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Original Article

Malfunction Rates of Bird Flight Diverters on Powerlines in the Mongolian Gobi

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Abstract

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The Oyu Tolgoi (OT) project, one of the world's largest copper and gold mines, is located in Gobi Desert of Mongolia. To help meet its target of Net Positive Impact on key biodiversity features such as the Houbara bustard (*Chlamydotis undulata*) the OT installed bird flight diverters (BFDs include spiral and flapper devices) to its power transmission lines to reduce the risk of birds hitting the wires. Despite the many studies demonstrating that BFDs reduce collision rates, we could find no published information on malfunction rates of BFDs. In January 2013, we surveyed the physical function of 1,200 BFDs (e.g. 600 flappers and 600 spirals) in three sample areas on each of four lines of varying voltage and structure. Of the 600 flappers examined, 123 had malfunctioned within nine months of installation, while the malfunction rate of the 600 spirals studied was zero. Using a Generalized Linear Mixed Model, we found that the rate of flapper malfunction increased with decreasing flapper size and power line diameter. Further, the flapper malfunction rate increased as the distance between poles increased. The cost of replacing malfunctioning BFDs is very high as there are serious health and safety constraints related to working with live wires. Factors affecting diverter malfunctioning need to be considered for future powerline projects and our information can serve as basis for developing national standards or regulations for powerline mitigation in Mongolia.

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Introduction

The Oyu Tolgoi (OT) project, one of the world's largest copper and gold mines, is located in Khanbogd soum in Umnugobi province of Mongolia. In 2012, OT constructed a 96 km 220 kV power transmission line between the OT mine site and the Gashuun Sukhait (GS) check point at the Mongolia-China border. OT has also constructed a 35.5 km 35 kV transmission line from the mine site to Khanbogd town, a 68 km 35 kV line to the borefield at Gunii Hooloi (GH), shorter 35 kV lines within the mine site (LA), and 6.3 kV distribution lines to individual production bores (PB) (Figure 1).

OT has a specific aim to achieve a Net Positive Impact on key biodiversity features in the Southern Gobi region, notably the

Asiatic wild ass (khulan in Mongolian; *Equus hemionus*), Goitered gazelle (or Black-tailed gazelle; *Gazella subgutturosa*) and Houbara bustard (*Chlamydotis undulata*) (TBC & FFI, 2012). Some of the OT powelines cross the Galba Gobi Important Bird Area that supports a globally important population of Houbara bustard (Batbayar & Natsagdorj, 2009; Batbayar *et al.,* 2011). The OT Environmental and Social Impact Assessment predicted that collisions with project power lines would significantly impact some bird species including the Houbara bustard, as they are particularly susceptible to colliding with power lines (Martin & Shaw, 2010).

Powerlines are estimated to kill 12-64 million birds each year in the USA (Loss *et al.,* 2014) and 2-26 million in Canada (Rioux *et al.,* 2013). Marking power lines with bird flight diverters (BFDs) to increase the visibility of these lines to flying birds has been shown to reduce mortalities by 55–94% (Barrientos *et al.,* 2011). Common BFDs include spiral and flapper devices: Polyvinyl chloride (PVC) spirals, alone, have been shown to reduce bird collisions by up to 81% (Janss & Ferrer, 1998), while flappers on their own have been shown to reduce collisions by 60-63% (Brown & Drewien, 1995; Yee, 2008), and flappers added to spirals have been shown to reduce collisions by an additional 52% (Anderson, 2002).

During 2013, there were 118 recorded incidents of birds colliding with the OT-GS power transmission line, despite the installation of BFDs. However, a significant proportion of flappers appeared to malfunction soon after the installation. There is no published information available on malfunction of BFDs. This study aimed to identify causes of BFD malfunction, and to recommend improved operating procedures.

Study area

The OT study area is located in Khanbogd soum in Umnugobi province, approximately 80 km north of the Mongolia-China border and 550 km south of Ulaanbaatar (Figure 1). The climate is strongly continental with daily means reaching 40^{o}C in summer and dropping to -35^{o}C in winter. The long-term average (1976–2014) wind speed around OT is 4.2 m.sec-1, with the strongest wind recorded being 49.9 m.sec-1 in June 2007 (Oyu Tolgoi General Site Conditions report, 2015). Elevations in the study area range from 600-1350 m. Vegetation is sparse and in large parts dominated by drought adapted central Asian desert species, particularly *Stipa gobica*, *Allium mongolicum*, *Iljina regelii,* and *Anabasis brevifolia* (von Wehrden *et al.,* 2009). To date, 225 species of birds have been recorded in and around the OT mine site. Several globally and regionally threatened species found at the site include endangered Dalmatian pelican

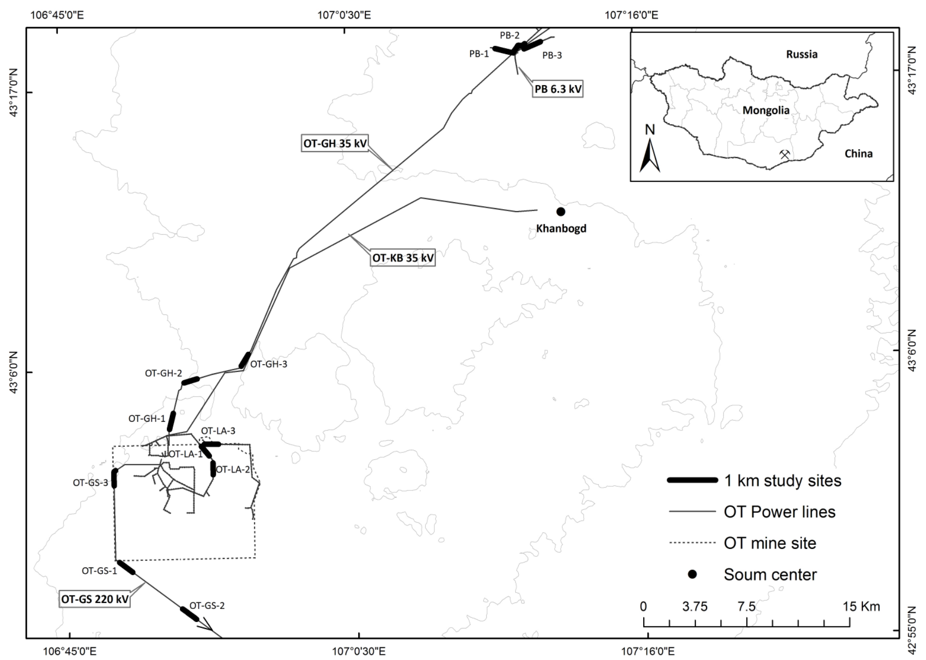

Figure 1. Study area in the southern Gobi, Mongolia, showing the location of power lines and study sites.

(*Pelecanus crispus*), Relict gull (*Larus relictus*) and Great bustard (*Otis tarda*) and, in addition to these species, Saker falcon (*Falco cherrug*), Houbara bustard (*Chlamydotis undulata*), Short-toed snake eagle (*Circaetus gallicus*) and Amur falcon (*Falco amurensis*) do also occur (Purevsuren *et al.,* 2013).

Materials and Methods

To mitigate the impacts of power lines, BFDs were installed in April and May 2012 at 10 m intervals along the OT-GS power transmission line, alternating between BirdMark™, hereafter called 'flappers' (Clydesdale Ltd, Kempston, Bedford, United Kingdom), and Swan-Flight Diverter™, hereafter called 'spirals' (Ampirical Solution LLC, Mandeville, Louisiana State, USA) (Figure 2A). Two sizes of flapper were installed – small flappers were designed to fit wires of 6-16 mm diameter and large flappers to fit wires of 16-70 mm diameter. This is the first time that BFDs have been installed in Mongolia. Flappers were designed to rotate, flap, and whistle in response to wind and wire movement, to reflect light, and to glow for up to 10 hours after the sun has set (Figure 2B). Spirals were designed to be highly visible but immobile

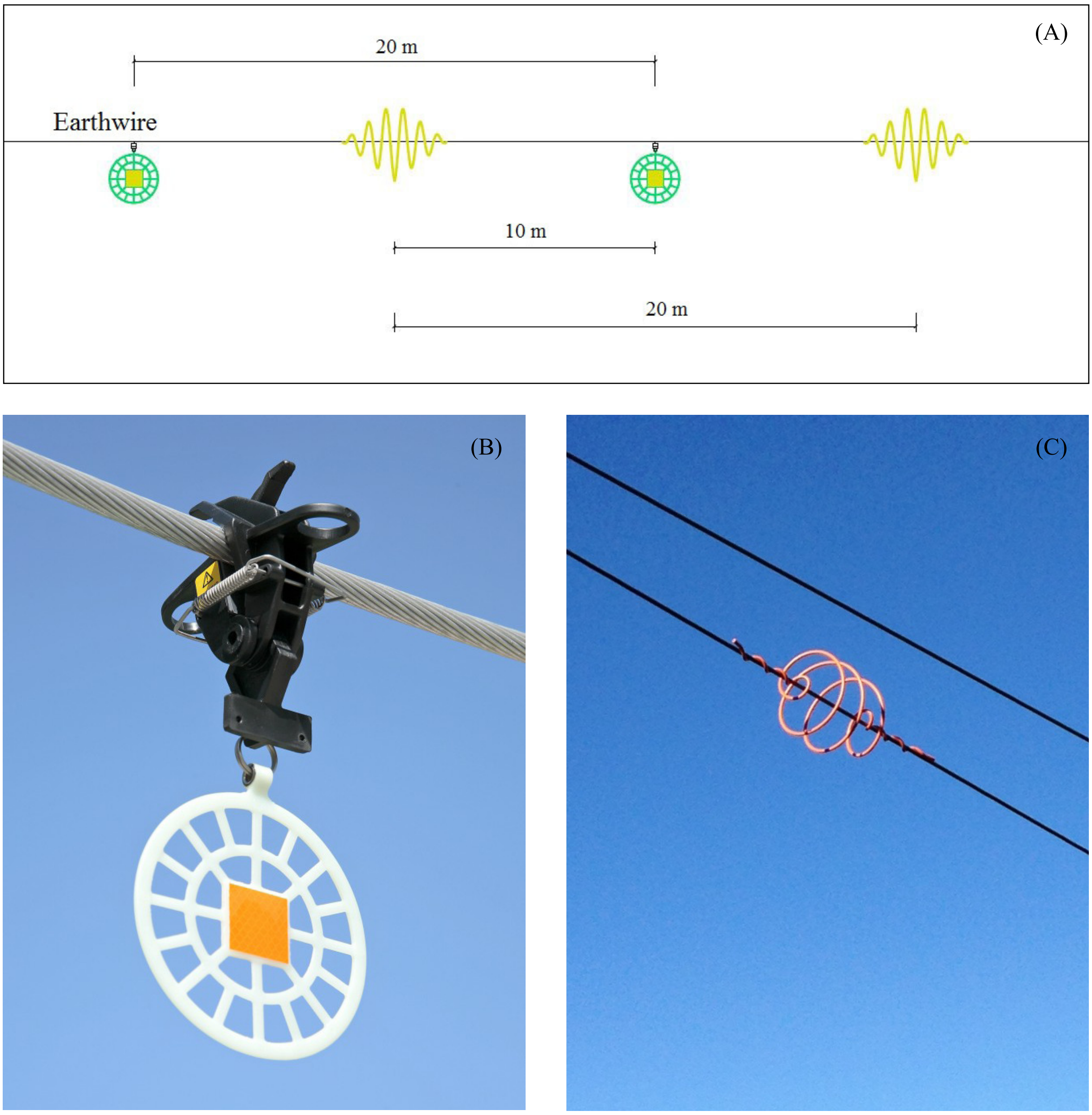

Figure 2. Schematic of the installation pattern of Bird Flight Diverters (A) and photos of a flapper (B) and a spiral (C) installed on power line in Southern Gobi, Mongolia.

(Figure 2C). Both types of BFDs were installed on the highest wire because the majority of collisions are with these earth wires, which are higher, thinner, and in a single row (e.g. APLIC, 2006).

In January 2013, we surveyed the physical function of 600 flappers and 600 spirals in three sample areas, each containing 100 BFDs (e.g. 50 flappers and 50 spirals), on each of four lines: the OT – GS 220 kV transmission power line (GS), OT – GH 35 kV transmission power line (GH), 35 kV power lines inside the OT site area (LA) and 6.3 kV power distribution lines (PB) (Figure 1). Each sample area was spaced 1 km apart on the GS and GH lines, but the samples were continuous on the shorter LA and PB lines. We walked along the sample areas, and observed each flapper with 10x42 binoculars to determine whether it was properly working (e.g., rotating and flapping), and photographed it with a Canon 7D camera and 100-400 mm lens. We considered flappers to have malfunctioned when stuck in the up position and immobile, or when fallen. We also considered spirals to have malfunctioned when fallen. To explore potential causes of malfunction, we measured the distance between adjacent pylons or poles, the distance from each BFD to the nearest pylon or pole, and the height of each BFD from the ground using a Swarovski 10 x 30 laser rangefinder. We also recorded the elevation (above sea level) of each BFD using a Global Positioning System.

We used General Linear Mixed Models (GLMMs) to model the combined effects of the six variables on physical function of flappers: the distance between adjacent poles (Pole-pole), the distance from each BFD to the nearest pole (Flap-pole), the height of each BFD from the ground (Height), elevation (Elevation), flapper size (Size), and the wire diameter (Diameter). We fitted GLMMs with a binomial error distribution to the data using the ‘lme4’ library in R (R Development Core Team, 2008). We excluded Height from the model because it was positively correlated with Flap-pole (rho = 0.93) and Elevation (rho = 0.72). We scaled each continuous predictor variables using ‘z-score’ standardization to have a mean of 0 and a standard deviation of 1. We incorporated site (e.g. GS, GH, LA, and PB) as a random factor in the analysis to account for potential differences in topography. We ran all possible model subsets of the five variables and ranked them using the Akaike Information Criterion (AICc) for small sample sizes. The final set of models was the most parsimonious based on ΔAICc < 4 (Anderson, 2008). Models with a ≤ 2 AICc unit difference were considered equivalent (Burnham & Anderson, 2002). To quantify the influence of each covariate on diverter function, we used model-averaging techniques to obtain parameter estimates, unconditional standard errors and the relative support of each variable (Burnham & Anderson, 2002) within the ‘MuMIn’ library in

Table 1. Number of flappers and spirals studied and percent of those that malfunctioned on four power transmission lines (GS = Gashuun Sukhait, GH = Gunii Hooloi, LA = OT mine site, and PB = Production bores) of varying voltage and diameter in the Southern Gobi, Mongolia. * The malfunction rate of the spirals studied was zero.

Site	GS	GH	LA	PB	Total
Voltage (kV)	220	35	35	6.3	
Diameter (mm)	16	10.5	10.5	18.9	
No. spirals studied*	150	150	150	150	600
No. flappers studied (large: small)	150 (0:150)	150 (5:145)	150 (142:8)	150 (77:73)	600 (224:376)
No. flappers malfunctioned (large: small)	39 (0:39)	51 (1:50)	22 (19:3)	11 (6:5)	123 (26:97)
% large flappers malfunctioned	- -	20% (1/5)	13% (19/142)	8% (6/77)	12% (26/224)
% small flappers malfunctioned	26% (39/150)	34% (50/145)	38% (3/8)	7% (5/73)	26% (97/376)

R (Barton, 2012). In addition, we calculated the model AICc weights to measure the likelihood of a candidate model being the best among the set of fitted models. We acknowledge that these modelling approaches are post-hoc analyses and no manipulations or field experiments was made.

Results

We surveyed a total of 600 flappers (376 small and 224 large) in four sites, of which 123 had malfunctioned (97 small and 26 large; Table 1). Whereas, the malfunction rate of 600 spirals examined in the four power transmission lines of varying voltage and diameter was zero. The parameter estimates of full model indicated strong influence of covariates such as Size, Diameter, and Pole-pole on the malfunction rate of flappers (Table 2). The probability of the flapper malfunction increased as the size of the device (β = -1.134, SE = 0.304) and the diameter of the wire decreased (β = -0.727, SE = 0.270), while the flapper malfunction rate increased as the distance between poles increased (β = 0.482, SE = 0.233; Table 2). However, Elevation and Flap-pole appeared as weak predictors given that the estimated coefficients of these covariates overlapped zero (Table 2). The estimated variance of the random effect (e.g. site) was nearly zero, suggesting site-specific differences

Table 2. Model averaged-parameter estimates of the full model for determining physical function of bird flight diverters installed on powerlines in Southern Gobi, Mongolia. All variables were scaled using 'z-score' standardization. Coefficient estimates, standard errors and relative importance of variables were obtained based on the Akaike Information Criterion for small samples sizes (AICc) statistic following Burnham & Anderson (2002) model averaging procedures. NS – not significant.

Coefficients	Estimate	*SE*	*Z* value	*P* value	Variable importance
Intercept	-1.103	0.141	-7.847	<0.001	
Size	-1.134	0.304	-3.730	<0.001	1.00
Diameter	-0.727	0.270	-2.694	<0.005	1.00
Pole-pole	0.482	0.233	2.066	<0.05	0.81
Elevation	-0.402	0.357	-1.124	NS	0.39
Flap-pole	-0.033	0.131	-0.250	NS	0.28

Table 3. Model selection results for estimation of factors affecting malfunction rate of bird flight diverters installed on powerlines in the Southern Gobi, Mongolia. We present results of the top 7 ranked models that have AICc weight > 0.05.

Rank	Model structure	LogLik	AICc	ΔAICc	Weights
1	Size + Pole-pole + Diameter	-283.980	578.1	0.00	0.345
2	Size + Pole-pole + Diameter + Elevation	-283.304	578.8	0.60	0.244
3	Size + Pole-pole + Diameter + Flap-pole	-283.961	580.1	2.00	0.127
4	Size + Pole-pole + Diameter + Elevation + Flap-pole	-283.273	580.7	2.67	0.091
5	Size + Diameter	-286.457	581.0	2.92	0.080
6	Size + Diameter + Flap-pole	-285.675	581.5	3.39	0.063
7	Size + Diameter + Elevation	-285.905	581.9	3.85	0.050

LogLik = log likelihood; AICc = corrected Akaike information criterion; ΔAICc = difference between model AICc and the minimum AICc; weights = model AICc weight.

Table 4. Model-averaged estimates and standard errors ($\beta \pm SE$) of the top ranked 2 competitive models (e.g. ΔAICc value is within 2 AICc) for determining physical function of bird flight diverters installed on powerlines in Southern Gobi, Mongolia. Significance code: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1.

Rank	Intercept	Size	Pole-pole	Diameter	Elevation
1	-1.160 ± 0.133***	-0.962 ± 0.264***	0.266 ± 0.120*	-0.462 ± 0.122***	
2	-1.103 ± 0.140***	-1.133 ± 0.304***	0.456 ± 0.209*	-0.726 ± 0.269**	-0.397 ± 0.356.

in malfunction rate of the flappers was negligible.

When running all possible subset models, the model of flapper malfunction rates that best fit our data (minimum AICc) contained covariates of Size, Diameter, and Pole-pole (Table 3). The inclusion of the Elevation into the best model produced the second ranked competitive model (AICc weight 24%). These parameters accounted for 59% of the AICc weight among the seven models (Table 3). We found slight changes in the parameter estimates from the top ranked two competitive models, relative to the parameter estimates from the full model (Table 2 and 4). Based on the hierarchical partitioning approach, the relative importance of Diameter, Size, and Pole-pole were greater than those of Elevation and Flap-pole for explaining physical function of flapper performance (Table 2).

Discussion

This is the first effort to examine factors influencing performance of BFDs in Mongolia, and the first published study we could find to evaluate BFD malfunction rates. We found that 123 of 600 flappers had malfunctioned within nine months of installation. During subsequent monitoring we found that the malfunction rate increased with time. In contrast, none of 600 spirals studied along the four power transmission lines of varying voltage and diameter was malfunctioned. This is probably due to the spirals were designed and installed to be immobile. When modelled, we found physical function of flapper failed as the size of the device and the diameter of the wire decreased, while the flapper malfunction rate increased as the distance between poles increased. However, elevation and the distance from each flapper to the nearest pole appeared as weak predictors influencing malfunction of flappers.

The causes of these malfunctions of the flappers are not known but likely related to the design of the grounder that connects the flapper to the wire and/or to the wire ring that allows the flappers to rotate and flap with wind and wire movement. Some small flappers (designed for 35 kV lines) might have been incorrectly installed on unsuitably large 220 kV lines. High wind speeds might have caused swinging and twisting of wires which locked flappers into fixed positions, and/or wore through the wire rings, and/or dislodged or damaged the grounders. Additionally, sub-zero temperatures and encrusted ice might have damaged the wire rings, grounders or other parts of the flappers.

The cost of replacing malfunctioning BFDs is now very high because of health and safety constraints related to working with live wires. There are two 'lessons learned' arising from this research as the first effort to mitigate the impacts on birds of power lines in Mongolia. First, this study acts as a cautionary warning to the "national power transmission grid" state owned company, other mining companies, and power line installers about the high rate of BFD malfunction (e.g. flappers), possibly related to the weather conditions of the South Gobi. Secondly, our experience with the installation of BFDs should be incorporated into national standards, specifically MNS 2919: 2003, MNS 5350: 2003 (Mongolian National Standard, 2004 and 2016), and power construction and regulations for the mitigation of powerline impacts on birds (Ministry of Infrastructure of Mongolia, 2004).

Electric power supply networks in Mongolia are responsible for causing bird mortality, especially raptors, through electrocution and collision (Amartuvshin & Gombobaatar 2012). We recommend that future power lines installed in Mongolia in areas of high risk to threatened birds, such as bustards, include spirals as BFDs because their malfunction rate was zero. Flappers should be installed on an experimental basis to investigate their durability and their efficacy as BFDs. More importantly, where possible, projects and developers should design-out the need for power lines, or minimise their length and locate them along routes of minimum risk to threatened birds. Lower-risk designs of pylons, poles and wire arrays should always be chosen to permanently reduce the risk to both threatened birds and the installer's reputation. This is particularly topical in the South Gobi, as new powerlines are being constructed in areas supporting Houbara bustards and other species of conservation concern.

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