metal crossarm with few or obsolete retrofitting, usually redirection) and habitat conditions without natural perches (Harness et al. 2008; Amartuvshin and Gombobaatar 2012; Dixon et al. 2018). One of the largest concerns is the high mortality rate of the Saker Falcon (*Falco cherrug*; Dixon et al. 2020), which is globally endangered (BirdLife International 2021) and a large part of its breeding population is in Mongolia (Gombobaatar et al. 2004). Despite previous research about birds and power lines carried out in Mongolia (Harness et al. 2008; Amartuvshin and Gombobaatar 2012; Dixon et al. 2013a), most studies have been located in the central and eastern part of the country (Ganbold et al. 2018). By contrast, large areas in southern Mongolia have remained understudied. The Gobi Desert extends in this area, an extremely arid ecosystem in which many species adapted to these extreme ecosystems survive. Although the abundance of species that are more sensitive to power lines impacts, such as birds of prey, is slightly lower than in other areas previously studied in the country, the presence of potential natural perches is even lower, so the interaction between birds and power lines can be high (Gombobaatar et al. 2004).

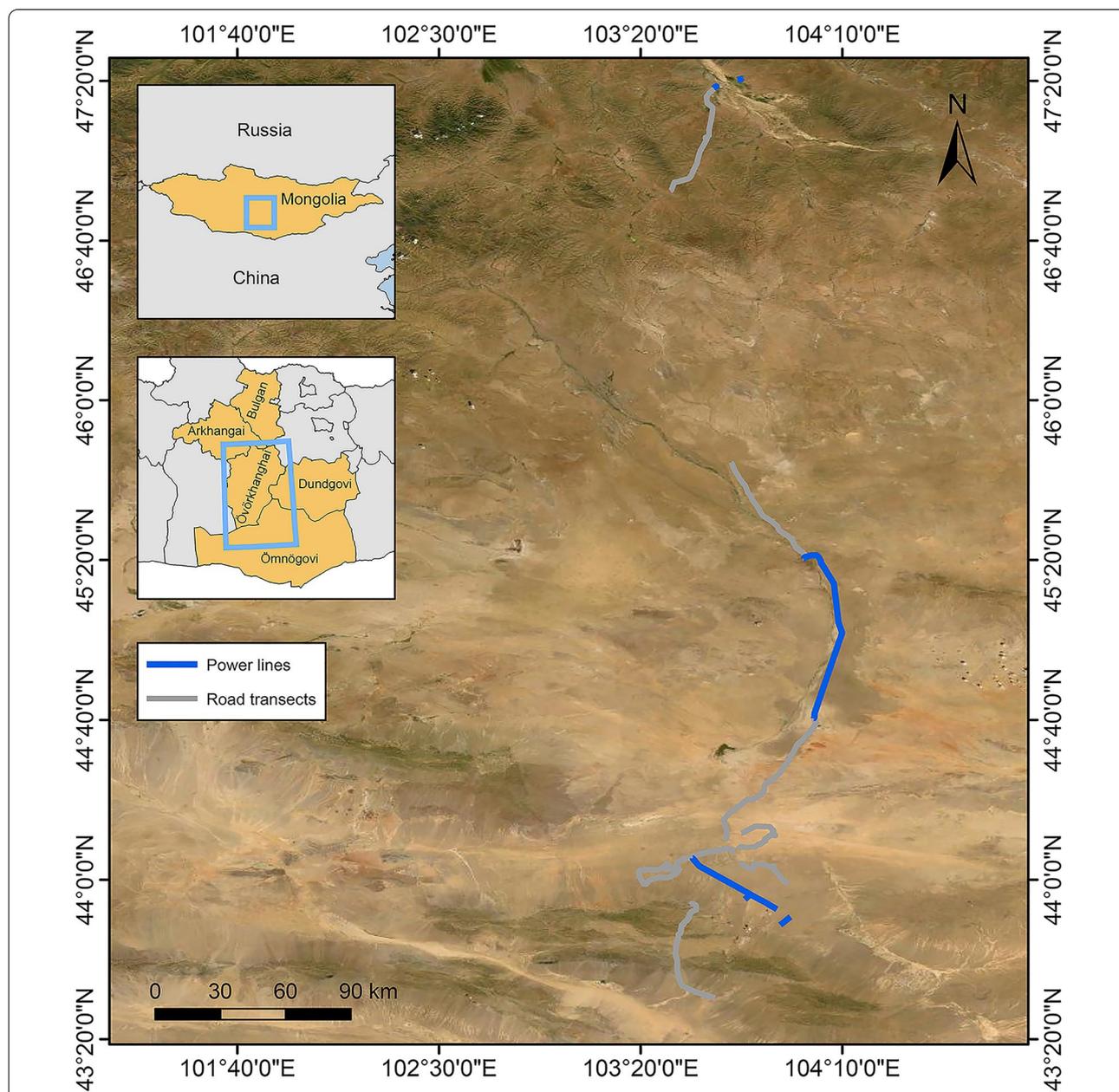
In this study, our main goal was to study bird mortality at power lines in the Gobi Desert (southern Mongolia). Specifically, we aimed to: (1) evaluate bird mortality by electrocution and collision with power lines, (2) explore the factors that increase the risk of bird electrocution, such as the crossarm configuration and the size or abundance of the bird species in the area, and (3) evaluate the effectiveness of the retrofitting measures used.

**Methods**

**Study area**

Our study area was located across several provinces (aimags) of Mongolia, between the Khogno Khan National Park in the north (47°19' N, 103°41' E), and Dalanzadgad city in the south (43°34' N, 104°25' E) of the study area (Fig. 1). Power lines cross the Gobi Desert, an undulating landscape mainly composed of arid steppes and scattered

mountains ranging from 706 and 2825 m a.s.l. (Begzsuren et al. 2004). Short bunch grasses are dominant in steppe zone lacking trees and natural perches. In the desert zone vegetation cover generally reaches values of <10%, often only 1–2% (Walter 1993). This region has sharp temperature contrasts reaching 40 °C in summer and –49 °C in winter, concentrating 125 mm rainfall annually between April and September (Pfeiffer et al. 2003).



**Fig. 1** Map of the study area across several aimags (provinces) in the Gobi Desert, Mongolia. We show road car transects (354.6 km) performed to estimate raptor and corvid abundance and systematic transects (132.9 km) conducted along power lines to record bird mortality from both electrocution and collision

### Data sampling

On July 2019, we systematically covered a total of 132.9 km of 15 kV power lines, checking a total of 1092 poles to record bird mortality from both electrocution and collision. Due to the favorable visibility conditions for finding dead birds in the study area, we used car transects. We drove under the power lines at a speed of 15–20 km/h. Two observers, one on each side of the car, searched for remains, and two additional people noted the field data (i.e. dead species, pole characteristics and causes of death: electrocution or collision) and GPS positions. In those places with worse visibility (e.g. with vegetation) the searching was carried out on foot. We checked for dead birds within a 5-m radius around each pole, and 8 m on each side under the lines. All dead birds found were examined for burn marks or trauma. Additionally, we recorded all casualties found outside the systematic transects, but these data were excluded from analyses and mortality rate estimates.

All power lines were constructed with concrete poles and metal crossarms. We recorded the crossarm configuration (type and number of isolators, number of jumper wires), the presence of retrofitting measures (i.e. redirection), such as perch deterrent, and their type (e.g. brush perch deflectors or rotating-mirrors perch deterrents). No bird collision deterrent was recorded in any of the monitored power lines.

Estimation of diurnal raptor and corvid abundance (i.e. number of individuals of each species) were performed by road car transects (Viñuela 1997). Transects were performed from two hours after sunrise to one to two hours before sunset, at an approximate speed of 30 km/h. Two observers were identifying and counting birds (raptors and corvids). Transects were conducted up to a maximum distance of 50 km from the sampled power lines. This threshold was considered a representative measure of the maximum distance that highly mobile resident birds, potentially sensitive to power lines, could move (e.g. Dixon et al. 2017a,b; Reading et al. 2020). We sampled a total of 354.6 road km during 5 days and lasting a total of 14.9 h.

For all the species recorded in the road and the mortality surveys, we gathered information on the species conservation status (IUCN 2020) and its mean wingspan (del Hoyo et al. 1994), which was used to classify them into two categories (small-wingspan  $\leq 70$  cm, medium-wingspan 70–160 cm) according to Dixon et al. (2019).

### Statistical procedures

We calculated the “electrocution rate” as number of electrocuted birds per 100 poles and per 10 km, to compare it with that of previous studies. We only used the dead birds found during systematic sampling for the statistical

analyses. We also calculated the “collision rate” as number of collided birds per 10 km.

To test if large or abundant raptors and corvids are more vulnerable to electrocution by relating species abundance and wingspan with “electrocution rate” (birds/100 poles), we used Generalized Linear Models (GLMs), where the “electrocution rate” for each species was the dependent variable and the species-specific (1) total abundance or (2) mean wingspan were the predictors. As we could not normalize the data, we used a randomization approach, where the predictor was kept constant but the values for “electrocution rate” were randomized. We repeated the analyses 1000 times and we checked if the coefficients of the predictor in our model were within the range of values of the coefficients of the models with the randomized variables.

We assessed the mortality of different crossarm configurations by comparing the observed and expected-by-chance proportion of birds electrocuted below each crossarm configuration (one-pin insulator, double pin insulator and strain insulators with one jumper) using Chi-square tests.

To evaluate the effectiveness of retrofitting in reducing bird mortality, we used the Chi-square test, which compares the observed and expected-by-chance proportion of electrocuted birds below full-corrected crossarms (two or four brush perch deflectors) and uncorrected crossarms (without brush perch deflectors) in general, and per crossarm configuration. Partially retrofitted crossarms (i.e. lost one perch deflector) were excluded from the statistical analyses because we could not determine if birds had been electrocuted in the part of the crossarm where the perch deflector was present or where it was not. We also excluded the rotating-mirror perch deterrents from the analyses because of the small sample size ( $n = 28$  poles).

Finally, to test if there was a correlation between the mitigation measures effectiveness and the bird size, we used the Chi-square test to compare the proportion of electrocuted birds below the full-corrected poles (with two and four brushes) and the uncorrected ones by wingspan (small and medium). All the analyses were run in R 3.6.0 (R Core Team 2019).

### Results

We found a total of 76 electrocuted birds of 7 species at 55 poles (5% of the total sampled poles) during 132.9 km of systematic transects. The most affected species was the Common Raven (*Corvus corax*;  $n = 33$ ), followed by the Upland Buzzard (*Buteo hemilasius*;  $n = 11$ ; Table 1). The electrocution of 5 individuals of the endangered Saker Falcon is also noteworthy. Electrocution rate was 6.96 birds/100 poles or 5.72 birds/10 km (see Table 1 for

**Table 1** Avian mortality by electrocution and collision in 15 kV power lines in the Gobi Desert (Mongolia)

Taxonomic group	Species	Electrocution		Collision	Abundance/10 km	Birds/100 poles	Birds/10 km	IUCN
		Syst.	Non-Syst.					
Raptors	<i>Aegypius monachus</i>	0	0	0	0.39	0	0	NT
	<i>Aquila chrysaetos</i>	0	0	0	0.03	0	0	LC
	<i>Aquila nipalensis</i>	0	0	0	0.14	0	0	EN
	<i>Bubo bubo</i>	0	1	0	–	0	0	LC
	<i>Buteo hemilasius</i>	11	3	0	0.56	1.01	0.83	LC
	<i>F. tinnunculus/naumanni</i>	5	0	0	0	0.46	0.38	LC
	<i>Falco cherrug</i>	5	2	0	0.03	0.46	0.38	EN
	<i>Falco naumanni</i>	4	0	0	0.03	0.37	0.30	LC
	<i>Falco tinnunculus</i>	1	0	0	0	0.09	0.08	LC
	<i>Gypaetus barbatus</i>	0	0	0	0.11	0	0	NT
	<i>Gyps himalayensis</i>	0	0	1	1.02	0	0.08	NT
	<i>Milvus migrans</i>	4	0	0	1.80	0.37	0.30	LC
Corvids	<i>Corvus corax</i>	33	3	0	0.39	3.02	2.48	LC
Other birds	<i>Charadrius veredus</i>	0	0	1	–	0	0.08	LC
	<i>Eremophila alpestris</i>	0	0	2	–	0	0.15	LC
	<i>Melanocorypha mongolica</i>	0	0	1	–	0	0.08	LC
	<i>Phalacrocorax carbo</i>	2	2	0	–	0.18	0.15	LC
	<i>Syrrhaptes paradoxus</i>	0	0	3	–	0	0.23	NT
Unidentified	Unknown species	11	1	0	–	1.01	0.83	
	Total	76	12	8		6.96	5.72	

The table shows the number of electrocuted birds in systematic (Syst.) and non-systematic sampling (Non-Syst.); birds colliding with power lines (Collision); recorded birds in transects carried out in the area of the power lines studied (Abundance/10 km); electrocution rate measured in number of birds per 100 poles (Birds/100 poles); electrocution or collision rate measured in number of birds per 10 km (Birds/10 km). For the "Total", we have only used electrocuted birds. For electrocution and collision rates we have only used birds recorded in the systematics samplings; abundance was estimated only for diurnal raptor and corvids; global threat level according to the International Union for Conservation of Nature (IUCN)

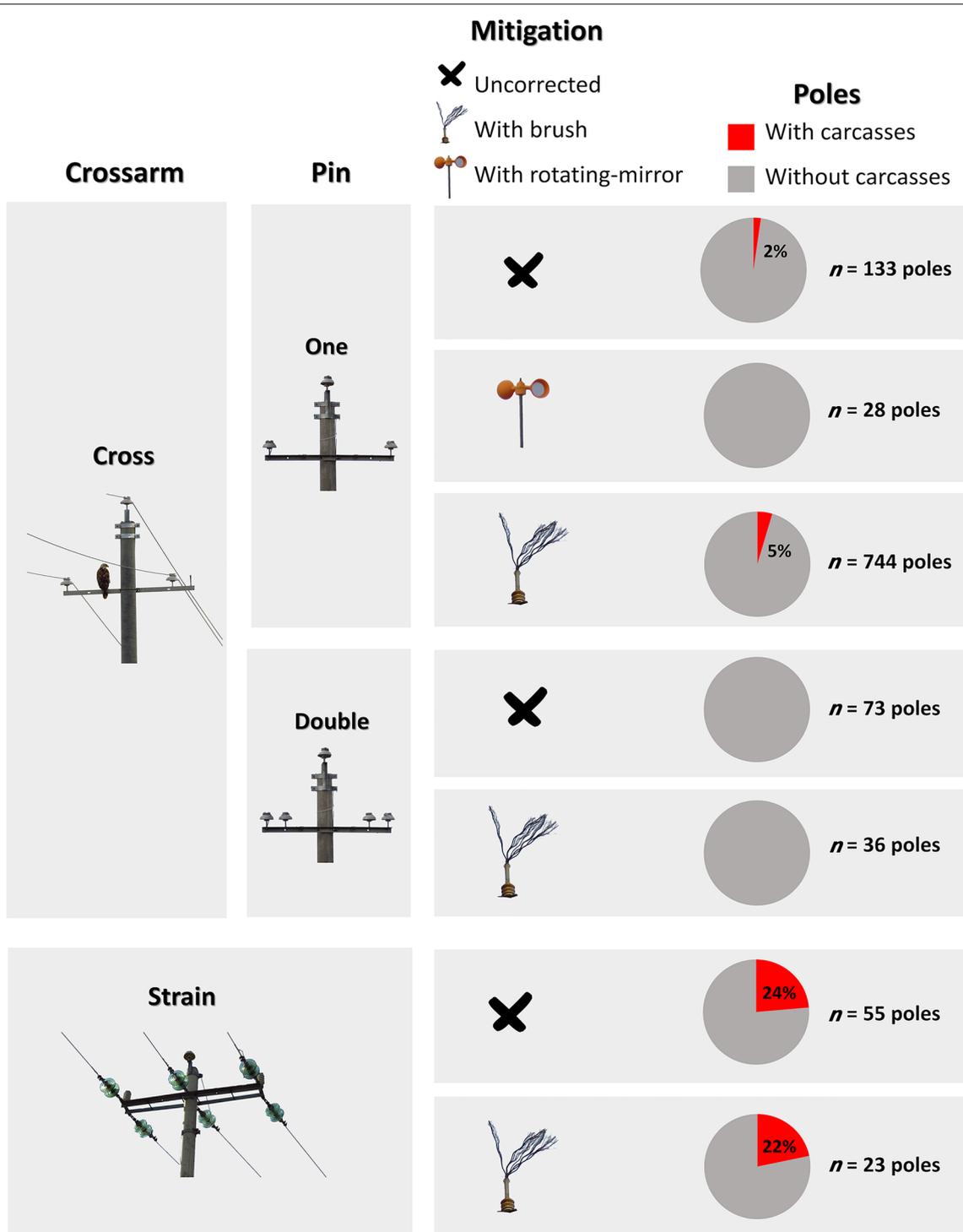
electrocution rates by species). We also detected the electrocution of 12 individuals of 6 species found in non-systematic sampling, where a new electrocuted species was recorded, the Eurasian Eagle Owl (*Bubo bubo*; Table 1). Also, we found no relationship between species-specific electrocution rates and their abundances (GLMs, coefficient  $\pm$  SD =  $0.094 \pm 0.249$ ,  $p = 0.223$ ) or their wingspan sizes (GLMs, coefficient  $\pm$  SD =  $-0.002 \pm 0.003$ ,  $p = 0.21$ ). The most abundant species in the transects were Black Kites (*Milvus migrans*) and Himalayan Griffons (*Gyps himalayensis*) which had low or non-existent electrocution or collision rates (Table 1). In addition, power poles with strain insulators had a much higher electrocution rate than the other crossarm configurations ( $\chi^2 = 16.56$ ,  $df = 2$ ,  $p < 0.001$ ; Fig. 2).

Bird species affected by electrocution were different from the species affected by collision. Regarding collisions, only eight individuals of five species were recorded, the most affected being the Pallas's Sandgrouse (*Syrrhaptes paradoxus*) with three individuals (Table 1). Total collision rate was 0.6 birds/10 km.

About 76.1% of the sampled poles had some retrofitting mechanism, of which 96.6% used brush perch

deflectors and only 3.4% used rotating-mirror perch deterrents. Some 62.2% of crossarms were retrofitted with two brush perch deflectors, whilst 13.4% had lost one and 24.4% had lost all brush perch deflectors. In contrast, 83.3% of the crossarm poles with rotating-mirror perch deterrents conserved all mirrors, 10% had one and 6.7% had lost all perch deterrents.

There were no differences in bird mortality between poles with and without brush perch deflectors ( $\chi^2 = 0.033$ ,  $df = 1$ ,  $p = 0.855$ ). Surprisingly, poles with brushes showed a higher percentage of carcasses below than poles without these mechanisms on crossarms with one pin-insulators (4.6% vs. 2.3%). Similar percentage of carcasses below the poles were found on crossarms with strain insulators (21.7% vs. 23.6%), even though there were no significant differences ( $\chi^2 = 1.336$ ,  $df = 1$ ,  $p = 0.248$  and  $\chi^2 \leq 0.001$ ,  $df = 1$ ,  $p = 1$ , respectively). In contrast, we found no electrocuted birds below double-pin isolator crossarms ( $n = 109$  poles; Fig. 2) and one pin insulator crossarm with rotating-mirrors perch deterrents, although a small number of poles with this retrofitting were sampled ( $n = 28$  poles; Fig. 2).



**Fig. 2** Percentage of poles with carcasses below each type of pole in the Gobi Desert, Mongolia. We show the percentage of carcasses below each type of pole (red) with mitigation strategies (brush perch deflectors and rotating mirror perch deterrents) and at uncorrected poles. The number (*n*) shows the total number of each type of sampled pole

Mortality of small raptors in the corrected poles were significantly lower than expected (37.5% observed vs. 71.8% expected,  $\chi^2=4.59$ ,  $df=1$ ,  $p=0.032$ ), while for medium-sized birds (raptors and corvids), there were no differences between corrected and uncorrected poles ( $\chi^2=0.60$ ,  $df=1$ ,  $p=0.438$ ).

## Discussion

Bird electrocution in Mongolia remains a severe problem that seriously threatens endangered species. At least 30 electrocuted bird species have been recorded in this country, which has one of the largest electrocution rates worldwide. Although our study does not reach the highest rates recorded in Mongolia such as 21 birds/100 poles (Dixon et al. 2017a) or 65 birds/100 poles (Dixon et al. 2018), our mortality rate (6.96 birds/100 poles) remains similar (Harness et al. 2008) and even higher (Ganbold et al. 2018) than studies conducted further north. Through our study, we reaffirm the high bird electrocution rate in the understudied region of the Gobi Desert.

Power line bird collisions have been much less studied than bird electrocutions in Mongolia. Our results support that bird mortality by collisions with power lines is much lower than by electrocution. Interestingly, the bird community affected by collision and electrocution are different. While electrocution affected mainly corvids and raptors, collision affected mainly steppe birds, including Charadriiformes. In particular, the high collision rates of the Pallas's Sandgrouse is alarming. Amartuvshin and Gombobaatar (2012) found 407 collided individuals in Mongolia, and they cite a record from the Veterinary Institute of Mongolia of 2300 collided individuals of this species, also in this country. This also occurs in Spain where large number of sandgrouses (*Pterocles orientalis* and *Pterocles alchata*) have been found to collide in the Peninsula (Barrientos et al. 2011) or the Canary Islands (Gómez-Catasús et al. 2020). These species usually fly at dawn and dusk in search of water in very remote areas and this could make them more susceptible to collision, as well as many species of Charadriiformes that migrate at night. Although not threatened, populations of the Pallas's Sandgrouse may be declining due to high collision mortality. Detailed studies of how the population of this species is being affected would be desirable. Besides, the bird mortality rate shown in this study should be taken as a minimum, as the scavenger consumption rate may be high (Dixon et al. 2017a,b; Orihuela-Torres et al. 2021), especially for small birds (Gómez-Catasús et al. 2020).

In the Gobi Desert, we have shown that the most abundant species are not the most electrocuted, suggesting that susceptibility to electrocution depends on other non-evaluated factors such as behavior. Common Ravens, Upland Buzzards and Saker Falcons showed a

high sensibility to electrocution likely due to their preference for roosting and nesting on poles (Dixon et al. 2013a,b). Even though the Saker Falcon is globally classified as "Endangered", its high electrocution rate has been known in the country for years (Dixon et al. 2020). This incidence has also been found in our study, indicating that it does not seem to show a decrease on a national scale despite the conservation actions promoted by the government and private entities. Given this situation, it is likely that this cause of mortality is dramatically affecting its population dynamics as some studies point out (Dixon et al. 2020). In other hand, the presence of jumper wires over the crossarm are directly related with a higher electrocution rate (Guil et al. 2011). Fortunately, the configuration of the power lines reported in the study area is very homogeneous, the pylon material is always metal and the crossarm configuration has no more than five versions, so the potential designs are limited. This fact contrasts with what happens in other areas of Europe such as Spain where configurations can exceed a hundred (Guil et al. 2011). This could simplify decision making when it comes to implementing safer mitigation measures.

Despite the widespread use of perch deterrents in the Mongolian power line network, our study has shown that this is a low-effective mitigation strategy, even more, some mechanisms such as brush perch deflectors could be increasing the electrocution rate of some medium and large species (Harness et al. 2008; Amartuvshin and Gombobaatar 2012). Our results show that the presence of perch deterrents reduced the mortality rate of small birds, while are ineffective to reduce the medium-sized birds. This unexpected result could be explained by the fact that the height of the brushes coincides with the head of the small birds, disturbing them. The same brush may approximate larger birds closer to the wire, increasing their probability of being electrocuted. This mitigation strategy was widely used in the 1980s and 1990s in the US, but its use is declining because of its questioned effectiveness (Slater et al. 2020). However, there are places where it is still applied because of its low cost (Janss and Ferrer 1999; Prather and Messmer 2010). In addition, brush perch deflectors are often not placed properly, or have no maintenance and last little time in good condition, becoming death traps (Dwyer et al. 2020). Almost 40% of sampled retrofitted poles had lost at least one of the perch deterrents. By contrast, despite the low number of covered poles, we found no electrocution under poles with rotating-mirror perch deterrents. This is in line with the study by Dixon et al. (2019) that proved the effectiveness of this mitigation strategy, suggesting that this strategy is much more effective than brush perch deflectors, although it also needs maintenance. Despite this, mitigation strategies such as the modification of crossarm to a

save design and the insulation of conductors, which have been proved more effective, an extended life-time and lower maintenance and installation failures (APLIC 2006; Guil et al. 2011), should be applied.

It is important to underline that our study does not account for the imperfect detection of the electrocuted birds, which may be an important problem in areas with dense vegetation and very rocky areas that difficult finding the dead individuals (Stevens et al. 2011; Gómez-Catasús et al. 2020). However, our study area was mostly covered by bare ground with almost no vegetation or rocks and the electrocuted individuals could be easily seen from the distance.

## Conclusions

Our study confirms that the Gobi Desert has a worrying avian electrocution rate, especially for the endangered Saker Falcon, and that mitigation strategies are partially effective and show a short lifetime. We suggest avoiding brush perch deflectors as mitigation strategy, and retrofitting the most dangerous crossarm configuration (strain insulators with one jumper) by installing effective insulation systems or changing the design using, for example, suspended insulators (Tintó et al. 2010). In parallel, governments should increase the surveillance and impose penalties on utilities that do not meet certain avian friendly power line requirements. These strategies have been taken in the United States, South Africa or some European countries (Antal 2010; Schürenberg et al. 2010), which has led to saving species that were on the verge of extinction (López-López et al. 2011) if these standards are met.

## Acknowledgements

To our driver Bilgee, who never gave up and encouraged us to continue surveying poles, and our guide Jargal and organizer Soyolo, who made our trip easier.

## Authors' contributions

JMPG, ESG, JASZ designed the study; JMPG, ESG, JASZ, ZMR, LNA participated in the field work; AOT, JMPG, ESG carried out the statistical analysis; AOT, JMPG, ESG drafted the earlier version of the manuscript; ZMR, LNA, JASZ revised the manuscript; All authors read and approved the final manuscript.

## Funding

This project was supported by Generalitat Valenciana (SEJI/2018/024). JMPG and ESG were supported by Spanish Ministry of Science, Innovation and Universities contracts (IJC-2019-038968 and RYC-2019-027216-I), ZMR and LNA by contracts cofunded by the Generalitat Valenciana and the European Social Fund (APOSTD/2019/016 and ACIF/2019/056, respectively).

## Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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Received: 2 March 2021 Accepted: 12 August 2021

Published online: 21 August 2021

## References

- Alonso JC, Alonso JA, Muñoz-Pulido R. Mitigation of bird collisions with transmission lines through groundwire marking. *Biol Conserv*. 1994;67:129–34.
- Amartuvshin P, Gombobaatar S. The assessment of high risk utility lines and conservation of globally threatened pole nesting steppe raptors in Mongolia. *Ornis Mongolica*. 2012;1:2–12.
- Angelov I, Hashim I, Oppel S. Persistent electrocution mortality of Egyptian Vultures *Neophron percnopterus* over 28 years in East Africa. *Bird Conserv Int*. 2013;23:1–6.
- Antal M. Policy measures to address bird interactions with power lines—a comparative case study of four countries. *Ostrich*. 2010;81:217–23.
- Avian Power Line Interaction Committee (APLIC). Suggested practices for avian protection on power lines: the state of the art in 2006. Washington and Sacramento: Edison Electric Institute and the California Energy Commission; 2006.
- Barrientos R, Alonso JC, Ponce C, Palacin C. Meta-analysis of the effectiveness of marked wire in reducing avian collisions with power lines. *Conserv Biol*. 2011;25:893–903.
- Begzsuren S, Ellis JE, Ojima DS, Coughenour MB, Chuluun T. Livestock responses to droughts and severe winter weather in the Gobi Three Beauty National Park. *Mongolia J Arid Environ*. 2004;59:785–96.
- Bernardino J, Bevanger K, Barrientos R, Dwyer JF, Marques AT, Martins RC, et al. Bird collisions with power lines: state of the art and priority areas for research. *Biol Conserv*. 2018;222:1–13.
- Bevanger K. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. *Biol Conserv*. 1998;86:67–76.
- BirdLife International. BirdLife Species Factsheet: Saker falcon (*Falco cherrug*). 2021. <http://datazone.birdlife.org/species/factsheet/saker-falcon-falco-cherrug>.
- Chaurey A, Ranganathan M, Mohanty P. Electricity access for geographically disadvantaged rural communities—technology and policy insights. *Energy Policy*. 2004;32:1693–705.
- del Hoyo J, Elliott A, Sargatal J. Handbook of the birds of the world. Volume 2: New World vultures to guineafowl. Barcelona: Lynx Edicions; 1994.
- Dixon A, Maming R, Gunga A, Purev-Ochir G, Batbayar N. The problem of raptor electrocution in Asia: case studies from Mongolia and China. *Bird Conserv Int*. 2013a;23:520–9.
- Dixon A, Purev-Ochir G, Galtbalt B, Batbayar N. The use of power lines by breeding raptors and corvids in Mongolia: nest-site characteristics and management using artificial nests. *J Raptor Res*. 2013b;47:282–91.
- Dixon A, Rahman ML, Galtbalt B, Gunga A, Sugarsaikhan B, Batbayar N. Avian electrocution rates associated with density of active small mammal holes and power-pole mitigation: implications for the conservation of threatened raptors in Mongolia. *J Nat Conserv*. 2017a;36:14–9.
- Dixon A, Li X, Rahman ML, Batbayar N, Zhan XJ. Characteristics of home range areas used by Saker Falcons (*Falco cherrug*) wintering on the Qinghai-Tibetan Plateau. *Bird Conserv Int*. 2017b;27:525–36.
- Dixon A, Bold B, Tsolmonjav P, Galtbalt B, Batbayar N. Efficacy of a mitigation method to reduce raptor electrocution at an electricity distribution line in Mongolia. *Conserv Evid*. 2018;15:50–3.
- Dixon A, Rahman ML, Galtbalt B, Bold B, Davaasuren B, Batbayar N, et al. Mitigation techniques to reduce avian electrocution rates. *Wildlife Soc Bull*. 2019;43:476–83.

- Dixon A, Batbayar N, Bold B, Davaasuren B, Erdenechimeg T, Galtbalt B, et al. Variation in electrocution rate and demographic composition of Saker Falcons electrocuted at power lines in Mongolia. *J Raptor Res.* 2020;54:136–46.
- Dwyer JF, Taylor RC, French GA. Failure of utility pole perch deterrents modified during installation. *J Raptor Res.* 2020;54:172–6.
- Eccleston DT, Harness RE. Raptor electrocutions and power line collisions. In: Sarasola J, Grande J, Negro J, editors. *Birds of prey: biology and conservation in the XXI century.* Cham: Springer; 2018. p. 273–302.
- Ganbold O, Bing GC, Purevee E, Munkhbayer M, Choi WS, Jargalsaikhan A, et al. Bird accidents in southern Mongolia: a case study of bird electrocution. *Kor J Ornithol.* 2018;25:94–100.
- García-del-Rey E, Rodríguez-Lorenzo JA. Avian mortality due to power lines in the Canary Islands with special reference to the steppe-land birds. *J Nat Hist.* 2011;45:2159–69.
- Gombobaatar S, Sumiya D, Shagdarsuren O, Potapov E, Fox N. Saker Falcon (*Falco cherrug milvipes* Jerdon) mortality in Central Mongolia and population threats. *Mong J Biol Sci.* 2004;2:13–21.
- Gómez-Catasús J, Carrascal LM, Moraleda V, Colsa J, Garcés F, Schuster C. Factors affecting differential underestimates of bird collision fatalities at electric lines: a case study in the Canary Islands. *Ardeola.* 2020;68:71–94.
- Guil F, Àngels Colomer M, Moreno-Opo R, Margalida A. Space-time trends in Spanish bird electrocution rates from alternative information sources. *Glob Ecol Conserv.* 2015;3:379–88.
- Guil F, Fernández-Olalla M, Moreno-Opo R, Mosqueda I, Gómez ME, Aranda A, et al. Minimising mortality in endangered raptors due to power lines: the importance of spatial aggregation to optimize the application of mitigation measures. *PLoS ONE.* 2011;6:e28212.
- Haas D. Protecting birds from powerlines (Nature and Environment No. 140). Strasbourg: Council of Europe Publishing; 2005.
- Hammons TJ. Electricity infrastructure in Asian region and energy security problems. In: Hammons TJ, editor. *Electricity infrastructures in the global marketplace.* InTech; 2011. p. 415–50.
- Harness R, Gombobaatar S, Yosef R. Mongolian distribution power lines and raptor electrocutions. In: *IEEE Rural Electric Power Conference (REPC).* 2008.
- IUCN. IUCN red list of threatened species. 2020. <https://www.iucnredlist.org/>.
- Janss GFE. Avian mortality from power lines: a morphologic approach of a species-specific mortality. *Biol Conserv.* 2000;95:353–9.
- Janss GFE, Ferrer M. Mitigation of raptor electrocution on steel power poles. *Wildlife Soc b.* 1999;27:263–73.
- Lehman RN, Kennedy PL, Savidge JA. The state of the art in raptor electrocution research: a global review. *Biol Conserv.* 2007;136:159–74.
- López-López P, Ferrer M, Madero A, Casado E, McGrady M. Solving man-induced large-scale conservation problems: the Spanish imperial eagle and power lines. *PLoS ONE.* 2011;6:e17196.
- Martin GR, Shaw JM. Bird collisions with power lines: failing to see the way ahead? *Biol Conserv.* 2010;143:2695–702.
- Meretsky VJ, Snyder NFR, Beissinger SR, Clendenen DA, Wiley JW. Demography of the California condor: implications for reestablishment. *Conserv Biol.* 2000;14:957–67.
- Orihuela-Torres A, Morales-Reyes Z, Pérez-García JM, Naves-Alegre L, Sánchez-Zapata JA, Sebastián-González E. Unravelling the vertebrate scavenger assemblage in the Gobi Desert, Mongolia. *J Arid Environ.* 2021;190:104509.
- Pfeiffer M, Chimedregzen L, Ulykpan K. Community organization and species richness of ants (Hymenoptera/Formicidae) in Mongolia along an ecological gradient from steppe to Gobi desert. *J Biogeogr.* 2003;30:1921–35.
- Prather PR, Messmer TA. Raptor and corvid response to power distribution line perch deterrents in Utah. *J Wildl Manage.* 2010;74:796–800.
- R Core Team. R: a language and environment for statistical computing. R foundation for statistical computing. R version 3.6.0. 2019.
- Reading RP, Azua J, Garrett T, Kenny D, Lee H, Paek WK, et al. Differential movement of adult and juvenile Cinereous Vultures (*Aegypius monachus*) (Accipitriformes: Accipitridae) in Northeast Asia. *J Asia Pac Biodivers.* 2020;13:156–61.
- Real J, Grande JM, Mañosa S, Sánchez-Zapata JA. Causes of death in different areas for Bonelli's Eagle *Hieraetus fasciatus* in Spain. *Bird Study.* 2001;48:221–8.
- Sánchez-Zapata JA, Clavero M, Carrete M, DeVault TL, Hermoso V, Losada MA, et al. Effects of renewable energy production and infrastructure on wildlife. In: Mateo R, Arroyo B, García JT, et al. editors. *Current trends in wildlife research.* Cham: Springer; 2016. p. 97–123.
- Schürenberg B, Schneider R, Jerrentrup H. Implementation of recommendation No. 110/2004 on minimising adverse effects of above ground electricity transmission facilities (power lines) on birds. In: Report to the Council of Europe, Convention on the conservation of the European Wildlife and natural habitats. 2010. <https://wcd.coe.int/com.instranet>.
- Slater SJ, Dwyer JF, Murgatroyd M. Conservation letter: raptors and overhead electrical systems. *J Raptor Res.* 2020;54:198–203.
- Stevens BS, Reese KP, Connelly JW. Survival and detectability bias of avian fence collision surveys in sagebrush steppe. *J Wildlife Manag.* 2011;75:437–49.
- Tintó A, Real J, Mañosa S. Predicting and correcting electrocution of birds in Mediterranean areas. *J Wildlife Manage.* 2010;74:1852–62.
- Viñuela J. Road Transects as a large-scale census method for raptors: the case of the Red Kite *Milvus milvus* in Spain. *Bird Study.* 1997;44:155–65.
- Walter H. Deserts of Central Asia. In: West NE, editor. *Ecosystems of the world: temperate deserts and semi-deserts.* Amsterdam: Elsevier Scientific Publishing Co; 1993. p. 193–236.

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