Proposed power transmission lines in Cambodia constitute a significant new threat to the largest population of Bengal florican *Houbaropsis bengalensis*

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Abstract

The remaining Indochina population of the Critically Endangered Bengal florican *Houbaropsis bengalensis* breeds in the floodplain of the Tonle Sap. The population has declined substantially but survival rates have not been published previously. Survival could potentially be reduced by the planned construction of high tension power transmission lines that may begin as early as 2016. Using data from 17 Bengal florican monitored by satellite transmitters over four years, we estimated annual adult survival rate at 89.9% (95% CI 82.2–97.6%), comparable to other bustards. Interrogation of movement paths showed that for the 13 individuals for which we had sufficient data to cover non-breeding seasons, all annual migration routes between breeding and non-breeding areas crossed the proposed transmission line route that also impinged on the margins of one important and one minor breeding concentration. A review of bustard collision rates confirmed the vulnerability of bustards to power lines and the transmission route therefore presents an additional and serious threat to the future of this species in Indochina.

Key Words

power line, collision mortality, Cambodia, bustard

Introduction

Rapid economic growth drives increasing energy demands (Toman & Jemelkova, 2003). In Southeast Asia this demand is being met through development of hydropower dams on the Mekong and its tributaries (MRC, 2011), with the inevitable construction of associated high-voltage power transmission lines. Power lines are a well-documented threat to birds globally (e.g. Jenkins et al., 2010) with hundreds of millions killed annually through collisions and, to a lesser extent, electrocution (e.g. Rioux et al., 2013; Loss et al., 2014). Collisions disproportionately impact species with high wing-loading and low aspect, whose heavy bodies and small wings restrict rapid reactions to obstacles (Bevanger, 1998) and species with narrow fields of view in the frontal plane, such as storks, cranes and in particular bustards (Martin & Shaw, 2010).

The Critically Endangered Bengal florican *Houbaropsis bengalensis* occurs in the Southeast Asia and the Indian Subcontinent; *H. b. blandini* is the only bustard taxon in Southeast Asia, where it is now restricted to the Tonle Sap floodplain, Cambodia (Collar et al., 2014). The population declined by an estimated 44–64% between 2005/7 and 2012 to just 216 (95% CI 156–275) displaying male Bengal floricans (Packman et al., 2014), primarily due to rapid loss of floodplain grassland (Packman et al., 2013). The impact of a range of other potential threats, such as hunting and nest predation by domestic dogs, is unknown. Population trends within Bengal florican Cambodian breeding sites vary, although most are negative (Packman et al, 2014); only at Stoung-Chikreang Bengal Florican Conservation Area (BFCA) is the population stable (WCS Cambodia unpublished data 2016). Bengal floricans disperse annually from the breeding grounds as lake levels rise (Gray, 2008; Packman, 2011), migrating up to 60 km to degraded Dipterocarp forest and farmland (Packman, 2011. Outside of Southeast Asia, the nominate subspecies is restricted to an estimated 75–96 individuals in Nepal and less than 100 in India (BirdLife International 2016).

Although important in the diagnosis of population declines, basic demographic parameters for the species are poorly known; breeding productivity is unquantified, however a preliminary estimate based on a limited data set indicated potentially high adult survival (Packman, 2011), as typical for many bustard species (Dolman et al., 2015). Planned power line construction adjacent to the major breeding concentrations of Bengal florican and intercepting migration routes between these and non-breeding areas, poses a potentially new and serious threat, but migration routes relative to proposed transmission lines are poorly known.

In contrast to most other countries in Southeast Asia, Cambodia has a relatively low human population density and is still ranked as a Least Developed Country (UN-OHRLLS, 2015), with only approximately 250 km of power transmission lines (ADB, 2013). This is set to change over the next few years with the announcement in 2015 of plans for 230 kilovolt power transmission lines running from Battambang to Siem Reap and along the northern edge of the Tonle Sap floodplain (Fig. 1a) through Kampong Thom and Kampong Cham (350 km), linking that line at Kampong Thom with the international border with Laos PDR (190 km) and linking Kampong Cham with the Lower Seasan 2 hydropower dam in Stung Treng Province (125 km) (Electricité du Cambodge, 2015a,b; The Cambodia Daily, 2015). The breeding grounds of 81% of the Cambodian Bengal florican population are located in the floodplain immediately to the south or along the route of the proposed Tonle Sap proposed power transmission line (Packman et al., 2014; our Figure 1a). In common with most countries, Cambodian government policy and practice prioritise economic development. Pre-Environmental Impact Assessments (EIA) on the proposed Tonle Sap and Kampong Thom –Lao PDR power transmission lines were conducted (possibly in advance of a full EIA), but were not available to the authors. Government press releases issued prior to conducting the pre-EIAs made clear the proposed power transmission lines had been approved by the Prime Minister (Electricité du Cambodge, 2015a,b); they are therefore likely to proceed.

Here we provide a baseline estimate of annual survival rates of Cambodia's Bengal floricans prior to transmission line construction. In order to qualitatively assess potential impact of power lines on Bengal florican we reviewed published and unpublished data on bustard power line collision rates and examined the location of breeding and non-breeding areas and migration routes relative to planned transmission routes.

Methods

Mortality rate of Bengal florican in absence of power lines

Between May 2010 and January 2015 (when the program stopped collecting data), 11 male (10 adults, 1 sub-adult) and 6 female (5 adults, 1 sub-adult) Bengal florican were monitored via Argos Platform Telemetry Transmitters (PTTs) from Microwave Telemetry, Inc. (35 g Solar Argos PTT-100 and Solar Argos/GPS PTT-100 45 g) and North Star Science and Technology (30 g) (Table 1). This sampling intensity represented approximately 4% of the 2012 adult Cambodian Bengal florican population (assuming an approximate 1:1 sex ratio). All PTTs had an expected transmission lifespan of *c.*3 years as stated on their product sheets (Microwave Telemetry, Inc., 2015; Northstar Science and Technology, 2015) and used solar power to remain charged, except for one non-solar unit with a 1-year life expectancy. Catch methods are detailed in Packman (2011). Satellite transmitters were attached using permanent Teflon backpack harnesses with no possibility of tag loss and unit failure was considered unlikely. As mortalities could not be interpreted in the field, outcomes were interpreted from engineering data including Argos location classes 2 (one standard deviation (sd) of estimated error: 250-500m) and class 3 (one sd of estimated error: <250m error), temperature, activity sensor and voltage data (following

Burnside et al., 2016). Due to spatial error in Argos fixes, location data alone could not confirm mortality (with uncertainty as to whether a position was static), but location data could confirm a bird was still alive when seasonal movements exceeded the error margin of location fixes. Mortality was interpreted when the activity sensor remained static, average unit temperature dropped, voltage pattern changed from the previous cycle (although the unit typically initially continues to transmit). Sudden cessation of transmissions where engineering data had been regular with no indication of voltage deterioration was also attributed to death and associated destruction, burying or permanent covering of the solar panel leading to permanent signal loss (Burnside et al., in press). In contrast, signs of transmitter failure are progressive deterioration of the voltage and increasing gaps in transmission of engineering data. Consequently, all individuals had a known fate (1=death and 0=unit failure or still alive at end of data transmission period) allowing direct measures of daily mortality rate, with variance estimated by binomial error using the number of exposure days as the number of binomial trials, with the annual survival estimated as (1-daily mortality rate)^{365}.

Assessment of risk to Bengal florican from proposed power lines

We collated and reviewed quantified estimates of bustard mortality rates from power line collisions, from published studies located using Web of Science supplemented by unpublished reports that were known to us. We only included studies where repeat surveys were conducted on cleared lines.

Bengal florican breeding and non-breeding areas were located and mapped based on ten years of field surveys (Davidson, 2004; Gray et al., 2009; Mahood et al., 2013) and unpublished satellite transmitter data (this study). Movement paths of

Bengal florican were interpreted from PTT relocations, filtered using only locations of class 2 or 3 with any locations outside Cambodia excluded as outliers. To quantify the risk of encountering power lines during annual movements between breeding and non-breeding areas, movement paths were examined and the occurrence and date of each potential power line crossing event was recorded.

Results

Survival rate of Bengal florican in absence of power lines

Rates at which PTTs provided high-quality location fixes (i.e. classes 2 or 3) varied between individuals (total = 12,782 filtered locations, Table 1). Much greater frequency of engineering data was received (118,700 lines, Table 1) with fewer gaps (54.0 % of exposure days covered) allowing outcomes to be determined for all monitored individuals. The 17 Bengal florican were monitored for a total of 20,566 exposure days between 2010 and the end of January 2015. Three clear mortalities interpreted from engineering data together with three sudden cessations with no prior transmitter failure or battery deterioration (Table 1); indicated a total of 1 female and 5 male mortalities over the study. One non-solar powered unit reached its 1 year life-expectancy (Table 1). The ten remaining individuals survived and were transmitting until the end of the program. Annual survival was estimated as 89.9% (95% CI 82.2–97.6%).

Assessment of risk to Bengal florican from proposed power lines

Published and unpublished data for five bustard species across 11 studies and five countries (Table 2) confirmed that bustards, including relatively small species, are extremely vulnerable to power line mortality. These studies varied in duration from 2-

24 months and in population size and/or density, flight propensity and methods and frequency of carcass searches, but gave a mean number of detected bustard collision fatalities of 0.69 $km^{-1}.yr^{-1}$ (range: 0.04–3.21 $km^{-1}.yr^{-1}$).

Fifteen Bengal florican with satellite transmitters were monitored long enough to reach the flooding period and initiate non-breeding movements (Figure 1b). In 2010, not all individuals undertook wet-season migration, whereas in 2011, 13 moved to non-breeding areas while the other two died around the time of migration (Figure 2). All 13 migrating individuals crossed the proposed Tonle Sap power transmission line route, typically twice in each non-breeding season during outward and return movements (Figure 2). However, some individuals' breeding areas were over-lapping or close to the proposed power line indicating a potential to come into contact with the power line more frequently than just during seasonal movements (Fig. 1c).

Discussion

Annual adult survival rate of tagged Bengal florican (89.9%) was comparable to that of other long-lived, slowly-reproducing, large bustards such as great bustard *Otis tarda*, 90.9% ± 1.6 SE (Martín et al., 2007) and Asian houbara, 92.5% (Combreau et al., 2001). The limited satellite telemetry data available do not suggest age- or sex-related differences in movements or mortality. Of the six satellite tagged Bengal florican that died during the study, three died in August or September, when the birds had moved a short distance from the breeding grounds but remained in the densely populated outer floodplain where they are vulnerable to disturbance and hunting. The relatively high adult survival, along with low clutch size (1-2, typically one in Cambodia: Gray, 2008) suggests population dynamics will be sensitive to even a slight change in adult mortality rate, as shown in demographic modelling for other bustard species (Combreau et al., 2001, Burnside et al., 2012, Dolman et al., 2015).

Migration routes between breeding and non-breeding areas crossed proposed power line routes at least twice each year, with a few Bengal floricans that held breeding territories in close proximity to the transmission route crossing more frequently. Mean rates of power line collision for bustards from collated studies were 0.69 mortalities $km^{-1}.yr^{-1}$. It is not possible to express this in terms of mortality risk per individual, as studies varied in population size, density and likely in individual risk (in terms of timing and frequency of flights, and proximity to lines), which likely accounts for some of the variation in mortality rate detected. However, all studies were conducted where power lines crossed areas supporting concentrations of bustards (e.g. Alonso & Alonso, 1999; Marques et al., 2007; Jenkins et al., 2011; LPN, 2012; Burnside et al., 2015), broadly similar to the situation in Cambodia where sub-populations also vary in population density and proximity to proposed power lines. Mortalities due to collisions with power lines have been shown to account for a large proportion of non-natural deaths in a partially migratory population of great bustard, sufficient to influence population demography and behaviour (Palacin et al, 2016).

Demographic impacts of proposed power lines on Bengal Florican in Cambodia cannot yet be quantified, in part because there are insufficient data to quantify the demographic impacts of existing threats (e.g. hunting, nest predation, habitat loss, and indeed, mortality due to power distribution lines). Nonetheless there is a substantial risk that construction of the proposed Tonle Sap power transmission lines will exacerbate ongoing declines and detrimentally impact the only significant population of the Southeast Asian subspecies of Bengal florican.

Hot spots of high collision rates are often reported in studies of avian power line mortalities (e.g. Shaw et al., 2010; Raab et al., 2012). Identification of areas of high collision risk allows mitigation measures to be targeted to appropriate areas (Shaw, 2009). The Tonle Sap proposed power transmission line bisects one breeding site (Pouk) containing at least five displaying males and passes within one kilometer of Stoung-Chikraeng BFCA, the only site with a stable population of Bengal florican (Mahood & Hong Chamnan, 2013). Of the approximately 40 displaying males that use Stoung-Chikraeng BFCA, density of birds is high in the area within a few kilometres of the proposed Tonle Sap power transmission line (S.P. Mahood, pers. obs.). Male floricans make aerial displays (Collar et al., 2014) within an exploded lek (Davidson 2004) and at the beginning of the breeding season aerial disputes for lek position can be seen daily (S.P. Mahood, pers. obs). Birds are particularly vulnerable to power line collisions during aerial displays (Henderson et al., 1996) and an elevated rate of collisions is likely on this section.

Although most non-breeding areas were located north of the proposed power line, one satellite tagged bird from Baray BFCA spent a single non-breeding season in the vicinity of the Tonle Sap proposed power line and it is likely that others might do the same in years where flooding is incomplete.

The proposed power transmission lines may also impact other vulnerable species. The breeding sites of the Bengal florican are used by a significant number of sarus crane *Antigone antigone* (IUCN Vulnerable), another species prone to collision (Sundar & Choudhury, 2005), which annually migrate into the floodplain from areas to the north of the Tonle Sap proposed power transmission line. The waterbird colony at Prek Toal, Battambang Province is located approximately 15 km from the proposed Tonle Sap power transmission line; this supports at least 40,000 pairs of large waterbirds, including five species of stork, half the global population of greater adjutant *Leptoptilos dubius* (IUCN Endangered) and the entire Southeast Asian population of spot-billed pelican *Pelecanus philippensis* (Near-Threatened) (Sun Visal & Mahood, 2015). Elsewhere in the floodplain an additional two species of stork and a small population of Critically Endangered white-shouldered ibis *Pseudibis davisoni* also breed close to the proposed power transmission line. All of these large waterbirds disperse widely during the non-breeding season rendering them vulnerable to collisions. The proposed power transmission line from Kampong Thom to the international border with Laos PDR passes through forest inhabited by three Critically Endangered vulture species and giant ibis *Thaumatibis gigantea* (IUCN Critically Endangered). The route of the proposed power transmission line from Kampong Cham to the Lower Season 2 hydropower dam is unknown, but is likely to pass through areas where white-shouldered ibis and other threatened species breed.

Mitigation measures that reduce incidence of bird, and especially Bengal florican, collisions were not included in proposed power transmission line designs but were recommended to the team developing the pre-EIA. Re-routing or burying power lines is considered the most effective mitigation measure for bird species that are particularly prone to collisions (Silva et al., 2014). Re-routing sections of the proposed power line that are otherwise likely to become collision hotspots, such as that near Stoung-Chikraeng BFCA, is considered important in order to reduce Bengal florican collisions. Bird collisions with power transmission lines can usually be reduced through use of bird flight defectors or line markers, but with high voltage transmission lines most signalling devices can only be used on the earth cables. The reduction of collisions with marked cables can be as high as 78% (Barrientos et al., 2012), however reductions are species-specific and less for species with especially constrained visual fields such as bustards (Jenkins et al., 2010).

We recommend urgent research and stakeholder consultation (with Electricité du Cambodge, construction companies, financers and communities) to identify appropriate areas where proposed transmission lines can be re-routed and recommend that appropriate line-markers or bird-flight deflectors be installed along Cambodia's entire transmission line network. Given the likely impacts of the proposed Tonle Sap power transmission line to Cambodia's globally important population of the Critically Endangered Bengal florican and risks to other threatened waterbirds, it is essential that these mitigation measures be adopted, and monitoring of their effectiveness conducted.

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Biogeographical sketches

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Table 1. Deployment and outcomes for 17 Bengal floricans tracked via Argos transmitters between 2010 and 2014. Argos # refers to the number of location data of quality class 2 or 3 and outcome is coded as 1 = dead, 0 = alive on last monitoring day. EOP: individual alive at End of Programme

TAG-ID	SEX	DEPLOYED	ARGOS			ENGINEERING			EXPOSURE DAYS	OUTCOME	MORTALITY		
			1st	#	Last date	#	Days	Last date				Date	Location
67512	M	Mar-2008	18/05/2010	297	23/01/2015	572	403	26/01/2015	1714	EOP	0		
72044	M	Mar-2008	24/05/2010	547	28/01/2015	1116	634	31/01/2015	1713	EOP	0		
72047	M	Mar-2008	23/05/2010	565	30/01/2015	1350	772	01/02/2015	1715	EOP	0		
28410	F	Feb-2009	30/05/2010	146	03/06/2012	247	140	27/07/2012	758	Death	1	27/06/2012	12.994°N 104.474°E
90587	F	Feb-2009	18/05/2010	1591	01/02/2015	15845	1302	01/02/2015	1720	EOP	0		
90588-10	M	Feb-2009	21/05/2010	101	03/08/2011	857	101	09/08/2011	445	Sudden stop	1	09/08/2011	12.439° N 105.04°E
90591	M	Mar-2009	23/05/2010	14	15/06/2010	141	15	24/06/2010	32	End of Battery	0		
52015	F	Feb-2010	28/05/2010	677	31/01/2015	7432	723	31/01/2015	1709	EOP	0		
52117	M	Feb-2010	18/05/2010	423	18/02/2012	4739	422	21/02/2012	644	Death	1	21/02/2012	12.594° N 104.86°E
52119	M	Feb-2010	18/05/2010	1097	25/09/2012	10979	703	25/12/2012	952	Sudden stop	1	25/12/2012	12.266° N 104.992°E
52121	M	Feb-2010	20/05/2010	751	31/01/2015	8071	767	31/01/2015	1718	EOP	0		
52123	M	Feb-2010	22/05/2010	1626	01/02/2015	16645	1083	01/02/2015	1716	EOP	0		
52129	F	Feb-2010	18/05/2010	468	01/02/2015	14776	1190	01/02/2015	1721	EOP	0		
52132	F	Feb-2010	20/05/2010	2430	01/02/2015	18687	1326	01/02/2015	1718	EOP	0		

52133	M	Feb-2010	18/05/2010	438	24/09/2011	4304	372	14/11/2011	494	Death	1	25/09/2011	12.231° N 105.174°E
52136	M	Feb-2010	20/05/2010	34	02/08/2010	1148	73	04/08/2010	76	Sudden stop	1	04/08/2010	12.755° N 104.676°E
52137	F	Feb-2010	20/05/2010	1577	01/02/2015	11791	1068	01/02/2015	1718	EOP	0		

Table 2. Reported bustard collision rates with power lines. T = transmission, D = distribution.

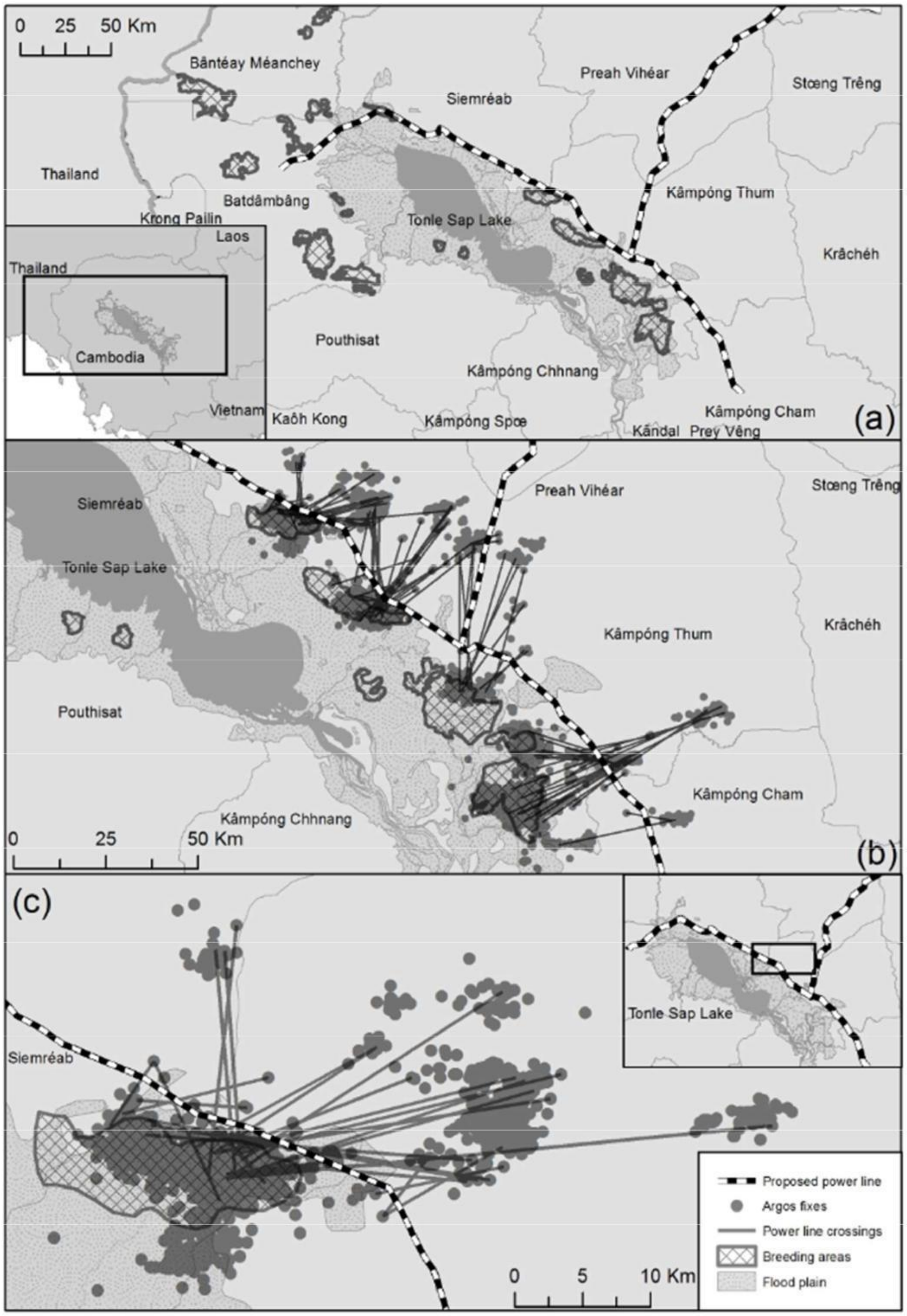
* Study consisted of a number of surveys of power lines; surveys varied in duration

Species	Location	Line type	Survey effort (km)	Study duration (months)	Visit interval (days)	No. collisions	Collision rate ($km^{-1}.yr^{-1}$)	Source
great bustard	Cáceres, Spain	T	3.9	24	30-60	23	2.95	Janss & Ferrer 1998
little bustard	Cáceres, Spain	T	3.9	24	30-60	25	3.21	Janss & Ferrer 1998
great bustard	Rosalejo, Spain	T	10	12	15	1	0.10	Alonso & Alonso 1999
little bustard	Rosalejo, Spain	T	10	12	15	12	1.20	Alonso & Alonso 1999
little bustard	Almaraz, Spain	T	10	12	15	2	0.20	Alonso & Alonso 1999
great bustard	Usagre, Spain	T	10	12	15	1	0.10	Alonso & Alonso 1999
little bustard	Pto. Lápice, Spain	T	10	12	15	2	0.20	Alonso & Alonso 1999
great bustard	Ferreira do Alentejo, Portugal	T	48	12	30	9	0.19	Neves et al., 2005
little bustard	Ferreira do Alentejo, Portugal	T	48	12	c. 30	19	0.40	Neves et al., 2005
houbara bustard	Lanzarote, Spain	D	140	6	182	33	0.47	Lorenzo & Ginovés 2007
houbara bustard	Fuerteventura, Spain	D	227	6	182	38	0.33	Lorenzo & Ginovés 2007

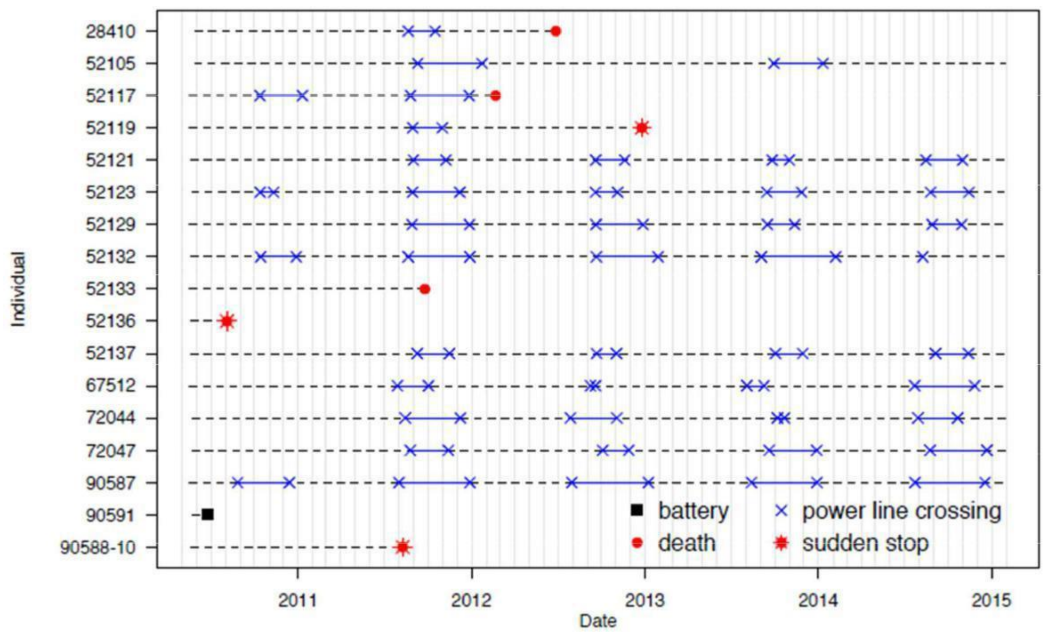
great bustard	Castro Verde, Portugal	T	11	16	15	23	1.57	Marques et al., 2007
little bustard	Castro Verde, Portugal	T	11	16	15	26	1.77	Marques et al., 2007
great bustard	Ervidel, Portugal	T	5.8	12	15	6	1.03	Marques et al., 2007
great bustard	Castro Verde, Portugal	D	50	12	15	5	0.10	Marques et al., 2008
little bustard	Castro Verde, Portugal	D	50	12	15	15	0.30	Marques et al., 2008
Ludwig's bustard	Helios-Juno, South Africa	T	252	24	90	214	0.42	Shaw 2013
kori bustard	Aries-Helios, South Africa	T	252	24	90	22	0.04	Shaw 2013
karoo korhaan	Hydra-Kronos, South Africa	T	252	24	90	21	0.04	Shaw 2013
great bustard	Castro Verde, Portugal	D	29.7	mean 18 (range 8-31)*	15	18	0.40	LPN 2012
little bustard	Castro Verde, Portugal	D	29.7	mean 18 (range 8-31)*	15	28	0.63	LPN 2012
houbara bustard	Bukhara, Uzbekistan	T	126	1.3	11-13	2	0.15	Burnside et al., 2015
houbara bustard	Bukhara, Uzbekistan	D	114	1.3	11-13	2	0.16	Burnside et al., 2015

Figure 1. Maps showing: a. the location of breeding sites (cross-hatched areas) of Bengal florican in Cambodia in relation to the proposed power transmission lines, within an area containing > 50% of the global population of Bengal florican; b. as a. but showing movements of 15 Bengal florican over four years inferred from satellite telemetry data; c. as b. but restricted to Stoung-Chikraeng BFCA and associated non-breeding areas.

Figure 2. Duration of satellite monitoring data for 17 Bengal florican. Dashed line indicates the individual was monitored and was on their breeding territory. Solid blue lines indicate that the individual had migrated to the non-breeding territory. Blue X indicates when an individual had crossed the proposed power line feature.



0 25 50 Km
Bântéay Méanchey
Siemréab
Preah Vihéar
Stœng Trêng
Thailand
Batdâmbâng
Krong Pailin
Tonle Sap Lake
Kâmpóng Thum
Laos
Krâchéh
Cambodia
Pouthisat
Kâmpóng Chhnang
Vietnam
Kaôh Kong
Kâmpóng Spœ
Kândal
Prey Vêng
Kâmpóng Cham
(a)
(b)
(c)
0 5 10 Km
Proposed power line
Argos fixes
Power line crossings
Breeding areas
Flood plain



28410
52105
52117
52119
52121
52123
52129
52132
52133
52136
52137
67512
72044
72047
90587
90591
90588-10
Individual
battery
death
power line crossing
sudden stop
2011
2012
2013
2014
2015
Date