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# Avian electrocution rates associated with density of active small mammal holes and power-pole mitigation: Implications for the conservation of Threatened raptors in Mongolia

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ABSTRACT

Avian electrocution at power lines is a well-documented phenomenon, yet factors influencing the frequency of electrocution events and the efficacy of mitigation techniques remain relatively under-reported. During May-July, we surveyed a 56 km long 15 kV electricity distribution line running across open steppe in Mongolia recording electrocuted birds of prey under the power poles. We recorded high rates of electrocution of several Threatened raptor species, particularly the Endangered Saker Falcon *Falco cherrug*, which was killed at a monthly rate of 1.6 birds per 10 km during the period of our study. Electrocution frequency at line poles was associated with density of small mammal holes and the deployment of mitigation measures. It is likely that local prey abundance influences the frequency of birds of prey perching on power poles, which is consequently reflected in electrocution rate. We evaluated the efficacy of mitigation measures and found that the use of perch deflector spikes on the crossarms of line poles reduced electrocution rates when 3 or 4 spikes were deployed. Perch deflectors probably worked by reducing the opportunity for birds to perch adjacent to pin insulators rather than by reducing the frequency of birds perching on the crossarm *per se*. At anchor poles, reconfiguration of jump wires at two phases, so they passed under the crossarm rather than over, significantly reduced electrocution rates. These mitigation measures potentially represent a relatively inexpensive method to reduce the frequency of raptor electrocution events in regions where cost is a key factor for power line managers in determining whether or not any form of mitigation is used.



## 1. Introduction

Electrocution of birds of prey at low and medium voltage electricity distribution lines is a widespread global phenomenon that potentially has significant conservation implications (González, Bustamante, & Hiraldo, 1992; López-López, Ferrer, Madero, Casado, & McGrady, 2011; Sorenson, Burnett, & Davis, 2000). Mitigation methods to reduce risks of electrocution fall into three main categories: (i) isolation, by increasing separation between conductors, (ii) insulation, either of the live conductors (including burial below ground; Navrud, Ready, Magnussen, & Bergland, 2008) or the grounded components of the pole hardware and (iii) perch discouragers and deflectors to reduce the likelihood of a bird perching in position on a power pole where there is a high risk of electrocution (APLIC, 2006; Prinsen, Smallie, Boere, & Píres, 2011b). Isolation and insulation of conductors is relatively expensive compared to the deployment of perch deflectors and discouragers at dangerous poles. However, there are relatively few studies that assess the efficacy of different management measures to reduce the incidence of electrocutions (e.g., Bevanger, 1994; Guil et al., 2011; Janss & Ferrer, 1999; Negro & Ferrer, 1995), although perch deflectors have been shown to be effective at reducing predator perching rates on power poles (Dwyer & Doloughan, 2014; Lammers & Collopy, 2007).

Electrocution rates at power lines can vary in relation to the raptor community, land cover and topography, prey availability and pole configuration (e.g., Ferrer, Delariva, & Castroviejo, 1991; Guil et al., 2011; Harness and Wilson, 2001; Janss and Ferrer, 2001). With

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regard to the latter, a prevalent design for line poles on 10–15 kV distribution lines in Mongolia consists of grounded steel-reinforced concrete poles with metal crossarms and upright pin insulators to support the live phases. Electrocution can occur when birds perch on top of the pole or on the crossarm and touch an adjacent conductor, and every pole has the potential to electrocute birds of prey (Dixon, Maming, Gunga, Purev-Ochir, & Batbayar, 2013). At intervals of *ca.* 1.5 km and at deviation points along these lines there are anchor poles, where each phase of the conductors is connected via a jumper wire to a pair of pivoting chain insulators. The jumper wires can either pass above the hardware supporting the insulators or below it. Anchor poles have been shown to pose a significant electrocution risk to birds, particularly in relation to the configuration of the jumper wires (Dixon et al., 2013; Dwyer, Harness, & Donohue, 2013; Harness, Juvvadi, & Dwyer, 2013).

A positive relationship between electrocution rates of raptors and prey abundance has been documented among power lines (Guil et al., 2011, 2015), while open landscapes can result in greater use of poles and pylons as perching sites (Lehman, Kennedy, & Savidge, 2007). Consequently, high quality foraging areas in open landscapes can attract more individuals with an increased probability of electrocution from the higher likelihood of perching on power line infrastructure. In Mongolia, dangerous electricity distribution lines cross huge expanses of open steppe connecting settlements and industrial sites to the transmission network (Tserennyam, 2013). Every pole presents an electrocution risk and high prey densities can occur unpredictably around any distribution line so remediation needs to be carried out on a very large scale, which has significant cost implications.

The grounded concrete poles used for many electricity distribution lines in Mongolia are known to kill substantial numbers of birds of prey (Dixon et al., 2013; Dixon, 2016), thus there is a need to identify efficient and cost effective mitigation measures that can be implemented to address the problem of raptor electrocution. In this study, we recorded avian electrocution rates taking into account carcass removal by scavengers, and used this data to investigate the potential influence of (i) mitigation in form of pre-existing perch deflectors fitted to line poles and experimentally reconfigured jumper wires on anchor poles, and (ii) prey availability on raptor electrocution rates.

## 2. Material and methods

### 2.1. Study site

We undertook our study along a 56 km, 3-phase, 15 kV distribution line traversing open, undulating steppe landscape at an elevation of *ca.* 1250 m a.s.l between the district centres of Uulbayan and Monkhkhaan in Sukhbaatar Province, Mongolia (46.491N 112.347E to 46.967N 112.053E). The regional climate is characterised by cold winters (typically below freezing from October to April) and short summers (frost-free period from June to August). Most precipitation falls during July and August. The landscape and vegetation cover around the line was relatively homogenous along its whole length, characterised by short, sparse grasses growing in sandy soil, enabling clear visibility of any carcasses lying on the ground below power poles. The area has no formal protected status and the landscape in the immediate vicinity of the power line had few potential nesting sites for the resident breeding species.

All poles were constructed of reinforced concrete and the surveyed line comprised 493 line poles and 35 anchor poles. All anchor poles had jumper wires passing over the pole top at the central 1st phase. Of these, 13 had jumper wires passing over the crossarm on the 2nd and 3rd phases (termed 3-over anchor poles) and 22 had jump-wires passing under the crossarm on the 2nd and 3rd phases (termed 1-over anchor poles; Fig. 1). In March 2012, we reconfigured all the 3-over anchor poles so that the jump wires on the 2nd and 3rd phases passed under the crossarm i.e., they were converted to 1-over anchor poles.

Line poles had an upright pin insulator affixed to a vertical section of angled steel at the top of the concrete pole (1st phase), with a single horizontal crossarm of angled steel with one (or two near villages at each end of the line; N = 29) upright pin-insulators bolted to each end to carry the 2nd and 3rd conducting phases. Over the whole line 218 (41%) line poles were equipped with 1–4 perch-deflector spikes. These spikes had been fixed to the crossarms by the power line company previously in an attempt to reduce electrocution risk for raptors. However, the initial installation was haphazard, such that some crossarms had two centrally-positioned spikes that did not prevent birds perching adjacent to the pin insulators at the ends of the crossarms, whereas other crossarms were equipped with four-spikes, where the two outermost spikes could potentially function to deflect birds from perching adjacent to the pin-insulators (Fig. 2). Furthermore, over time a number of spikes had broken-off, so that we recorded 17 with one deflector, 64 with two, 25 with three and 112 poles with four perch deflectors.

### 2.2. Data collection

We made an initial line survey on 08 March 2012 prior to reconfiguring jump wires at 3-over anchor poles on 15 March 2012. Thereafter, we conducted six line surveys from 11 May to 20 July 2012 at 10–15-day intervals; we removed all carcasses found on 11 May and recorded these in our overall total (Table 1). We recorded 'observed electrocution' rates over 51 days from 11 May to 01 July and 'observed carcass removal' rates over 37 days from the second survey visit to 01 July. On 07 July the majority of carcasses were removed from the line by another team of surveyors unaware that we were working on this line, thus we were not able to use the information from our final survey visit on 20 July in our mortality and removal rate calculations, though we did include any new carcasses in our overall totals. In addition to raptors (Accipitriformes and Falconiformes) we have also included two crow species (Corvidae) in our analysis i.e., Red-billed Chough *Pyrrhocorax pyrrhocorax* and Common Raven *Corvus corax*.

To find electrocuted birds we drove along the power line and searched for carcasses within an area of 10 m around each pole; vegetation along the line was sparse and any dead raptors were clearly visible on the ground. We recorded each carcass found, the type and individual identification number of the pole and the number of perch deflector spikes present on the crossarm. On successive line surveys we recorded whether or not a carcass found on a previous visit was still present. During the line survey on 04/05 June, we recorded the number of active small mammal holes within a 20 m radius of alternate poles (1257 $m^2$; N = 191 poles) to record spatial variation in small mammal availability along the line. Active small mammal holes were identified from droppings or tracks at the entrance and searches were conducted by two people. The main small mammal species identified using the holes were Daurian Pika *Ochotona dauurica*, Mongolian Gerbil *Meriones unguiculatus* and Brandt's Vole *Lasiopodomys brandti*. However, we were not able to determine how many species, nor the number of individuals, that were using each burrow entrance.

### 2.3. Statistical analysis

We calculated daily removal rate by recording the number of days exposure ($E_s$) for each carcass between successive survey visits ($s$), with a period of 10, 12 and 15 days exposure for carcasses first found on the 1st, 2nd and 3rd survey visits respectively. If a

**Fig. 1.** Left: anchor pole with jumper wires (arrowed) over the crossarm at phases 2 and 3 (3-over anchor pole). Saker Falcon electrocuted at 3rd phase jumper wire. Right: reconfigured anchor pole with jumper wires passing under the crossarm at phases 2 and 3 (1-over anchor pole). Upland Buzzard electrocuted at 1st phase jumper wire.

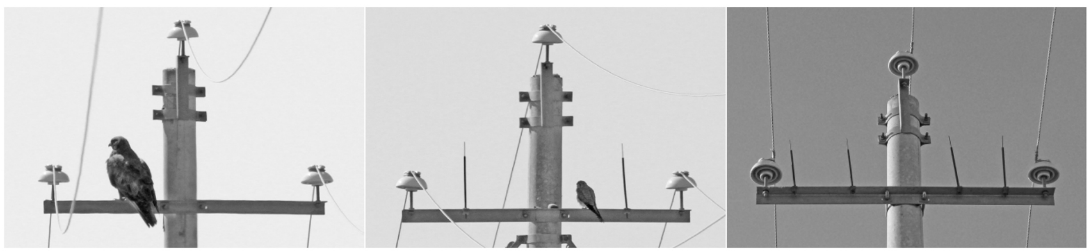

**Fig. 2.** Left: Upland Buzzard perched on line pole crossarm with 0 perch deflector spikes. Centre: Common Kestrel perched on line pole crossarm with 2 perch deflector spikes. Right: line pole crossarm with 4 perch deflector spikes.

**Table 1**
Number of electrocuted birds found during six power line surveys from 11 May–20 July 2012. Values in parentheses indicate number of birds that were removed by scavengers before the subsequent survey. † indicates resident species that could potentially breed in the general vicinity of the power line.

| SPECIES | Initial visit (11 May) | 1st survey (25 May) | 2nd survey (4 June) | 3rd survey (16 June) | 4th survey (1 July) | Final visit (20 July) | Total |
|---|---|---|---|---|---|---|---|
| Black Kite *Milvus migrans* | 9 | 1 | 0 | 2 (1) | 0 | 0 | 12 |
| Steppe Eagle *Aquila nipalensis* | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Short-toed Eagle *Circaetus gallicus* | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Common Buzzard *Buteo buteo* | 5 | 1 | 0 | 0 | 0 | 0 | 6 |
| †Upland Buzzard *Buteo hemilasius* | 13 | 0 | 2 | 1 (1) | 0 | 0 | 16 |
| Northern Goshawk *Accipiter gentilis* | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| †Saker Falcon *Falco cherrug* | 15 | 2 (1) | 3 (1) | 3 | 7 | 1 | 31 |
| †Common Kestrel *Falco tinnunculus* | 3 | 0 | 1 | 0 | 0 | 11 | 15 |
| †Chough *Pyrrhocorax pyrrhocorax* | 0 | 0 | 0 | 3 (3) | 0 | 0 | 3 |
| †Raven *Corvus corax* | 4 | 1 | 2 (2) | 8 | 0 | 0 | 15 |
| Total | 51 | 5 | 8 | 17 | 7 | 13 | 101 |

carcass was not present on the subsequent visit we assumed that it had been removed at the mid-point between visits and gave it an exposure value of $E_s/2$. A daily removal rate was calculated by dividing the number of removed carcasses by the sum of the exposure days for all carcasses.

For anchor poles, we compared electrocution rate at 3-over anchor poles prior to reconfiguration using data from survey visits on 12/13 May 2009, 07 September 2011 and 08 March 2012 (see Dixon et al., 2013 for further details). We compared the number of pole visits with and without carcasses for the same poles before and after reconfiguration using the Fisher's exact test.

To determine if there was any association between spatial variation in small mammal hole density and electrocution frequency we plotted the number of holes against pole number and used break-point analysis in the package 'segmented' (Muggeo, 2008) to define sections of line where hole density differed.

We used a generalized linear model (with a Poisson distribution of log link function) with total number of electrocution events at each line pole as a dependent variable and the number of perch deflector spikes on crossarms as a discrete variable, and whether or not the pole was in a line section with a high or low hole density as a categorical independent variable. We compared candidate models using the corrected Akaike Information Criterion ($AIC_C$). We assessed Akaike weights to identify best supported models; models with $\Delta AICc < 2$ are considered to be substantially supported by the data and similar in their empirical support of the best model

**Table 2**
Model selection for electrocution frequency with small mammal hole density and number of perch deflectors on crossarms as parameters. The relative importance of predictor variable ($w_i$) is expressed as the sum of Akaike weight across all models. df = degrees of freedom, $AIC_c$ = Akaike information criterion corrected for finite sample size, ΔAICc = difference between AIC values, $w_i$ = Akaike weights, Expl. Var. = percentage of explained variance ($R^2$).

| Models | df | $AIC_c$ | $\Delta AIC_c$ | $w_i$ | Expl. Var. |
|---|---|---|---|---|---|
| Intercept + holes + deflectors | 4 | 428.5 | 0.00 | 0.57 | 3.5 |
| Intercept + holes | 2 | 430.1 | 1.59 | 0.26 | 1.6 |
| Intercept + deflectors | 3 | 431.6 | 3.12 | 0.12 | 1.8 |
| Intercept | 1 | 433.1 | 4.56 | 0.06 | 0.0 |

(Burnham & Anderson, 2002). To calculate explained variance of each model, we first calculated residual deviance which = 2(log-likelihood (saturated model) – log-likelihood (current model)); then the null deviance which = residual deviance (intercept only model). Finally, we obtained a pseudo $R^2$ value which = 1 – (null deviance-residual deviance)/null deviance. We conducted a post-hoc analysis (Tukey's HSD test) to examine if perch deflectors have significant effect on electrocution events. Model selection and multi-model inference were implemented in R using the "MuMIn" package (Barton, 2009). All our analyses were computed in R (R Development Core Team, 2013).

## 3. Results

During six line visits from 11 May–20 July, we found 101 carcasses of 10 species that had been electrocuted (Table 1). At four line surveys from 25 May–01 July we found the carcasses of 37 electrocuted raptors, which had been killed within the monitoring period of 51 days i.e., 0.7 birds/day. Overall, 30% (9/37) of carcasses were removed by scavengers between successive surveys, with a calculated removal rate of 2.6% of carcasses each day. Overall electrocution rate for the whole power line, accounting for removal, was calculated as 0.75 birds per day; or 22.4 birds per month (i.e. 30-days) with a monthly mortality rate of 4.0 birds per 10 km. The estimated daily electrocution rate for Saker Falcons *Falco cherrug*, the species electrocuted most frequently, was 0.30 per day. This translates to approximately 9.1 Saker Falcons per month, equivalent to a monthly mortality rate 1.6 per 10 km during our period of study.

Prior to reconfiguration we found 8 carcasses during 39 visits to 3-over anchor poles, and after reconfiguration we found 1 carcass during 78 visits to these same poles (Fischer's exact test $P < 0.001$), which equates to 0.21 carcases per pole visit prior to reconfiguration compared to 0.01 carcasses per pole visit afterwards, a 16-fold reduction in electrocution events.

Break-point analysis identified four spatially discrete sections of line with low (mean = 0.8 holes/pole) and high (mean 6.8 holes/pole) hole density; there was a significant difference in small mammal hole density between line sections classified as either high or low ($t = 15.61$, $df = 361.7$, $P < 0.001$; Fig. 3).

We found 37 carcasses at 199 poles with no perch deflectors (0.19 per pole), 10 carcasses at 80 poles with 1 or 2 perch deflectors (0.13 per pole) and 13 carcasses at 127 poles with 3 or 4 perch deflectors (0.10 per pole). A model incorporating hole density and the number of perch deflectors on crossarms best predicted electrocution frequency at power poles (Table 2). Electrocution events were most frequent where hole density was high and the number of perch deflector spikes was lower. There were significantly fewer electrocution events with 3 or 4 perch deflectors compared to no perch deflectors ($Z = -2.26$, $P < 0.05$).

## 4. Discussion

Relatively few studies of bird electrocution provide reliable estimates of electrocution rate or demonstrate the effectiveness of mitigation procedures (Bevanger, 1994; Lehman et al., 2007). Our study shows that perch deflectors can reduce electrocution frequency on line poles, and poles with 3 or 4 perch deflector spikes had nearly half the number of carcasses per pole than those without perch deflectors. We believe that the deflectors reduced mortality frequency because they reduced the likelihood of a bird perching on the crossarm adjacent to the pin insulator supporting the live phase cable. When 3 or 4 deflectors were present the distance from the spike to the pin insulator was usually closer than when 1 or 2 deflectors were present. This suggests that 2 deflectors could have been more effective if they were positioned correctly on the crossarm and prevented birds from perching adjacent to the pin insulator. Alternatively, perch deflectors may have functioned to reduce the frequency of birds perching on the crossarm *per se*, but we believe this is unlikely as there was ample space on the crossarm for birds to perch between the deflectors when 3 or 4 were used and either side of the deflectors when 1 or 2 were used.

There was a significant reduction in mortality after we reconfigured the jumper wires on the 2nd and 3rd phases of 3-over anchor poles. Jumper wires over crossarms on anchor poles are especially dangerous for raptors (Dwyer et al., 2013; Guil et al., 2011; Harness & Wilson, 2001) and electrocution can occur through direct contact with the energized jumper wire or via the upright pin insulator (Harness et al., 2013; Prinsen, Boere, Píres, & Smallie, 2011). This risk is eliminated when the jumper wire passes under the crossarm. We cannot confirm which phase was responsible for each of the electrocution events at reconfigured anchor poles and line poles equipped with 3 or 4 perch deflectors, but the data suggests that further mitigation should be targeted at the central 1st phase on these poles to reduce electrocution mortality rates further. In addition to receiving accurate assessments of the efficacy of mitigation procedures, power line managers also need to understand how mitigation methods work and instruct engineers to fit them to power line hardware appropriately. In the specific case of our survey it was clear that the placement of perch-deflectors on crossarms was not targeted at deflecting birds from perch sites adjacent to insulators. Prather and Messmer (2010) also reported that some perch deterrents were not effective because of inherent design and placement flaws.

Electrocution frequency was higher in line sections with a greater density of small mammal holes. The explained variance was low in our model incorporating hole density and number of perch deflectors, although low pseudo $R^2$ values are the norm and do not assess goodness-of-fit as they are based on comparison of predicted values from the fitted model with the intercept only model (Hosmer & Lemeshow, 2000). We acknowledge that additional factors may also be involved in determining raptor electrocution rates and that unexplained variance might arise from our use of categorized proxy measures of rodent abundance. Hole density is not necessarily a good proxy measure of small mammal abundance (e.g., Van Horne, Schooley, Knick, Olson, & Burnham, 1997 but see also Price & Rachlow, 2011; Ramesh, Home, Jhala, & Qureshi, 2013). Nevertheless, there was a statistically significant 8.5 fold difference in mean density of actively-used holes in line sections classified as either high or low and an elevated electrocution rate in line sections with a high density of active holes suggests that our classification was a reliable indicator of relative small mammal densities. Prey abundance in the vicinity of power lines can influence electrocution rates by attracting birds of prey, where they may use the power poles as perches for hunting or loafing (Lammers & Collopy, 2007). Diurnal small mammals prevalent in the Mongolian steppe, such as Brandt's Vole, Mongolian Gerbil and Daurian Pika exhibit large

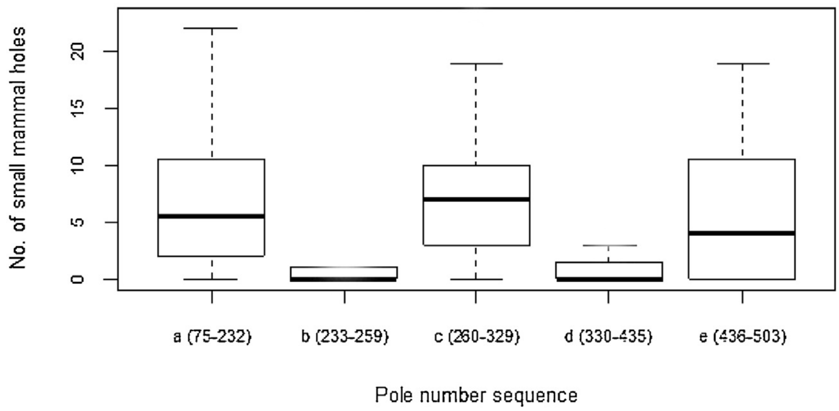


**Fig. 3.** Box plots showing median number of small mammal holes, with 25th and 75th percentiles, dashed lines show minimum and maximum values (outliers removed). Each plot represents a section of line identified by breakpoint analysis of the number of holes around poles, where a, c and e are high small mammal hole density line sections and b and d are low small mammal hole density line sections. Numbers in parentheses represent the contiguous pole numbers along the 15 kV Uulbayan-Munkhaan power line.

population fluctuations (Smith & Xie, 2008), and their abundance can vary greatly over time and space. Predictive models of avian electrocution risk at power lines typically incorporate parameters such as pole type and hardware configuration, geographical location, and surrounding habitat and topography, and prey availability (e.g., Dwyer et al., 2013; Harness et al., 2013; Tintó, Real, & Mañosa, 2010), but the predictive ability of such models to identify priority high risk lines can be compromised if prey availability varies greatly in time and space.

Estimating mortality rates per unit time require periodic surveys, whilst simple counts of carcasses below power poles during surveys can under-estimate the number of electrocution events because carcasses can be removed by scavengers (Bevanger, 1999; Ponce, Alonso, Argandona, Garcia Fernandez, & Carrasco, 2010). Potential scavengers include domestic dog, Red Fox *Vulpes vulpes*, Corsac Fox *Vulpes corsac*, Grey Wolf *Canis lupus*, Pallas's cat *Otocolobus manul*, Golden Eagle *Aquila chrysaetos* and Steppe Eagle *Aquila nipalensis*. While we were able to get a minimum estimate of carcass removal over 37 days, we were not able to detect carcasses of birds that were both electrocuted and removed between survey visits. Furthermore, the likelihood of removal by a scavenger is potentially related to carcass freshness, species, season and carcass density (Bevanger, 1999; Kemper, Court, & Beck, 2013; Ponce et al., 2010; Smallwood, 2007). If carcass removal rate is positively associated with carcass freshness, our estimation that carcasses were removed at the mid-point between visits will also lead to an under-estimate of removal rates. Consequently, an experimental approach is required to accurately estimate carcass removal rates. Furthermore, electrocution rates may vary seasonally and across years, thus it is not appropriate to extrapolate long-term mortality rates from surveys of relatively short duration.

Electrocution can potentially have a population impacts for some birds of high conservation concern, but few studies are able to demonstrate such impacts and those that do typically relate to relative sedentary species such as Eurasian Eagle Owl *Bubo bubo* (Sergio, Marchesi, Pedrini, Ferrer, & Penteriani, 2004) and Spanish Imperial Eagle *Aquila adalberti* (González et al., 1992; López-López et al., 2011). Identifying a population impact by determining whether or not electrocution mortality is additive or compensatory requires population and demographic data for species, some of which are globally threatened, that currently does not exist, particularly in vast, remote regions of the globe. Reliable data on the size of the raptor populations electrocuted at power lines in Mongolia does not exist, nor is there data on other major causes of mortality for the species affected. However, the Saker Falcon is subject to trapping for falconry, which, like electrocution, results in the removal of individuals from the population.

In our study, the globally endangered Saker Falcon comprised 31% of all birds killed and we estimate that even with the reconfiguration of anchor poles and deployment of 3 or 4 perch deflectors on nearly one-third of line poles, this 56 km power distribution line killed at least nine Saker Falcons per month during the period of our survey. In the steppe zone of Sukhbaatar province alone there are currently seven other 15 kV distribution lines of similar construction covering at least 520 km (Tserennyam, 2013), which all have the potential to kill Saker Falcons at the same rate. With at least 65 similar 15 kV distribution lines across the steppe zone of other Mongolian provinces (Tserennyam, 2013), dangerous power poles clearly have the potential to electrocute large numbers of Saker Falcons, with an estimated 4116 Saker Falcons (90% CI = 713–7951) electrocuted across Mongolia over a year (Dixon, 2016).

Avian electrocution at power distribution lines is preventable through appropriate planning and management, with stakeholders and states urged resolve the issue through multi-lateral environmental agreements such as the Convention of Migratory Species (UNEP/CMS, 2002, 2011; CMS Raptors MoU, 2012) and by international organizations such as IUCN (IUCN, 2016) and BirdLife international (Birdlife International, 2015). Consequently, it can be argued that no level of avian electrocution should be considered acceptable, irrespective of whether or not it has a population level impact on the species concerned.

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