Journal of Raptor Research

Advancing the science, conservation, and understanding of birds of prey

Journal of Raptor Research 59(2):jrr2476
doi: 10.3356/jrr2476

Electrocution of Steppe Eagles and Golden Eagles in Mongolia

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ABSTRACT.—We examined the spatial and temporal distribution of Steppe Eagle (*Aquila nipalensis*) and Golden Eagle (*Aquila chrysaetos*) electrocutions at power distribution lines in Mongolia from 2013 through 2015. Steppe Eagles were electrocuted most frequently during the summer in the steppe zone of Mongolia, coinciding with their occurrence as summer breeding visitors. In contrast, Golden Eagles were electrocuted mainly during the winter, when birds dispersed from their mountain or northern breeding areas and overwintered in open steppe landscapes. Eagles were more likely to be electrocuted at the crossarm than at the pole top. Pre-existing mitigation methods at power lines in Mongolia, comprising grounded metal perch deflectors and deterrents placed centrally on crossarms between the pole and pin insulator, did not significantly reduce electrocution rates for eagle species compared to unmitigated crossarms. We recorded an exceptionally high electrocution rate involving 22 Golden Eagles at one 98-km-long power line, possibly because of high prey abundance in the vicinity. The electrocution risk faced by eagles in Mongolia has diminished in recent years, because a nationwide program to insulate dangerous distribution lines was implemented in 2019–2022, and because the Mongolian government amended the national standard relating to distribution lines in September 2021 to include bird safety. Despite this progress, compliance needs to be enforced as dangerous lines continue to be constructed.

KEY WORDS: *avian electrocution*; *deterrent*; *mitigation*; *perch deflector*; *power lines*; *raptor*.

ELECTROCUCIÓN DE *AQUILA NIPALENSIS* Y *A. CHRYSAETOS* EN MONGOLIA

RESUMEN.—Examinamos la distribución espacial y temporal de las electrocuciones de *Aquila nipalensis* y *A. chrysaetos* en líneas de distribución eléctrica en Mongolia desde 2013 hasta 2015. Los individuos de *A. nipalensis* se electrocutaron con mayor frecuencia durante el verano en la zona esteparia de Mongolia, coincidiendo con su presencia como visitantes reproductores durante esta estación. Por el contrario, los individuos de *A. chrysaetos* se electrocutaron principalmente durante el invierno, cuando las aves se dispersaron de sus áreas de cría, desde las montañas o desde el norte, y pasaron el invierno en paisajes abiertos de estepa. Las águilas tenían más probabilidades de electrocutarse en la cruceta que en la parte superior del apoyo. Los métodos de mitigación preexistentes en las líneas eléctricas en Mongolia, que consistían en deflectores de percha metálicos conectados a tierra y disuasores colocados en el centro de

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la cruceta entre el apoyo y el aislador, no redujeron significativamente las tasas de electrocución para las especies de águilas en comparación con los apoyos no corregidos. Registramos una tasa de electrocución excepcionalmente alta que comprendió a 22 individuos de *A. chrysaetos* en una línea eléctrica de 98 km de longitud, posiblemente debido a la alta abundancia de presas en las cercanías. El riesgo de electrocución al que se enfrentan las águilas en Mongolia ha disminuido en los últimos años porque se implementó un programa nacional para aislar las líneas de distribución peligrosas entre 2019 y 2022, y porque el gobierno mongol modificó el estándar nacional relativo a las líneas de distribución en septiembre de 2021 para incluir la seguridad de las aves. A pesar de este progreso, es necesario hacer cumplir la normativa, ya que siguen construyéndose líneas peligrosas.

[Traducción del equipo editorial]

INTRODUCTION

Avian electrocution on distribution power lines is a major cause of mortality for raptors in central Asia (Dixon et al. 2013, Dwyer et al. 2022), India (Harness et al. 2013), Africa (Boshoff et al. 2011, Angelov et al. 2012), Europe (Prinsen et al. 2011) and North America (Avian Power Line Interaction Committee [APLIC] 2006). In Mongolia, many 15-kV distribution lines are particularly dangerous for birds of prey, especially those lines in open steppe habitats with a high density of rodent prey nearby (Harness et al. 2008, Dixon et al. 2017). Avian electrocution in Mongolia is primarily associated with infrastructure consisting of grounded steel-reinforced concrete poles with steel crossarms and brackets supporting upright pin insulators (Fig. 1; Harness et al 2008).

A 2015 assessment of the Steppe Eagle (*Aquila nipalensis*) population resulted in the species being categorized as endangered on the International Union for Conservation of Nature [IUCN] Red List of Threatened Species, as available information suggests that the population has undergone very rapid recent declines. Reliable estimates and trends of the breeding population in Mongolia are lacking, but the global population is estimated as fewer than 37,000 pairs (BirdLife International 2021). Qualitatively, Steppe Eagles are commonly observed in the Mongolian steppe, primarily during the April to September summer breeding season, although many individuals remain through fall, particularly in areas with high rodent densities, and some may overwinter (Gombobaatar et al. 2012). They breed in open, featureless steppe as well as more hilly areas and mountain massifs.

Golden Eagles (*Aquila chrysaetos*) are also commonly observed in Mongolia with a widespread breeding distribution. Most are resident year-round, breeding mainly in mountainous or hilly areas. The species is classified as least concern on national and global lists, although it is iconic with cultural value as a falconry bird, particularly for ethnic Kazakhs in western Mongolia (Altangul 2012).

Electrocution at electricity distribution lines is a threat faced by both species. The Steppe Eagle is the most frequently electrocuted raptor detected during surveys of power lines in central and western Kazakhstan (Levin and Kurkin 2013, Voronova and Pulicova 2013), and has also been reported as electrocuted in Russia (e.g., Karyakin et al. 2013) and Mongolia (e.g., Harness et al. 2008, Amartuvshin and Gombobaatar 2012, Dixon et al. 2013, 2017). In the USA, electrocution of Golden Eagles has received substantial attention since the early 1970s (see APLIC 2006 and references therein) and is the second most important cause of mortality for the species, killing an estimated 504 birds annually (95% confidence interval: 124 to 1494; Harness and Wilson 2001, US Fish and Wildlife Service 2016). In Europe and central Asia, the electrocution of Golden Eagles is also widely reported (see Prinsen et al. 2011 and references therein).

With a focus on the electrocution of two eagle species that hold significant conservation and cultural importance in Mongolia, we report on three distinct power line surveys to record the spatial distribution and temporal frequency of electrocutions to provide baseline information on the scale and extent of eagle electrocutions in Mongolia. This study is not intended to quantitatively compare the efficacy of various mitigation methods. Rather, we report on landscape-scale electrocution rates at lines with and without mitigation, and we qualitatively discuss the mitigation techniques employed.

METHODS

We report on three distinct power line studies in Mongolia (Fig. 2): (1) single-visit surveys of widely dispersed distribution lines from 2013 through 2015 to assess the extent of eagle electrocutions and the range of mitigation methods employed, (2) daily monitoring of a single line with experimental mitigation to elucidate temporal patterns of electrocution and specific danger points on power poles

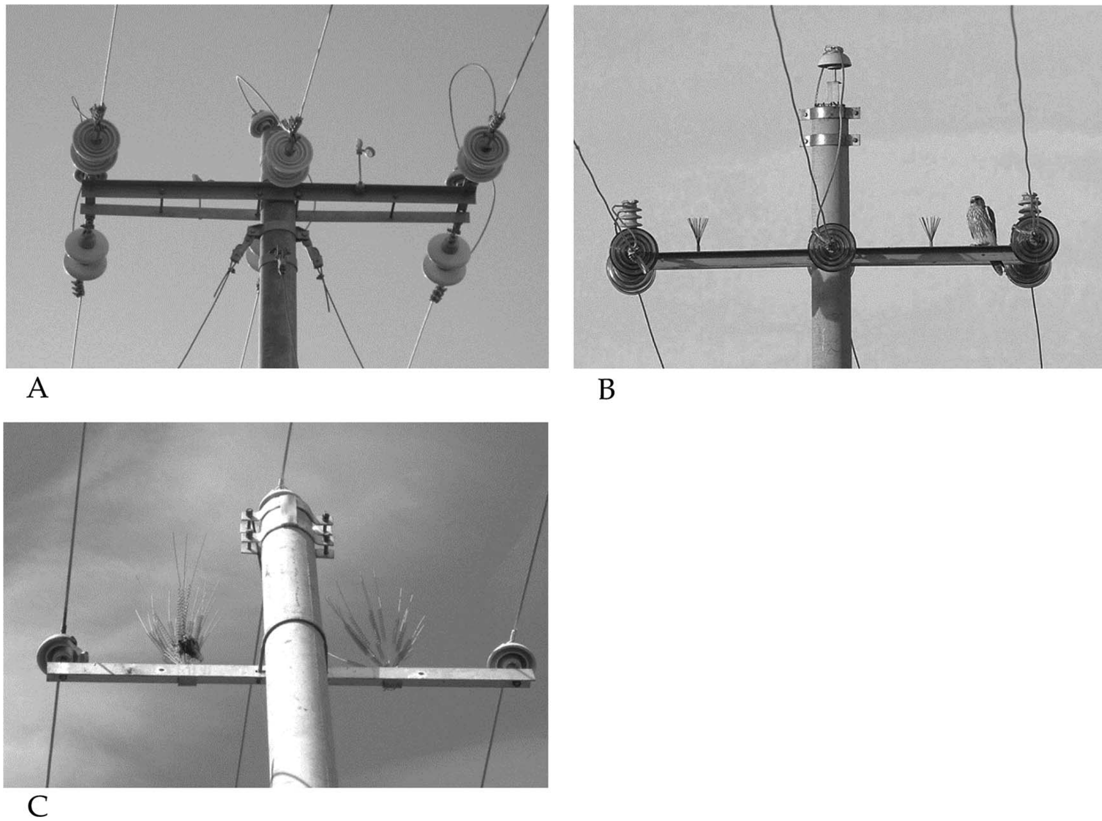

Figure 1. (A) Anchor pole with damaged mirror perch deterrents, (B) short wire brush perch deflectors and perched Saker Falcon (*Falco cherrug*), (C) long wire brush perch deflector, with head of Steppe Eagle.

(2013–2014), and (3) surveys from 2018 through 2022 of multiple lines in central Mongolia to document more recent eagle electrocution rates.

Single-visit Surveys of Widely Dispersed Lines (2013–2015). From 29 September to 03 October 2013, five teams of 2–4 people each surveyed 30 electricity distribution lines by vehicle, covering a total length of 1546 km (median line length 55 km, range 12–96 km). From 11–17 August 2014, four teams surveyed 29 electricity distribution lines (15 of which were repeated from 2013), with a total length of 1482 km (median line length 56 km, range 11–91 km), and from 14–21 August 2015, three teams surveyed 21 electricity distribution lines (13 and 17 of which were previously surveyed in one or two previous years, respectively), with a total length of 1555 km (median line length 56 km, range 11–91 km).

The poles at these lines were either unmitigated (not modified to reduce avian electrocution risk) or were mitigated with one of two main types of mitigation: (1) grounded steel perch deflectors, either wire brushes or spikes affixed centrally on the crossarm either side of the pole, or (2) rotating mirror perch deterrents that were similarly affixed midway between the pole and the upright pin insulator of the crossarm (Fig. 1).

Daily Monitoring of a Single Line (2013–2014). We surveyed a three-phase 15 kV line covering 56 km between the district centers of Munkhkhaan (46°58′N, 112°2′E) and Uulbayan (46°29′N, 112°19′E) in Sukhbaatar province, eastern Mongolia. This line had 532 poles, comprising 36 anchor poles and 496 line poles; anchor poles occur at the ends of the line (dead-ends), at deviation points (corner and intersections), and at intervals (double dead-ends; typically 1.5–2.0 km) along straight runs to adjust the strain on conductor wires. We undertook an experimental trial of mitigation methods on this line. However, we do not report the mitigation trial results here as they are already published in Dixon et al. (2019). Here we

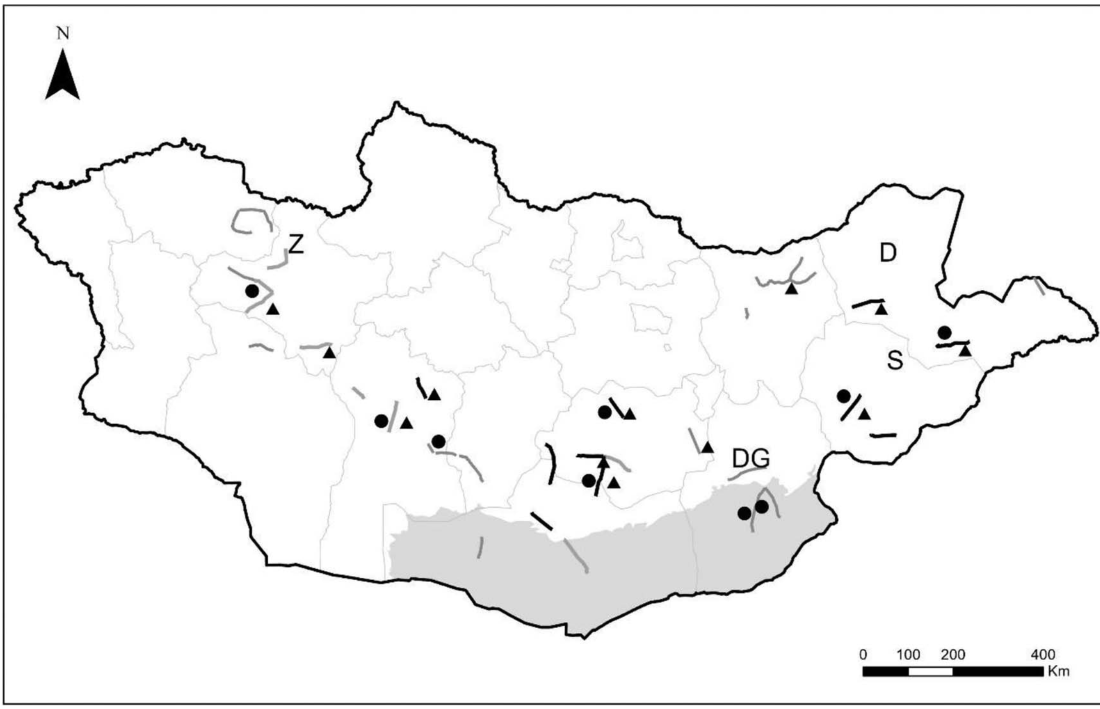

Figure 2. Map showing the distribution of surveyed 15-kV power lines in Mongolia. Black lines denote power lines that were surveyed in 2013, 2014, and 2015; and gray lines denote power lines that were surveyed daily from August 2013 to August 2014. More recent electrocutions of Steppe Eagles (black triangles) and Golden Eagles (black dots) were discovered during surveys from 2018 through 2022. Initials refers to provinces mentioned in the text: Z = Zavkhan, DG = Dornogovi, S = Sukhbaatar, and D = Dornod. The shaded area represents the portion of the Gobi Desert that occurs in southern Mongolia; all other lines were located in the central steppe zone.

simply report eagle electrocutions at poles with mitigation on pole tops or crossarms. In the mitigation trial, pole top mitigation ($n = 158$ poles) comprised reconfiguration of the mount holding the pin insulator, or pin-insulator and wire insulation covers, whereas crossarm mitigation ($n = 137$ poles) comprised steel brush perch deflectors, rotating mirror perch deterrents, or conductor covers (Dixon et al. 2019). The line also included poles that had no mitigation at pole top or crossarm ($n = 201$) but these were not informative in relation to where on the pole electrocution was likely to have occurred.

Two surveyors on motorcycles alternately undertook daily surveys of all poles from 21 August 2013 to 15 August 2014.

Single Visit Surveys of Multiple Lines in Central Mongolia (2018–2022). From 2018 through 2022, we conducted 37 vehicle surveys of 29 different lines in central Mongolia. This included repeated surveys ($n = 3$) of a line where we recorded an unusually high number of electrocuted Golden Eagles. The configuration of lines that we surveyed more than once remained consistent between surveys.

Survey Protocol. We undertook our vehicle surveys during daylight, traveling slowly (<10 km/hr) past each pole, visually searching the bases of power poles and the ground within a radius of 20 m and stopping when a carcass was observed. We recorded every carcass found, noting the species, condition, and location. During the surveys conducted from 2013 through 2015, we photographed all carcasses next to a whiteboard with the date and pole number recorded. In surveys from 2018 through 2022, we collected photographs incidentally. We attributed carcasses to electrocution by assuming the autopsy results of 286 Saker Falcon (*Falco cherrug*) carcasses (all electrocutions, and mostly found during daily monitoring of the Uulbayan-Munkhkhaan power line in 2013–2014) could be used to infer the cause of death for eagles in this study (Dixon et al. 2020). We classified carcass condition based on level of decomposition and assigned them to one of three categories: fresh (no decomposition and no insect larvae), dead <1 mo (carcass with insect larvae present), or dead >1 mo (desiccated carcass with no insect larvae). We did not record older skeletal remains. During all surveys, we recorded whether there was any mitigation in place. In all areas, vegetative ground cover was either absent or made up of sparse, short grasses, so we are unlikely to have missed many carcasses with no systematic difference in detection rates among power lines. We did not attempt to quantify scavenging bias, crippling bias, or detection bias among lines, so our findings should be interpreted as an index, not a census.

Statistical Analysis. For the single-visit surveys to widely dispersed lines, we compared eagle electrocutions (both species combined) at lines with and without pre-existing mitigation. First, we used a chi-square test of the proportion of eagles found at the lines. Second, to account for differences in the number of poles among lines, we expressed electrocutions as the number of eagle carcasses per 1000 poles, calculated by dividing the number of carcasses observed by the number of poles in the line and multiplying by 1000. We then applied a two-sample *t*-test, using an *F*-test to confirm homogeneity in variance, and the Shapiro-Wilk test to confirm normal distribution of the log-transformed data. For the daily monitoring of a single line, we used a Fisher's exact test to compare eagle electrocution rates at poles with mitigation at the pole top versus those with mitigation at the crossarm.

RESULTS

Single Visit Surveys of Widely Dispersed Lines (2013–2015). We recorded the electrocuted carcasses of 21 Steppe Eagles and 10 Golden Eagles at 11 and 9 different power lines, respectively. We found a trend toward a greater proportion of electrocuted eagles at lines with no existing mitigation (i.e., 6 of 10 lines) compared with lines with mitigation (i.e., 9 of 29 lines), but this difference was not statistically significant ($\chi^2 = 3.55$, df = 1, $P = 0.06$), possibly due to the small sample size. Expressing electrocution rates as the number of eagle carcasses per 1000 poles, we recorded zero electrocutions during 59 surveys (0 electrocutions/1000 poles across 24 different lines) and 1.2–8.1 carcasses per 1000 poles during 21 surveys (mean = 3.5; 15 different lines). We applied a two-sample *t*-test. An *F*-test confirmed no significant difference in variance between groups with or without mitigation ($F = 0.87$, df = 8, $P = 0.82$). The Shapiro-Wilk test indicated that the log-transformed data followed a normal distribution ($W = 0.95$, $P = 0.66$). There was no significant difference in eagle electrocution rates per 1000 poles between lines with and without mitigation ($t = 1.266$, df = 13, $P = 0.23$). Both species were mainly killed at power lines in the central steppe zone of Mongolia, from Zavkhan in the west to Dornod province in the east. Only Golden Eagles were electrocuted in the Gobi Desert in Dornogovi province (Fig. 2).

Daily Monitoring of a Single Line (2013–2014). We detected 12 Golden Eagle and 8 Steppe Eagle electrocutions during daily monitoring of the line. Eight electrocutions occurred at poles with mitigation at the top of the pole, while none occurred at poles with mitigation at the crossarm (Fisher's exact test, $P < 0.01$). Furthermore, all electrocutions occurred at line poles with no crossarm mitigation (i.e., at 13 of 359 poles) compared with no electrocution at poles with deflectors, deterrents, and covers (i.e., 0 of 137 poles), indicating that mitigation on the crossarm can reduce eagle electrocution rates. All eight Steppe Eagle electrocutions occurred in summer between April and September, whereas six of the 12 Golden Eagles electrocutions occurred in winter between October and March.

Single Visit Surveys of Multiple Lines in Central Mongolia (2018–2022). During line surveys from 2018 to 2022, we recorded 37 eagle electrocutions in this part of our research, highlighting the persistent risks posed by power lines to raptors in Mongolia. Expressing electrocution rates as the number of eagle carcasses per 1000 poles, we recorded zero electrocutions during 20 line surveys (0 electrocutions/1000 poles), 1.2–5.7 electrocutions/1000 poles during seven line surveys (mean = 3.1/1000 poles) and 24.6 electrocutions/1000 poles at one line. One unmitigated line with an exceptionally high rate of eagle electrocutions ran for 98 km from the settlement of Ulaanbadrakh (43°51′N, 110°24′E) to Khamriin Khiid (44°36′N, 110°16′E) in Dornogovi province. During a single visit survey on 25–26 May 2021, we found the carcasses of 22 electrocuted Golden Eagles, all of which had a broadly similar stage of decomposition indicating they were probably electrocuted during February–March 2021 (Fig. 3). A survey of the same line conducted the previous autumn on 10–11 October 2020 recorded only four Golden Eagle carcasses, while an earlier survey conducted on 30 September 2013 recorded just one Golden Eagle carcass, which had been lying on the ground for at least 1 mo.

DISCUSSION

The absence of any significant difference in eagle electrocution at mitigated vs. unmitigated lines suggested that the pre-existing mitigation,

Figure 3. An electrocuted Golden Eagle, one of 22 found during a single visit survey at a power line in Dornogovi province on 25–26 May 2021.

targeted at crossarms, was ineffective. This result contrasted with our finding at the experimental trial line where there were fewer eagles electrocutions at poles with crossarm mitigation. This discrepancy can be explained by the placement of perch deflectors close to the pin insulator (i.e., ca. 10 cm away) at poles on the experimental trial line. We hypothesize that placement likely resulted in the displacement of perching eagles farther away from the conductor cable. In contrast, when the deflector was placed centrally on the crossarm, as was the case for poles with pre-existing mitigation, perch displacement was likely directed closer to the energized conductors. Furthermore, mirror perch deterrents easily breakdown (Dixon et al. 2019), and at lines with older pre-existing mitigation many rotating mirror deterrents were nonfunctional. Finally, the trial line also included conductor insulation, which was not deployed elsewhere.

At our experimental trial line, eagle electrocutions were significantly more prevalent at poles with mitigation at the pole top than at the crossarms, indicating that more eagle electrocutions occurred at the crossarm than at the top of the pole. Eagles cannot easily perch directly on top of the concrete pole because the live conductor cable inhibits access to the pole top. Instead, eagles may perch on top of the pin insulator, where they are relatively safe from simultaneously contacting the grounded, concrete pole top. Alternatively, eagles may opt to perch on the grounded crossarms where they risk simultaneously touching the energized conductor and being electrocuted.

Seasonal variation in electrocution frequency between the two species reflects the fact that Steppe Eagles are predominantly summer visitors in Mongolia. Further, it indicates that Golden Eagles range over a wide area of steppe during winter, including predominantly flat, open landscapes like those traversed by the Uulbayan–Munkhkhaan power line. Previous surveys of the same power line found a similar seasonal pattern of electrocution for both Steppe Eagles and Golden Eagles (Dixon et al. 2013).

The exceptionally high number of eagle fatalities over a short period at one line during late winter in 2021 suggests specific factors contributed to this mass electrocution event. The semidesert scrub habitat along this line was particularly suitable for Tolai hares (*Lepus tolai*), a potential prey species for Golden Eagles in winter. It is possible that high prey densities resulted in large numbers of eagles using the line for hunting over a limited period during spring migration in 2021. The approximately north-south direction of the line would intercept Golden Eagles migrating toward the Gobi-Altai mountains from the eastern grasslands of Mongolia and China, causing all birds transiting the area to encounter this line. Golden Eagles do not migrate in flocks, so it is unlikely that significant numbers were simultaneously forced to seek perching sites on power poles during harsh weather conditions.

In recent years, the situation relating to avian electrocution has improved in Mongolia. Over the period 2019–2022, a large-scale program to retrospectively deploy insulation covers at dangerous poles was undertaken across the Mongolian power distribution network (Dixon et al. 2023). Furthermore, legislation and bird safety standards for new power lines in Mongolia are improving. In 2021, the Mongolian Government amended the national standard relating to the construction of 0.4–22-kV overhead lines to include bird safety standards. However, despite this new standard, compliance is not comprehensive. This deficiency in enforcement has led to the continued construction of dangerous power lines, posing significant risks to raptors and other bird species. Enhanced regulatory oversight and stricter enforcement of these standards are essential to mitigate these risks and protect threatened bird species.

ACKNOWLEDGMENTS

Power line surveys and mitigation trials were funded by and undertaken on behalf of the Environment Agency Abu Dhabi and the Mohamed Bin Zayed Raptor Conservation Fund. We thank HE Mohammed Al Bowardi and HE Majid Al Mansouri for their support. We also thank Batkhuu Sugarsaikhan and engineers of the Eastern Electricity Distribution Company, and J. Gombosuren, U. Boldbaatar, E. Tuvshinjargal, E. Ochirkhand, N. Jugdernamjil, R. Ganchimeg, B. Tsoggerel, E. Baasansuren, O. Bulgan, E. Bolormunkh, O. Adiya, and B. Erdenekhuu for participation in field surveys.

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Received 24 October 2024; accepted 21 February 2025
Associate Editor: James F. Dwyer