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

Simon P. Mahood, João P. Silva, Paul M. Dolman and Robert J. Burnside

Abstract The remaining Indochina population of the Critically Endangered Bengal florican *Houbaropsis bengalensis* breeds in the floodplain of Cambodia's Tonle Sap Lake. 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 in 2016. Using data from 17 individuals monitored by satellite transmitters over 4 years we estimated the annual adult survival rate to be 89.9% (95% CI 82.2–97.6%), which is comparable to that of other bustards. Interrogation of movement paths revealed that for the 13 individuals for which we had sufficient data for non-breeding seasons, all annual migration routes between breeding and non-breeding areas crossed the proposed route of the transmission line. The route 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 proposed development therefore presents an additional threat to the future of this species in Indochina.

Keywords Bengal florican, bustard, Cambodia, collision mortality, *Houbaropsis bengalensis*, power line, Tonle Sap

Introduction

Rapid economic growth drives increasing energy demands (Toman & Jemelkova, 2003). In South-east Asia this demand is being met through the development of hydropower dams on the Mekong River 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 of birds killed annually through collisions and, to a lesser extent, electrocution (e.g. Rioux et al., 2013; Loss et al., 2014). Collisions have a disproportionate impact on 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 South-east Asia and the Indian subcontinent; *H. bengalensis blandini* is the only bustard taxon in South-east Asia, where it is now restricted to the Tonle Sap floodplain, in Cambodia (Collar et al., 2014). The population declined by an estimated 44–64% between 2005–2007 and 2012, when only 216 (95% CI 156–275) displaying males remained (Packman et al., 2014), primarily as a result of rapid loss of floodplain grassland (Packman et al., 2013). The effects of other potential threats, such as hunting and nest predation by domestic dogs, are unknown. Population trends at Cambodian breeding sites vary, although most are negative (Packman et al., 2014); the only stable population is in Stoung–Chikraeng Bengal Florican Conservation Area (WCS Cambodia, unpubl. data, 2016). Bengal floricans disperse annually from their breeding grounds as lake levels rise (Gray, 2008; Packman, 2011), migrating up to 60 km to degraded Dipterocarp forest and farmland (Packman, 2011). Outside South-east Asia the nominate subspecies is restricted to an estimated 75–96 individuals in Nepal and fewer than 100 in India (BirdLife International, 2016).

Basic demographic parameters, which are important in the diagnosis of population declines, are poorly known for the Bengal florican. Breeding productivity is unquantified; however, a preliminary estimate based on a limited data set indicated potentially high adult survival (Packman, 2011), as is typical for many bustard species (Dolman et al., 2015). The planned construction of a power line adjacent to the major breeding concentrations of the Bengal florican could potentially intercept migration routes between these and non-breeding areas, and could pose a serious threat to this species.

In contrast to most other countries in South-east Asia, Cambodia has a relatively low human population density

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and is still ranked as a Least Developed Country (UN-OHRLLS, 2015), with only c. 250 km of power transmission lines (ADB, 2013). This is set to change over the next few years following the announcement in 2015 of plans for 230 kV 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; hereafter Tonle Sap power line), linking that line at Kampong Thom with the international border with Laos PDR (190 km) and linking Kampong Cham with the Lower Sesan 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 power transmission line (Packman et al., 2014; Fig. 1a). In common with most countries Cambodian government policy and practice prioritize economic development. Pre- Environmental Impact Assessments (EIA) were conducted for the proposed Tonle Sap and Kampong Thom–Lao PDR power transmission lines (possibly in advance of a full EIA) and were obtained by the authors after submission of the manuscript. Government press releases issued prior to 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.

We provide a baseline estimate of annual survival rates of Cambodia's Bengal floricans prior to the construction of power transmission lines. To assess qualitatively the potential impact of power lines on the Bengal florican we reviewed published and unpublished data on rates of collision between bustards and power lines and examined the location of breeding and non-breeding areas and migration routes in relation to planned transmission routes.

Methods

Mortality rate in the absence of power lines

During May 2010–January 2015 11 male (10 adults, 1 subadult) and six female (5 adults, 1 subadult) Bengal floricans were monitored using Argos platform telemetry transmitters (35 g Solar Argos PTT-100 and 45 g Solar Argos/GPS PTT-100 45 g, Microwave Telemetry, Inc., Columbia, USA; 30 g, North Star Science and Technology, King George, USA; Table 1). This sample represented c. 4% of the 2012 adult population of Bengal floricans in Cambodia (assuming an approximate 1 : 1 sex ratio). All transmitters had an expected transmission lifespan of c. 3 years as stated on their product sheets (Microwave Telemetry, Inc., 2015; North Star Science and Technology, 2015) and remained charged using solar power, except for one non-solar unit with a 1-year life expectancy. Catch methods are described in Packman (2011). The transmitters were attached using permanent Teflon backpack harnesses with no possibility of tag loss, and unit failure was considered to be unlikely. As mortalities could not be interpreted in the field, outcomes were interpreted from engineering data about the activity state of the transmitter, including Argos location classes 2 (1 SD of estimated error: 250–500 m) and 3 (1 SD of estimated error: < 250 m), and temperature, activity sensor and voltage data (following Burnside et al., 2016). Spatial error in Argos fixes meant that location data alone could not confirm mortality (with uncertainty as to whether a position was static), but location data could confirm that an individual was still alive when seasonal movements exceeded the error margin of location fixes. Mortality was inferred when the activity sensor remained static, the mean unit temperature dropped and the voltage pattern changed from the previous cycle (although the unit typically initially continues to transmit). Sudden cessation of transmission where engineering data had been regular with no indication of voltage deterioration was also attributed to death and subsequent destruction, burying or permanent covering of the solar panel leading to permanent signal loss (Burnside et al., 2016). In contrast, progressive deterioration of the voltage and increasing gaps in transmission of engineering data are signs of transmitter failure. Consequently, the fate of all individuals was known (1 = death and 0 = unit failure or still alive at the end of the data transmission period), facilitating 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 to be $(1 - \text{daily mortality rate})^{365}$.

Assessment of risk from the proposed power lines

We collated and reviewed quantified estimates of bustard mortality rates from power line collisions, based on published studies located using Web of Science, and unpublished reports that were known to us. To the best of our knowledge only studies in which repeat surveys were conducted on cleared lines were included in our review.

Bengal florican breeding and non-breeding areas were located and mapped based on 10 years of field surveys (Davidson, 2004; Gray et al., 2009; Mahood et al., 2013) and unpublished satellite transmitter data (this study). Movement paths were interpreted from platform telemetry transmitter relocations, filtered using only locations of class 2 or 3. Any locations outside Cambodia were 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.

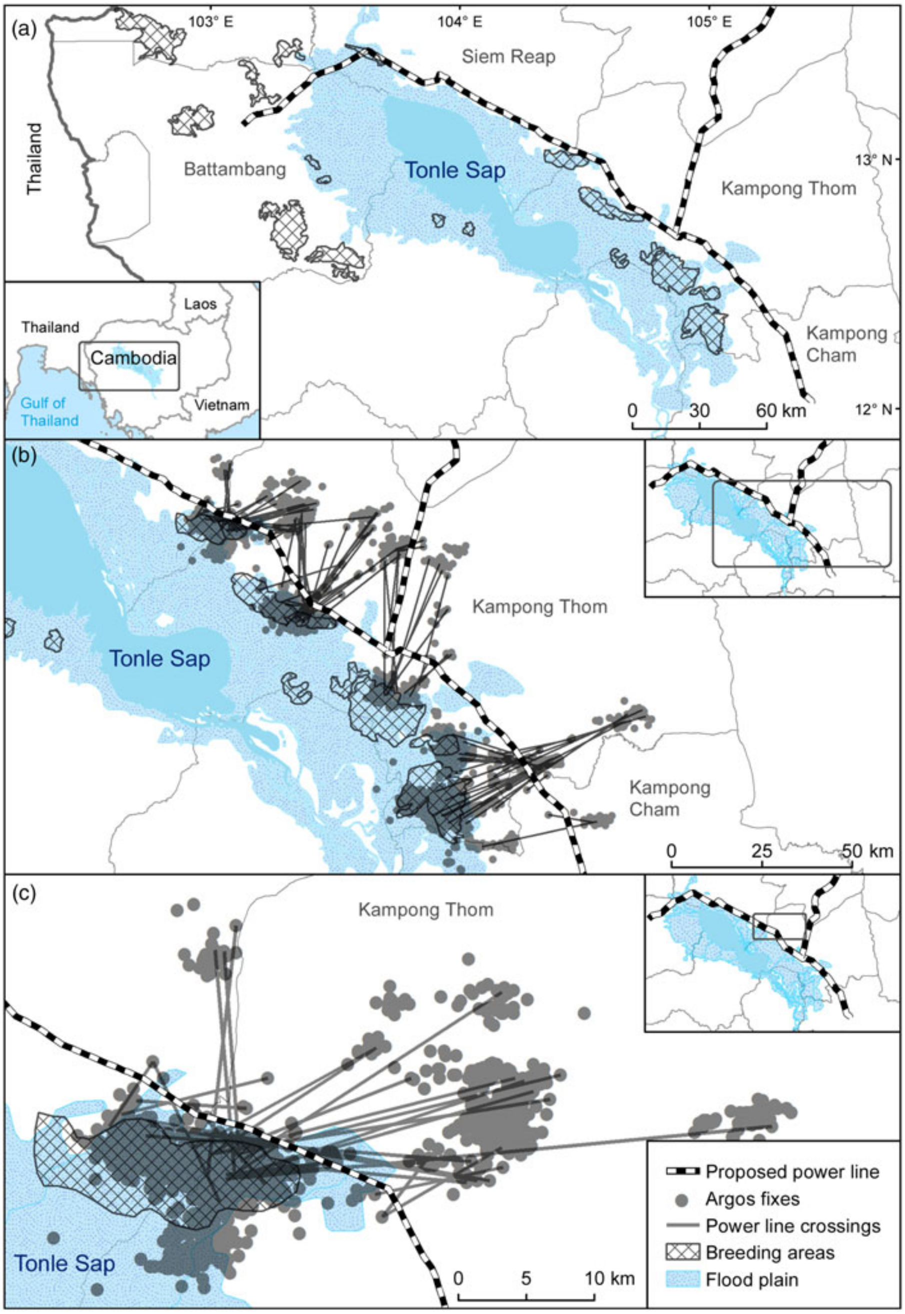

FIG. 1 Locations of breeding sites of the Bengal florican *Houbaropsis bengalensis* around Tonle Sap Lake in Cambodia, in an area that contains > 50% of the global population of the species, and the proposed routes for power transmission lines. (b) The movements of 15 Bengal floricans between May 2010 and January 2015 inferred from satellite telemetry data. (c) As in (b) but focused on Stoung–Chikraeng Bengal Florican Conservation Area and associated non-breeding areas.

Results

Survival rate in the absence of power lines

The rates at which transmitters provided high-quality location fixes (i.e. classes 2 or 3) varied between individuals (total = 12,782 filtered locations; Table 1). A greater frequency of engineering data was received (118,700 lines; Table 1), with fewer gaps (54.0% of exposure days covered), and thus outcomes could be determined for all monitored individuals. The 17 individuals were monitored for a total of 20,566 exposure days between 2010 and the end of January 2015. Three evident mortalities interpreted from engineering data together with three sudden cessations with no prior transmitter failure or battery deterioration (Table 1) indicated a total of six mortalities (one female, five male) during the study. One non-solar powered unit reached its 1 year life-expectancy (Table 1). The other 10 individuals survived and were transmitting until the end of the programme. Annual survival was estimated to be 89.9% (95% CI 82.2–97.6%).

Assessment of risk from the proposed power lines

Published and unpublished data for five bustard species across 11 studies and five countries (Table 2) confirmed

Table 1 Deployment and outcomes for 17 Bengal floricans *Houbaropsis bengalensis* tracked via Argos satellite transmitters between May 2010 and February 2015. Argos no. refers to the number of Argos location fixes of quality class 2 or 3. Engineering no. refers to the number of engineering transmissions received containing information on activity, temperature and voltage sensors, from which outcomes can be inferred. Engineering days refers to the number of days during the monitoring period on which engineering data were received. Exposure days refers to the total number of days an individual was monitored alive, as inferred from the Argos and engineering data. Outcomes are self-explanatory (except for EOP: individual alive at end of programme), and coded as 1 = dead, 0 = alive on last monitoring day.

			Argos			Engineering					Mortality	
Tag ID	Sex	Deployed	1st location date	No.	Last location date	No.	Days	Last date engineering received	Exposure days	Outcome	Date	Location
67512	M	Mar. 2008	18 May 2010	297	23 Jan. 2015	572	403	26 Jan. 2015	1,714	EOP (0)		
72044	M	Mar. 2008	24 May 2010	547	28 Jan. 2015	1,116	634	31 Jan. 2015	1,713	EOP (0)		
72047	M	Mar. 2008	23 May 2010	565	30 Jan. 2015	1,350	772	1 Feb. 2015	1,715	EOP (0)		
28410	F	Feb. 2009	30 May 2010	146	3 June 2012	247	140	27 July 2012	758	Death (1)	27 June 2012	12.994°N 104.474°E
90587	F	Feb. 2009	18 May 2010	1,591	1 Feb. 2015	15,845	1,302	1 Feb. 2015	1,720	EOP (0)		
90588-10	M	Feb. 2009	21 May 2010	101	3 Aug. 2011	857	101	9 Aug. 2011	445	Sudden stop (1)	9 Aug. 2011	12.439°N 105.04°E
90591	M	Mar. 2009	23 May 2010	14	15 June 2010	141	15	24 June 2010	32	End of battery (0)		
52015	F	Feb. 2010	28 May 2010	677	31 Jan. 2015	7,432	723	31 Jan. 2015	1,709	EOP (0)		
52117	M	Feb. 2010	18 May 2010	423	18 Feb. 2012	4,739	422	21 Feb. 2012	644	Death (1)	21 Feb. 2012	12.594°N 104.86°E
52119	M	Feb. 2010	18 May 2010	1,097	25 Sep. 2012	10,979	703	25 Dec. 2012	952	Sudden stop (1)	25 Dec. 2012	12.266°N 104.992°E
52121	M	Feb. 2010	20 May 2010	751	31 Jan. 2015	8,071	767	31 Jan. 2015	1,718	EOP (0)		
52123	M	Feb. 2010	22 May 2010	1,626	1 Feb. 2015	16,645	1,083	1 Feb. 2015	1,716	EOP (0)		
52129	F	Feb. 2010	18 May 2010	468	1 Feb. 2015	14,776	1,190	1 Feb. 2015	1,721	EOP (0)		
52132	F	Feb. 2010	20 May 2010	2,430	1 Feb. 2015	18,687	1,326	1 Feb. 2015	1,718	EOP (0)		
52133	M	Feb. 2010	18 May 2010	438	24 Sep. 2011	4,304	372	14 Nov. 2011	494	Death (1)	25 Sep. 2011	12.231°N 105.174°E
52136	M	Feb. 2010	20 May 2010	34	2 Aug. 2010	1,148	73	4 Aug. 2010	76	Sudden stop (1)	4 Aug. 2010	12.755°N 104.676°E
52137	F	Feb. 2010	20 May 2010	1,577	1 Feb. 2015	11,791	1,068	1 Feb. 2015	1,718	EOP (0)		

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Table 2 Reported rates of collision between bustards and power lines, with species, location, line type, survey effort, study duration, visit interval, no. of collisions, collision rate, and data source.

Species	Location	Line type[1]	Survey effort (km)	Study duration (months)	Visit interval (days)	No. of collisions	Collision rate (km^{-1} yr^{-1})	Source
Great bustard *Otis tarda*	Cáceres, Spain	T	3.9	24	30–60	23	2.95	Janss & Ferrer (1998)
Little bustard *Tetrax tetrax*	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	Puerto 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 *Chlamydotis undulata*	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 *Neotis ludwigii*	Helios-Juno, South Africa	T	252	24	90	214	0.42	Shaw (2013)
Kori bustard *Ardeotis kori*	Aries-Helios, South Africa	T	252	24	90	22	0.04	Shaw (2013)
Karoo korhaan *Eupodotis vigorsii*	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)[2]	15	18	0.40	LPN (2012)
Little bustard	Castro Verde, Portugal	D	29.7	mean 18 (range 8–31)[2]	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)

[1]T, transmission; D, distribution.
[2]Study consisted of a number of surveys, which varied in duration.

that bustards, including relatively small species, are vulnerable to mortality as a result of collisions with power lines. These studies varied in duration (2–24 months) and in population size and/or density, flight propensity and methods and frequency of searches for carcasses but yielded a mean of 0.69 detected bustard collision fatalities per km per year (range 0.04–3.21 $km^{-1}yr^{-1}$).

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

Discussion

The annual adult survival rate of tagged Bengal floricans (89.9%) was comparable to that of other long-lived, slow-reproducing large bustards, such as the great bustard *Otis tarda* (90.9 ± SE 1.6%; Martín et al., 2007) and the Asian houbara *Chlamydotis undulata* (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 floricans 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 indicated by 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 the proposed route of the Tonle Sap power line at least twice each year, with a few individuals that held breeding territories in close proximity to the transmission route crossing more frequently. The mean rate of bustard fatalities as a result of collision with power lines, from collated studies, was 0.69 per km per year. It is not possible to express this in terms of mortality risk per individual, as studies varied in population size, density, and probably in individual risk (in terms of timing and frequency of flights, and proximity to lines), which probably 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 subpopulations also vary in density and proximity to proposed power lines. Mortalities resulting from collisions with power lines have been shown to account for a significant proportion of non-natural deaths in a partially migratory population of great bustards, sufficient to influence population demography and behaviour (Palacín et al., 2016).

Demographic impacts of proposed power lines on the 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 existing power lines). Nonetheless there is a risk that construction of the proposed Tonle Sap power transmission line will exacerbate ongoing declines and have a detrimental impact on the only significant population of the South-east Asian subspecies of Bengal florican.

Hotspots of high rates of collision with power lines are often reported in studies of avian mortalities (e.g. Shaw et al., 2010; Raab et al., 2012). Identification of areas of high collision risk facilitates targeting of mitigation measures to appropriate areas (Shaw, 2009). The proposed Tonle Sap power transmission line bisects one breeding site (Pouk) with at least five displaying males and passes within 1 km of Stoung–Chikraeng Bengal Florican Conservation Area, the only site with a stable population of Bengal floricans (Mahood & Chamnan, 2013). Of the c. 40 displaying males that use Stoung–Chikraeng, the density of birds is highest within a few kilometres of that proposed 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 collision with power lines during aerial displays (Henderson et al., 1996).

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

The proposed power transmission lines may also affect other vulnerable species. The breeding sites of the Bengal florican are used by a significant number of sarus cranes *Antigone antigone*, another species prone to collision (Sundar & Choudhury, 2005), and categorized as Vulnerable on the IUCN Red List. The cranes migrate into the floodplain annually from areas to the north of the proposed Tonle Sap power line. The waterbird colony at

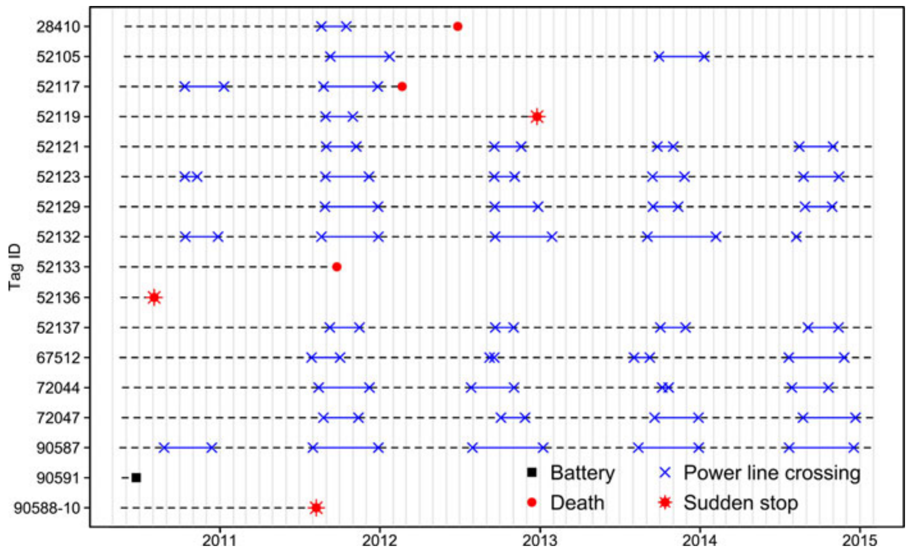

FIG. 2 Duration of satellite monitoring data for 17 Bengal floricans. A dashed line indicates that an individual was on its breeding territory. A solid line indicates that the individual had migrated to the non-breeding territory. The points at which an individual crossed the proposed power line are indicated by x.

Prek Toal, Battambang Province, is located c. 15 km from that proposed power line; the colony supports at least 40,000 pairs of large waterbirds, including five species of storks, half the global population of the Endangered greater adjutant *Leptoptilos dubius* and the entire South-east Asian population of the Near Threatened spot-billed pelican *Pelecanus philippensis* (Sun & Mahood, 2015). Elsewhere in the floodplain an additional two species of storks and a small population of the Critically Endangered white-shouldered ibis *Pseudibis davisoni* also breed close to the proposed Tonle Sap power line. All of these large waterbirds disperse widely during the non-breeding season, rendering them vulnerable to collisions. The proposed power line from Kampong Thom to the international border with Laos PDR would pass through forest inhabited by three Critically Endangered vulture species and the Critically Endangered giant ibis *Thaumatibis gigantea*. The route of the proposed power line from Kampong Cham to the Lower Sesan 2 hydropower dam is unknown but is likely to pass through areas where the white-shouldered ibis and other threatened species breed.

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

We recommend urgent research and consultation with stakeholders (Electricité du Cambodge, construction companies, financers and communities) to identify appropriate areas where proposed transmission lines could be re-routed, and that appropriate line markers or bird-flight deflectors be installed along the entire network of power lines in Cambodia. As a result of multi-stakeholder consultations that used the analyses presented here, the construction company is considering installing bird-flight deflectors along the section of the power line closest to Stoung–Chikreang Bengal Florican Conservation Area. Given the likely impacts of the proposed power line on Cambodia's globally important population of Bengal floricans and the risks to other threatened waterbirds, it is essential that these mitigation measures be adopted, and their effectiveness monitored.

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Author contributions

SPM conceived and wrote the paper, JPS collated bustard collision data, PMD edited the paper, and RJB analysed the satellite transmitter data and drew the figures.

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Biographical sketches

Simon Mahood attempts to reconcile development interests with the conservation of threatened species. João Silva studies the ecology and conservation of steppe birds, and in particular the impacts of power lines on birds. Paul Dolman leads an inter-disciplinary conservation ecology research team working on evidence-based biodiversity conservation in human-modified landscapes in Europe and Asia. Robert Burnside is a conservation biologist with a particular interest in ex situ management and translocations.