Ornis Hungarica 2025. 33(1): 202–212.
DOI: 10.2478/orhu-2025-0013

Comparison of perch deflection, conductor separation and insulation methods at reducing avian electrocutions at an electricity distribution line in Mongolia

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Received: February 05, 2024 – Revised: November 10, 2024 – Accepted: November 12, 2024

Dixon, A., Batbayar, N., Bold, B., Ganbold, M., Gungaa, A., Purev-Ochir, G. & Tsolmonjav, P. 2025. Comparison of perch deflection, conductor separation and insulation methods at reducing avian electrocutions at an electricity distribution line in Mongolia. – Ornis Hungarica 33(1): 202–212. DOI: 10.2478/orhu-2025-0013

Abstract We report persistent high rates of raptor electrocution, particularly of Saker Falcons *(Falco cherrug)*, in the Mongolian steppe grasslands. In 2018–2019, we conducted a trial to compare the efficacy of five mitigation techniques to reduce avian electrocutions at a 15 kV 3-phase power distribution line in Mongolia with a history of consistently high electrocution rates. All five techniques significantly reduced electrocution rates in comparison to controls with no mitigation. At phase 1 on the pole top, we found no significant difference in the efficacy of conductor insulation, arch-type pin-insulator mounts and the use of two pin-insulators as a means of deflecting birds from dangerous perch sites. At phases 2 and 3 on the crossarm, we found no significant difference in the efficacy of conductor insulation and the use of suspended insulators. We discuss the utility of insulation methods and pole hardware reconfiguration for retrospective mitigation of dangerous power poles that pose an avian electrocution risk.

Keywords: Saker Falcon, *Falco cherrug*, electrocution mitigation, retrofitting

Összefoglalás A mongóliai sztyeppéken tartósan magas az áramütést szenvedő ragadozómadarak száma, ezek között különösen a kerecsensólymoké. 2018–2019-ben egy 15 kV-os, háromfázisú elektromos elosztóvezetéken öt különböző módszer hatékonyságát összevető kísérletet végeztünk, olyan szakaszon, ahol korábban folyamatosan magas volt az áramütéses esetek száma. Mind az öt megoldástípus jelentősen csökkentette az áramütéses esetek számát a beavatkozás nélküli kontrollcsoporthoz képest. Az oszlop tetején futó fázis esetén nem találtunk szignifikáns különbséget a hatékonyság terén a porcelánszigetelő és a be-, illetve kilépő sodronyok burkolása (szigetelése), az ív alakú szigetelőtartó konzolok és a kettőzött szigetelők használata esetén, a madarak veszélyes ülőhelyekről való eltérítése, távoltartása szempontjából. A másik fázisoknál, a keresztkarokon, nem találtunk szignifikáns különbséget a szigetelőburkolatok és hosszabbító elemeik segítségével történő utólagos kiegészítés és a függesztett szigetelőkre való csere hatékonysága között. Megvitatjuk az utólagos átalakítási (szigetelési) módszerek, technikák és az oszlopok fejszerkezetének átépítését jelentő megoldások alkalmazhatóságát és hatékonyságát a madár-áramütések kockázatát hordozó hagyományos építésű, veszélyes oszlopok kezelésében.

Kulcsszavak: kerecsensólyom, *Falco cherrug*, áramütés-csökkentés, szigetelés

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Introduction

Avian electrocution at power distribution lines is a long-standing, significant and widespread cause of bird mortality across the world (Lehman *et al.* 2007, Guil & Pérez-García 2022). The problem is well-documented and methods to remediate dangerous infrastructure can be implemented (APLIC 2006, Prinsen *et al.* 2012), but in many countries most existing dangerous power poles have not been remediated and new lines with dangerous pole configurations continue to be installed. One issue that potentially influences remediation rates is the paucity of information available to power line engineers on the efficacy of various items of equipment that are commercially available to reduce electrocution risk for birds. In Mongolia, avian electrocution is widespread and involves large numbers of birds, with the globally endangered Saker Falcon *(Falco cherrug)* being particularly affected (Dixon *et al*. 2013, 2020), while attempts to remediate the problem by electricity distribution companies have often relied on ineffectual or inappropriate methods (Dixon *et al.* 2019).

We previously assessed the efficacy of different mitigation techniques at reducing electrocution risk in a typical Mongolian 3-phase electricity distribution system. These trials indicated that hardware changes and additions that 'deflected' birds away from dangerous perch sites at the top of the pole and on crossarms could reduce electrocution rates by 85%, i.e. by using arch-type pin-insulator mounts at the pole top and additional unconnected pin-insulators at the crossarms (Dixon *et al.* 2018). Two perch deflector methods frequently deployed at crossarms by electricity distribution companies in Mongolia, i.e. grounded perch deflectors and rotating mirrors had contrasting efficacy, with only the latter significantly reducing electrocution risk (Dixon *et al.* 2019). However, arch-type mounts as used in the previous trials are not readily available from electricity distribution equipment manufacturers, so as an alternative way to deflect birds away from dangerous perch sites at the pole top, we established a trial to test to the efficacy of using a standard double-mount upright bracket used for fixing two pin-insulators at the top of the pole. A complimentary approach to reduce electrocution risk through spatial separation of conductors and perch sites at the crossarm, i.e. at phases 2 and 3, is to switch conductor attachment from upright pin-insulators to suspended insulators (Prinsen *et al.* 2012). In addition, we retained conductor insulation covers from our previous trial (Dixon *et al.* 2019) to compare the efficacy of insulation methods at both the pole top and crossarms.

Here, we describe the results of a trial in eastern Mongolia to compare the efficacy of mitigation techniques based on conductor insulation (pole top and crossarm), spatial separation of conductors from perch sites (crossarm only) and deflection from dangerous perch sites (pole top only).

Materials and Methods

Study site

The study was undertaken at a three-phase, 15 kV electricity distribution line running 56 km from the district centre of Uulbayan to the district centre of Monkhkhaan in Sukhbaatar

Province. The predominantly flat and rolling landscape surrounding the line was characterized by grass-dominated steppe habitat and sandy soils. The vegetation was sparse and short, being intensively grazed by livestock and it supported high densities of herbivorous small rodents. The Uulbayan-Monkhkhaan line has a history of avian electrocution (Dixon *et al.* 2013) and has been the subject of previous studies investigating avian electrocution rates (Dixon *et al.* 2017) and trials of mitigation methods (Dixon *et al.* 2019). The line comprises 532 poles, consisting of 36 'anchor or strain' poles and 496 standard 'line or tangent' poles. All poles were made of grounded steel-reinforced concrete, with galvanized steel crossarms. In this 3-phase distribution system, the phase 1 central conductor wire was attached at the top of the poles, while the phase 2 and 3 conductor wires were attached lower down, either side of the crossarms.

Trial design

We describe a trial of avian electrocution mitigation techniques where the unmitigated line pole configuration comprised a single pin insulator fixed to an upright galvanized steel bracket at the top of the pole (Phase 1; P1), and single pin insulators fixed at the ends of a galvanized steel crossarm (Phases 2, 3; P2/3) *(Figure 1)*. At P1, we compared the efficacy of three techniques:

Figure 1. Upland Buzzard *(Buteo hemilasius)* perched at an unmitigated standard line pole (control)
1. ábra Himalájai ölyv *(Buteo hemilasius)* egy szigeteletlen standard oszlopon (kontroll)

(i) insulation of the conductor cable, and physical deflection of birds from dangerous perching sites by (ii) adding an additional pin-insulator and (iii) changing the pin-insulator mount from an upright bracket to an arch-shaped mount, while at P2/3, we compared the efficacy of (i) insulation of the conductor cable, and the physical separation of perching sites from conductor cables by using (ii) suspended insulators at crossarms. For the experimental trial, we divided the line into 24 sections of line poles between anchor poles, excluding 72 and 42 poles at each end of the line. We allocated lines section to five treatment groups, which were determined by a pre-existing configuration based on random allocation for a previous trial (see Dixon *et al.* 2019). On 4 and 5 October 2018, we added additional pin insulators at P1 to 131 poles and suspended insulators at P2/3 to 223 poles in the following five treatment arrangements *(Figure 2)*: (i) P1 Additional Pin Insulator in combination with P2/3 Suspended Insulators (P1Add + P2/3Sus; 66 poles/4 line sections) *(Figure 3)*, (ii) P1 Additional Pin Insulator in combination with P2/3 Insulated Conductor (P1Add + P2/3Ins; 70 poles/4 sections), (iii) P1 Insulated Conductor in combination with P2/3 Suspended Insulators (P1Ins + P2/3Sus; 79 poles/5 sections), (iv) P1 Arch Type Mount in combination with P2/3 Suspended Insulators

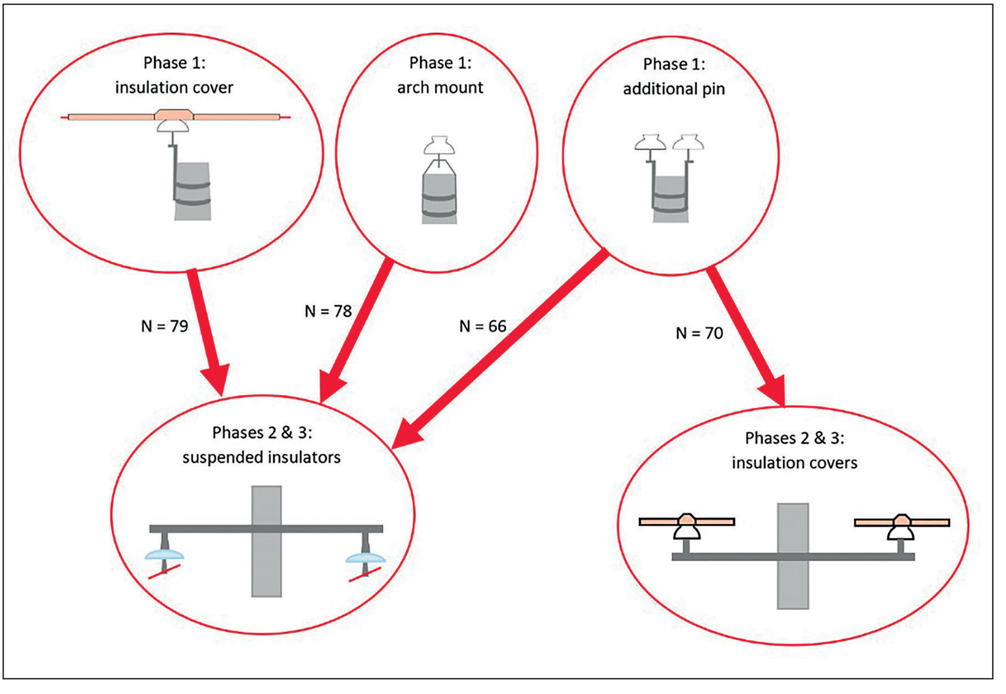

Figure 2. Trial set-up. Efficacy of insulation covers, arch mounts and additional pin-insulator at P1 was compared among poles with suspended insulators at the crossarm. The efficacy of suspended insulators and insulation covers at P2/3 was compared among poles with an additional pin-insulator at the pole top

2. ábra Az oszlopok keresztkarján függesztett szigetelőkkel ellátott oszlopok esetében összehasonlítottuk a szigetelőburkolatok, íves tartók és további csúcsszigetelők hatékonyságát az oszlop tetején (P1). Továbbá az oszlop tetején további csúcsszigetelővel rendelkező oszlopok esetében összehasonlítottuk a függesztett szigetelők és a szigetelőburkolatok hatékonyságát a keresztkarokon (P2/3)

Figure 3. Saker Falcon perched at experimental pole with an additional unconnected pin-insulator fitted to P1 to deflect birds from dangerous perch sites at the concrete pole top, and suspended insulators to separate conductors at P2/3 from perch sites on crossarm

3. ábra A kerecsensólyom egy kísérleti oszlopon ül, amelynek tetején (P1) egy további, nem csatlakoztatott csúcsszigetelőt helyeztek el, hogy elriassza a madarakat a veszélyes beülőhelyektől a betonoszlop tetején. Emellett a keresztkarokon (P2/3) függesztett szigetelők választják el a vezetékeket az esetleges beülőhelyektől, csökkentve ezzel a madarak áramütésének kockázatát

(P1Arc + P2/3Sus; 78 poles/5 sections), and (v) P1 Single Pin Insulator in combination with P2/3 Pin Insulators (Control; 171 poles/9 sections).

At all anchor poles, we reduced mitigation rates by switching the jumper wires at phases 2 and 3 to pass under the crossarm rather than over it (Dixon *et al.* 2019), and for the trial, we replaced the uninsulated jumper wires with insulated cable (n=12) to compare with untreated controls (n=24)

Data collection

In 2018 and 2019, we undertook seven surveys of all poles along the power line on the following dates: 12 and 22 October, 02 and 14 November 2018 and 11 April, 16 May, 23 August 2019. We searched the ground within a radius of 20 m around the base of each pole and recorded the presence of avian remains. The ground below all poles was open and sandy with very sparse grass vegetation, making carcasses highly visible and a low likelihood that any carcasses were not detected.

Statistical analysis

Line sections were allocated sequential numbers and each pole was assigned a section number, depending which section it was in on the line. We used spatial mixed models to test whether electrocution rates significantly differed between mitigation methods and in comparison to unmitigated controls. We used generalized mixed-effect models (GLMMs), with the number of electrocuted birds per pole in line sections being the dependent variable, with treatment type considered a fixed factor. GLMMs were implemented in the spaMM (spatial Mixed Models) package in R (Rousset & Ferdy 2014) based on a Poisson distribution and we accounted for spatial correlated random effects through a Matérn spatial correlation structure. The latitude and longitude of central pole locations in each line section were used as random effects in the models. The pairwise mean comparisons between mitigation methods were carried out using the glht function of multcomp package in R based on Tukey contrasts. We computed all analyses using R (R Development Core Team 2013).

Results

A total of 453 raptors and corvids were electrocuted at poles in our treatment groups, comprising Saker Falcon *Falco cherrug* (n=226), Upland Buzzard *Buteo hemilasius* (n=140), Common Raven *Corvus corax* (n=64), Golden Eagle *Aquila chrysaetos* (n=9),

Table1. Pairwise comparisons at line poles: experimental treatment groups in relation to control, suspended insulators *v* insulation at crossarm and arch mount *v* additional pin-insulator *v* insulation at the pole top

1. táblázat Páros összehasonlítások oszlopokon: kísérleti kezelési csoportok a kontrollhoz viszonyítva, függesztett szigetelők vs. keresztkar szigetelés, valamint íves tartó vs. extra csúcsszigetelő vs. oszlop tetején lévő szigetelés

Treatment comparisons	Estimate	Std. Error	z-value	Pr(>|z|)
Treatment groups v control				
P1 Add + P2/3 Ins *v.* Control	-1.5685	0.2220	-7.064	<0.001***
P1 Add + P2/3 Sus *v.* Control	-1.7511	0.2438	-7.182	<0.001***
P1 Arc + P2/3 Sus *v.* Control	-2.4006	0.2418	-9.927	<0.001***
P1 Ins + P2/3 Sus *v.* Control	-2.6958	0.3066	-8.792	<0.001***
Suspended insulators v conductor insulation at P2/3 on crossarm				
P1 Add + P2/3 Sus *v.* P1 Add + P2/3 Ins	-0.1826	0.3178	-0.574	0.9761
Arch mount v additional pin insulator v conductor insulation at P1 on pole top				
P1 Arc + P2/3 Sus *v.* P1 Add + P2/3 Sus	-0.6494	0.3351	-1.938	0.2770
P1 Add + P2/3 Sus *v.* P1 Ins + P2/3 Sus	-0.9447	0.3831	-2.466	0.0901
P1 Ins + P2/3 Sus *v.* P1 Arc + P2/3 Sus	-0.2952	0.3831	-0.771	0.9321

Eurasian Eagle Owl *Bubo bubo* (n=7), Black Kite *Milvus migrans* (n=2), Common Kestrel *Falco tinnunculus* (n=2), Steppe Eagle *Aquila nipalensis* (n=1), Long-legged Buzzard *Buteo rufinus* (n=1), and Eastern Buzzard *Buteo japonicus* (n=1). Saker Falcons were the most frequently electrocuted species, with most electrocutions occurring during the post-fledging dispersal period. We found 89 carcasses during two breeding season surveys in April and May 2019. Over a 40-day period from 5 October to 14 November 2018, Saker Falcons were electrocuted at a rate of at least 0.45 birds per day at control poles, equivalent to one per day for every 380 unmitigated poles. Of 119 carcasses recovered on a single survey during the post-fledging dispersal period in August 2019, we able to determine the age and sex of 114 birds, 54% of which were male and overall 76% were juveniles electrocuted in the year they hatched (HY; all other birds were recorded as electrocuted 'after hatch year', AHY), with no significant sex-bias among the age classes (Male : Female HY=48 : 39, Fisher's exact test P=0.55; Male : Female AHY=14 : 13, Fisher's exact test P=1.00).

At standard line poles, all treatments significantly reduced electrocutions in comparison to the control *(Table 1, Figure 4)*. Using treatment groups that all had additional pin insulators at the top of the pole to compare the efficacy of different configurations at P2/3

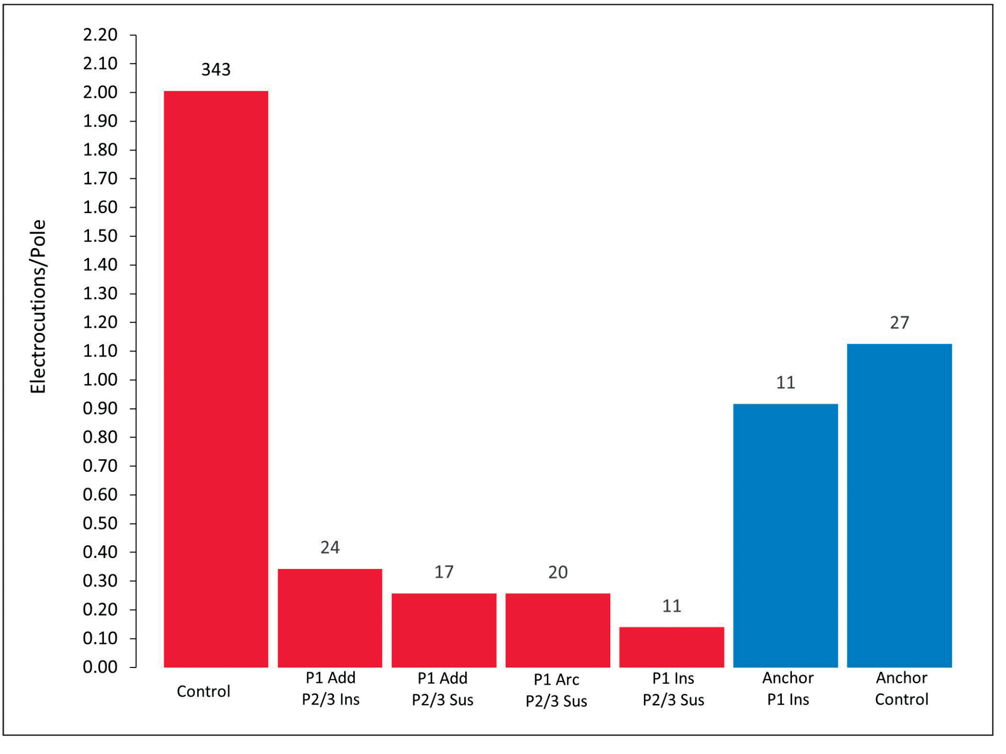

Figure 4. Avian electrocutions per pole in each treatment group of line/tangent poles (red) and anchor/dead-end poles (blue). Values represent the number of carcasses found for each treatment group

4. ábra A madarak áramütéses eseteinek száma oszloponként az egyes kísérleti csoportokban: standard állású/tangens oszlopok (piros) és feszítő/végoszlopok (kék). Az értékek az egyes kezelési csoportokban talált tetemek számát jelzik on the crossarm, we found no significant difference in efficacy between conductor insulation and suspended insulators *(Table 1)*. Additionally, using treatment groups that all had suspended insulators on the crossarms to compare the efficacy of different configurations at P1 on the pole top, we found no significant difference in efficacy at reducing electrocution rates between conductor insulation, arch-type insulator mounts and an additional pin insulator *(Table 1)*.

Table 2. Comparison of avian electrocution rate at anchor poles with insulated jumper wires *v* controls

2. táblázat A madarak áramütéses eseteinek összehasonlítása feszítőoszlopokon szigetelt összekötő vezetékekkel és kontroll csoportokkal

Treatment	Estimate	Cond. SE	t-value
Intercept	-0.1357	0.3317	-0.409
Insulated P1 jumpwire	-0.3178	0.5210	-0.610

At anchor poles, we found no effect of replacing uninsulated jumper wires at phase 1 with insulated cable *(Table 2)*. However, this anomalous result was probably due to incorrect fitting of the insulated jumper cables where the engineers had left an exposed section of uninsulated conductor cable at either end of the cable connecting joints *(Figure 5)*, which posed an electrocution risk for birds perching nearby.

Figure 5. Insulated jumper wires connected to conductors at anchor pole. A: shows correct fitting at P2/3 with cable connection in front of the dead-end clamp. B: shows incorrect fitting at P1 with cable connection on jumper wire after the dead-clamp, leaving exposed conductors above perch sites on the crossarm

5. ábra Szigetelt összekötő vezetékek csatlakoztatása feszítőoszlopon lévő vezetékekhez. A: helyes csatlakoztatás a P2/3 pontokon, ahol a kábelkapcsolat a végzáró bilincs előtt van. B: helytelen csatlakoztatás a P1 ponton, ahol a kábelkapcsolat a végzáró bilincs után van az összekötő vezetéken, így a keresztkaron lévő ülőhelyek felett szabadon maradnak a vezetékek

Discussion

The most frequently electrocuted species was Saker Falcon, accounting for half the raptors recorded in this study. As with previous surveys of this power line in eastern Mongolia, we found that during the post-fledging dispersal period most of the Saker Falcons killed were HY juveniles (Dixon *et al.* 2020). However, we found no evidence of sex bias among age classes, in contrast to previous results obtained during the post-fledging period at the same line (Dixon *et al.* 2020). Persistent high electrocution rates reported for this power line are likely related to asynchronous population cycles among the small mammal community (i.e. Daurian Pika *Ochotona dauurica*, Brandt's Vole *Lasiopodomys brandtii*, and Mongolian Gerbil *Meriones unguiculatus*) maintaining a consistently high abundance of prey in the adjacent grassland.

Our results confirm previous findings based on trials at the same power line in 2013–2014 (Dixon *et al.* 2019), in that arch-type pin-insulator mounts and conductor insulation were effective at reducing electrocution rates at the pole top (P1). The addition of a second pin insulator was also effective at reducing electrocution risk at the pole top. The additional pin insulator reduced the space available for medium- and large-sized raptors and corvids to perch on the concrete pole top, and likely acts by deflecting the birds to perch on top of the insulators, which is relatively safe with a lower risk of contact with the grounded pole. Although there was no significant difference in electrocution rates between these three treatments, the use of conductor insulation at phase 1 on the pole top resulted in the lowest electrocution rates. Conductor insulation at phases 2 and 3 on the crossarm was equally as effective as using suspended insulators that carried the conductor cable under the crossarm.

It is noteworthy that none of the mitigation measures eliminated electrocution risk. Increased separation of live conductor cables from raptor perch sites using suspended insulators at crossarms can significantly reduce electrocution rates, but there is still a risk of electrocution through feacal 'streamers' (Eccleston & Harness 2018). There is also a logistical issue with retrospectively reconfiguring crossarms with suspended insulators in that to achieve minimum regulatory ground clearance heights for conductor cables it may be necessary to move the crossarm higher up the pole, which is not always possible or safe on preexisting poles. New lines utilizing suspended insulators require alternate crossarm designs, taller poles or closer pole-spacing distances, which increases cost. Deflecting raptors from dangerous perch sites at the top of the pole may not always work, especially for smaller species that can still find a place to perch. Larger birds may flap more vigorously when trying to settle on a smaller perch space on the concrete pole top, increasing their risk of simultaneously contacting the conductor cables. When deflected to perch on the top of the pin insulator instead, where their feet are in contact with the live conductor cable, larger raptors may still simultaneously contact the concrete pole or galvanized steel insulator mount with their tail, wing, feacal 'streamer' or even dangling prey (e.g. Dixon *et al.* 2018). Adding insulation to the existing pole hardware is a relatively simple form of retrospective mitigation that can be applied to conductor phases at both the pole top and crossarm and can potentially be fitted without requiring power shutdown. However, depending on the design, insulation covers may have limited durability and require regular replacement and maintenance (e.g. Guil *et al.* 2011), while there can also be risks to conductor integrity (Göcsei *et al.* 2014) and power supply associated with flashover due to ice accretion (Farzanah & Chisholm 2008) and electrical creep caused by dust accumulation (Castillo Sierra *et al.* 2015). In our study, insulation covers were made from durable uPVC and had been in place for 6 years with no losses. We did not investigate any effect of insulation covers on power supply, but we did note that the rigid covers had resulted in many pin insulator mounts tilting from vertical, probably due to increased wind load.

Ongoing electrocution risk can be the result of incorrectly fitted mitigation, described by Dwyer *et al.* (2017) as 'application' errors in retrofitting. Our attempt to mitigate jumper wires at the central phase of anchor poles was unsuccessful due to the insulated jumper cable being too short, leaving a long length of uncovered jumper wire and an uninsulated cable connecter at each end. It is likely this occurred when engineers precut the insulated jumper wires too short at a fixed length prior to installation, and they did not fully appreciate the objective of ensuring that the whole length of the jumper wire from the dead-end clamp was insulated. Consequently, we were not able to examine the efficacy of using fully insulated jumper cables at reducing electrocution risk.

We conclude that retrospective mitigation techniques at dangerous power poles that involve adding additional insulation or changing configurations of pole hardware can be equally effective at reducing electrocution rates. While insulation covers can be quickly and simply applied to all three phases of a dangerous power line, there are potential issues with durability, maintenance and risks to conductor integrity and power supply. Such concerns are not applicable to reconfigured hardware, but it will always require significant input from line engineers and power shutdown, while techniques such as switching to suspended insulators cannot be retrospectively applied in all circumstances.

Acknowledgements

This study was funded by the Mohamed Bin Zayed Raptor Conservation Fund. We thank H. E. Mohammed Al Bowardi for his support.

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