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Population density and habitat loss of Chestnut-headed Partridge *Arborophila cambodiana* in south-west Cambodia

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Summary

Thirty-two percent of bird species in South-East Asia are likely to become extinct by the end of this century. However, due to a lack of data this number may be an underestimate. The Chestnut-headed Partridge *Arborophila cambodiana* found in south-west Cambodia's Cardamom Mountain range is a largely unknown potentially at-risk species. We used line transects and camera traps to survey *A. cambodiana* in four protected areas in the Cardamom Mountains to estimate population densities. We also assessed their current distribution range and broad scale habitat changes from 1996 to 2016. We found *A. cambodiana* in evergreen and semi-evergreen forest at a density of 1.23 calling males/km², and at altitudes above 400 m and where the slope was between 11 and 43°. From 1996 to 2016 *A. cambodiana's* potential habitat decreased by 11%, whilst the total evergreen forest cover in the Cardamom Mountains decreased by 20%. *A. cambodiana* has a very restricted range within which the habitat has been fragmented. Compounded by human disturbance and development activities that negatively affect the species, we suggest a revision of its IUCN Red List status from 'Least Concern' to 'Near Threatened' as it partially meets a range of threatened Red List species criteria.

Introduction

Human population growth has resulted in the largest impacts on biodiversity ever recorded, mostly as a result of conversion of natural forest to agricultural land (Corlett 2014). Over the past four decades, global biodiversity has decreased at an alarming rate, with the main declines occurring primarily in tropical areas, where most threatened vertebrates are found (Butchart *et al.* 2010, Hoffmann *et al.* 2010). In South-East Asia, extinction risk has increased markedly due to anthropogenic activities (Hoffmann *et al.* 2010, Duckworth *et al.* 2012), such as overexploitation and deforestation, the rate of which are among the highest in the tropics (Heino *et al.* 2015), and are still increasing (Miettinen *et al.* 2011). It is estimated that nearly 50% of the region's mammal populations and 32% of bird populations will be extinct by the end of this century (Brook *et al.* 2003). At least half of these could represent global extinctions, and the number could be even higher due to other threats such as climate change and invasive species (Brook *et al.* 2003). Within the region, Cambodia had the highest deforestation rate for 2013 (Hansen *et al.* 2013, Corlett 2014) as a result of its Economic Land Concession (ELC) development and road system expansion with consequent increases in hunting and logging (Clements *et al.* 2014).

Mainland South-East Asia mostly lies within the Indo-Burma Biodiversity Hotspot (Myers *et al.* 2000) and supports 72 galliform species (World Pheasant Association 2017) mostly comprising three genera: *Lophura*, *Arborophila* and *Polyplectron*. Galliforms show a globally high

extinction risk with 25% of the 308 species in the IUCN Red List listed as threatened, compared to 13% for all bird species (BirdLife International 2016), while for South-East Asia this rises to 27% of galliform species threatened with extinction. As for most biodiversity in the region, the major threats are habitat loss and fragmentation, and hunting. Unfortunately, the ecology and conservation status of most galliform species within the region is poorly known (Grainger *et al.* 2018) and for some genera, such as *Arborophila*, almost no quantitative data are available, with the exclusion of a few case studies (Vy *et al.* 2017).

The Chestnut-headed Partridge, *Arborophila cambodiana*, is restricted to the Cardamom Mountains in south-west Cambodia with a small population also found in south-east Thailand (Eames *et al.* 2002). Initially described from what is now Bokor National Park in 1928 (Delacour 1929) and thought to be a common resident of the mid-elevation (400–1,400 m) semi-evergreen and evergreen hill forests (Goes and Furey 2013), the species is little known and limited information has been collected and reported over the last 60 years, in part due to civil war in the area from 1967 to 1998 (Poole 1999). This paucity of information prompted *A. cambodiana* to be classified as 'Endangered' in 2002 (BirdLife International 2016). However as more information slowly trickled in, primarily consisting of anecdotal observations by birdwatchers, the species was downgraded to 'Vulnerable' in 2004 and to 'Least Concern' in 2009, mainly based on the estimated available habitat (BirdLife International 2016) and survey reports (Samnang *et al.* 2009). However, these assessments may not now reflect the true situation. Large areas of the Cardamom Mountains have been zoned as economic land concessions, which either have been or are likely to be cleared for agro-industrial plantations. Areas of both Bokor National Park and Kirirom National Park are threatened with poorly controlled tourism development, whilst agricultural development (pepper farming) is increasing in Phnom Samkos Wildlife Sanctuary and Botum Sakor National Park. This resulted in 2,146 km² (10% of the total area) of the Cardamom Mountain range being converted to agriculture through ELCs (Open Development Cambodia 2014). In addition, in 2007 hunting was believed to be the major threat, followed by land conversion (Samnang *et al.* 2009).

In order to assess the conservation status of *A. cambodiana* within its restricted and diminishing range, and to address the lack of detailed information on the species, we aimed to: 1) estimate the current distribution and population density of *A. cambodiana* in the Cardamom Mountain range; 2) assess habitat change over the past 20 years; and 3) provide an updated recommendation for the specie's conservation status based on revised habitat availability and density information.

Methods

Study sites

We surveyed *A. cambodiana* at four sites in Cambodia's Cardamom Mountains range: Bokor National Park (BKNP), Central Cardamom National Park (CCNP), Phnom Samkos Wildlife Sanctuary (PSWS) and Southern Cardamom National Park (SCNP) (Figure. 1). The Cardamom Mountains cover approximately 23,000 km² and range in elevation from 0 to 1,800 m (Stuart and Emmett 2006). The Cardamoms are covered with tropical evergreen and semi-evergreen forests (Eames *et al.* 2002) and are subject to a tropical monsoonal climate with a wet season from May to October (2,000–5,000 mm total rainfall) and a dry season from November to March (2,000–3,000 mm). Average temperatures range from 25–30° C, but can drop below 15°C at higher elevations (Daltry and Momberg 2000).

Bokor National Park (10°47′N, 104°01′E) is situated in the Elephant Mountains, a southern offshoot of the Cardamom Mountains, covering an area of 1,418 km² with an elevation range from 30 to 1,079 m. The park is dominated by a large massif with an extensive plateau at around 1,000 m. It supports large and intact areas of evergreen forest, with wet evergreen forests found mostly in the south, and deciduous and semi-evergreen forests in the north.

The Central Cardamom National Park (11°59′N, 103°29′E) covers an area of 4,015 km² and is characterised by large rivers and expanses of lowland evergreen forests on the rolling foothills

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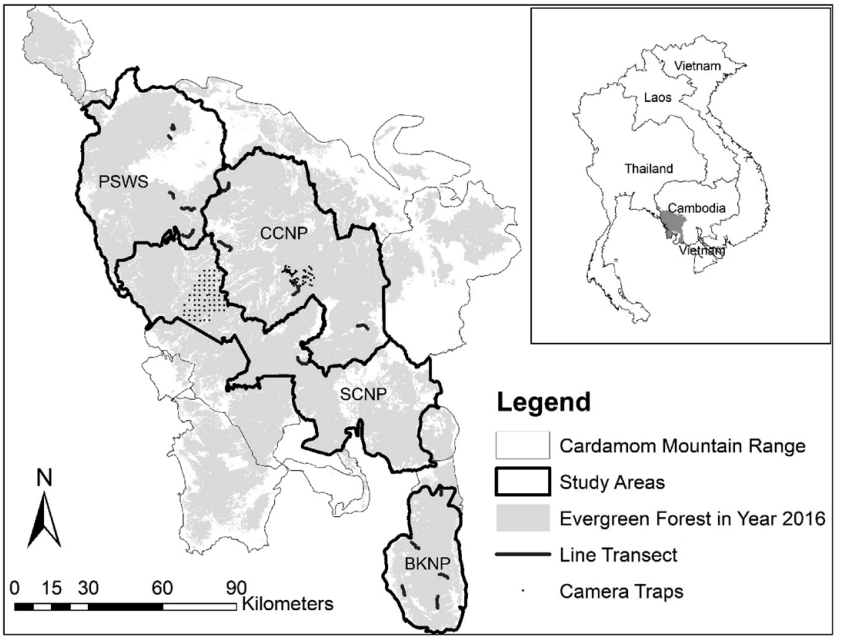

Figure 1. *Arborophila cambodiana* study sites at Bokor National Park (BKNP), Central Cardamom National Park (CCNP), Phnom Samkos Wildlife Sanctuary (PSWS) and Southern Cardamom National Park (SCNP) with the location of camera traps and line transects.

with an elevation ranging from 300 to 1,300 m. Unlike the other sites in the Cardamom Mountains range, this area is derived from Mesozoic sandstones.

Phnom Samkos Wildlife Sanctuary (10°29′N, 102°57′E) covers 3,302 km² and is named after Samkos Mountain, which is Cambodia's second highest peak (1,717 m). The vegetation consists of lowland evergreen forest, medium altitude evergreen forest, semi-deciduous forest, dry deciduous forest, lowland and medium altitude forests on limestone, pine forests and montane grasslands. PKWS ranges in elevation from 300 to 1,700 m.

Southern Cardamom National Park (11°48′N, 103°06′E) covers 4,114 km² with an elevation range from 10 to 980 m. The vegetation is like that present in CCNP and constitutes one of the region's largest continuous areas of rainforest. It is ecologically important as it provides the main corridor for Cambodia's largest remaining population of Asian elephant *Elephas maximus*, allowing them to move through the landscape, including into Thailand.

Density estimates

Bird densities were estimated using line transects in three different protected areas (BKNP, CCNP and PKWS). A total of 30 transects were established, 10 in each protected area, along existing human and animal trails when approximately straight. If trails were unsuitable, not straight, or not available, straight lines were cut through the forest, avoiding areas with land mines. In each protected area we established five study locations, each comprising two line transects spaced 300 m apart (Figure 1). Transect length varied from < 1 km, where they were cut through the forest, to > 4 km when existing human and animal trails were found. Line transects were surveyed from 28 January 2015 to 25 December 2015 and 9 January 2016 to 28 March 2016 which corresponded with the *A. cambodiana* breeding season (both nesting and mating) from April to June when detections are higher (Goes and Furey 2013).

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Each transect was walked by two different observers simultaneously four times a day (morning: 06h00–09h00 and 09h00–11h30 and afternoon 14h00–16h30 and 16h30–18h00) for three consecutive days, except during periods of heavy rain. The point at which a calling *A. cambodiana* was heard along a transect was recorded by GPS (Garmin 62SC), as was time, the estimated distance from the observer, and using a compass, the direction from the observer. These data were used to define the perpendicular distance of birds to the transect line using ArcGIS. To avoid double counting we assumed that if multiple birds were heard calling within three minutes of one another, within a bearing range of 10 degrees and within a radial distance of < 100 m they were a single calling group. We excluded from analysis eight line transects along which we did not detect any birds. Six of these were at an elevation below 400 m (four located in BKNP and two in CCNP), whilst two were in high elevation pine forests in CCNP.

We used distance sampling protocols to estimate *A. cambodiana* density (Buckland *et al.* 2001, 2008). Only calling male birds recorded from line transects were used to calculate density. Sighting-only detections were excluded from the analysis because only two groups of *A. cambodiana* were sighted during the survey period. Distance 7.1 (Thomas *et al.* 2010) was used to estimate *A. cambodiana* detection probability and density. Key functions 'uniform', 'half-normal', and 'hazard' with cosine adjustments were used to run the analysis. Model fitness was selected using a combination of visual assessment of the distribution curve, goodness-of fit test, and the lowest Akaike's Information Criterion (AIC) (Akaike 1973). As the number of detections of *A. cambodiana* from each study site was small, we tested the difference among detection functions of each study site by comparing the value of AIC between global and stratified models. For the global model, we estimated density by pooling all detections from each study site. For the stratified models, because of the small sample sizes, we used the pooled global detection function (half-normal) to derive stratum specific density estimates. Finally, the best model selection was based on the AIC value and coefficient of variance (CV) from each model (Buckland *et al.* 2001).

Camera trap survey and habitat association

To increase the number of *A. cambodiana* detections used in the habitat selection analysis we used data from two camera trap surveys (Figure 1). The first dataset consisted of paired cameras installed at 74 locations (total 15,080 trap-nights) from December 2013 to March 2014 by the Wildlife Conservation Research Unit of Oxford University to target the common leopard *Panthera pardus* at CCNP between elevations of 565 and 1,169 m. The second survey consisted of a single camera at 66 locations (total 8,236 trap-nights) set from December 2015 to January 2016 by Wildlife Alliance - Cambodia to target Indochinese tiger *Panthera tigris* prey in SCNP between elevations of 105 and 620 m. In both cases camera traps were set in a systematic 2-km grid and placed 20–50 cm above the ground. Elevation, slope and distance to the nearest water source were considered as the main environmental variables likely to influence *A. cambodiana*. Elevation and slope were extracted from the ASTER GDEM at a scale of 30 x 30 m (Global Digital Elevation Model) downloaded from the Earth Remote Sensing Data Analysis Center (http://www.jspacesystems.or.jp/ersdac/GDEM/E/4-.html). Distance to the nearest water source (DS) was derived from the Cambodian Ministry of Environment topographic map. All data was re-projected to the WGS1984 datum before analysis.

We investigated *A. cambodiana* habitat use using camera trap and line transect data. Generalized linear mixed models with binomial distribution including the null model were developed to determine the association between ecological variables and the presence of *A. cambodiana*. The 'glmmTMB' (Template Model Builder) package (Bolker 2016) was used with R version 3.4 (R Development Core Team 2017) for fitting generalized linear mixed models and extensions when sampling methods (camera trap and line transect) were treated as random effects. Explanatory variables were elevation, slope, and distance to water sources. Habitat selection models were developed using 619 km surveys from 22 transects and 23,296 trap-nights of 140 camera trap locations. The detection of calling (from line transect) and captures (from camera trap) of birds from each survey

were treated as the response variable (detection or non-detection). Forest type was excluded from analysis as only two birds were heard calling in semi-evergreen forest and none in the pine forest. Five binomial regression models, including the null model, were developed to determine the association between ecological variables and the presence of *A. cambodiana*.

Prior to running the models, the continuous variables including elevation, slope, and distance to water sources were checked and outliers were removed. These variables were then standardised by subtracting from the mean and dividing by its standard deviation (x variable – mean of x/sd of x) (Gelman 2008). We did not include highly correlated variables ($r > 0.5$) in the same model. The survey effort (number of visits multiplied by transect length and number of camera trap-nights) was treated as a fixed coefficient and set to 1 by using an "offset" (Gelman and Hill 2006). We selected models by comparing Akaike information criterion (AICc) values adjusted for small samples. Akaike model weights (AIC-*w*) were calculated as the weight of evidence in favour of a model among the models being compared. We assessed model accuracy using the area under the receiver operating characteristic curve (Hosmer and Lemeshow 2000, Franklin 2010) in the "Presence/Absence" package (Freeman and Moisen 2008). We chose an optimal threshold cut-off value for classification using the minimised difference between the proportion of presences correctly predicted (sensitivity) and the proportion of absences correctly predicted (specificity) (Franklin 2010).

Current suitable habitat

A. cambodiana habitat loss was defined as the reduction of evergreen forest above 400 m and slope between 11° and 43° from 1996 to 2016. Loss was calculated using LANDSAT 5 (1996), LANDSAT 7 (2006) and LANDSAT 8 images from http://glovis.usgs.gov/ using supervised classification (ESRI 2011) in ArcGIS 10.1 (ESRI, Redlands, USA). Images were downloaded for the Cardamom Mountain range for February 1996, 2006 and 2016 when there was likely to be the lowest level of cloud scatter (< 10%).

The images were defined into different colour bands (different vegetation types) based on the Cambodian forest cover layer (Open Development Cambodia 2016), then the total area of evergreen forest above 400 m each year was calculated using summary statistics in ArcGIS 10.1. The evergreen forest above 400 m was calculated for two ten-year periods (1996–2006 and 2006–2016) and compared to the whole area of evergreen forest. Separate loss statistics were generated for the Cardamom Mountains as a whole, as well as BKNP, CCNP and PSWS.

Results

Density estimation

One hundred and forty-eight calling males were recorded from the three study areas and 619 km of surveyed line transects. The half-normal key function was the most supported model with detection probability $P = 0.48$. Calling birds were detected up to 97 m from the transect line (Figure 2) and the overall density estimate was 1.23 calling males/km^2. Study area stratification was the most supported model with AIC = 189 compared to the global model (AIC = 1491). Estimated density was high in BKNP (2.65 calling males/km^2), but lower in both PSWS (~ 60% less) and CCNP (~ 90% less) (Table 1). As there was minimal overlap between 95% confidence intervals between estimates for CCNP and BKNP the density within the latter was higher. There was little difference in density between PSWS and either of the other two sites (Table 1).

Habitat association

The presence of *A. cambodiana* was positively associated with elevation (> 400 m) and slope (11 and 43°), whereas distance to water had no effect (Table 2). The best fitted model provided

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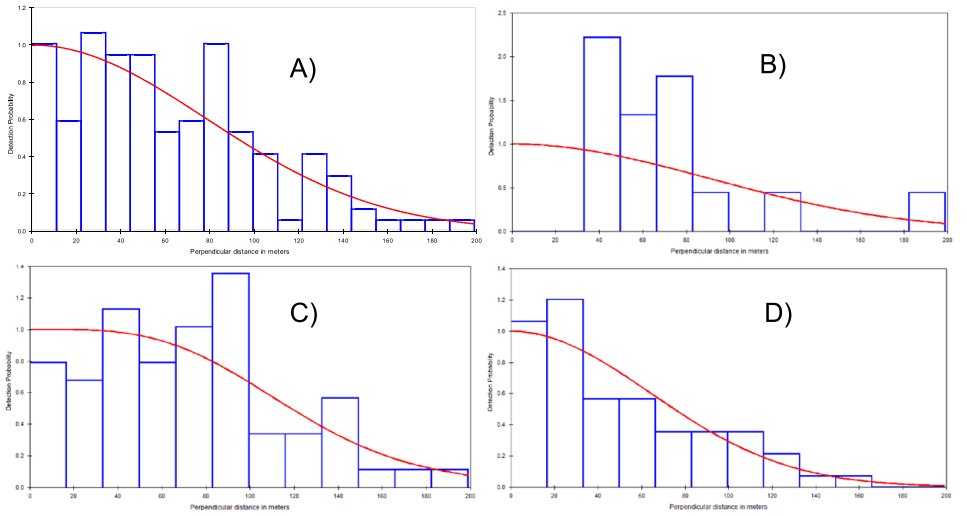

Figure 2. The detection function curve of A) the global model (all sites); B) Bokor National Park, C) Central Cardamom National Park and D) Phnom Samkos Wildlife Sanctuary.

Table 1. Distance sampling of detected male *Arborophila cambodiana* calls using line transects from Bokor National Park (BKNP), Central Cardamom National Park (CCNP), Phnom Samkos Wildlife Sanctuary (PSWS).

Study area	Effort* (km)	No detected	Encounter rate (n/L)	*P* detection	Density (calling birds km²)	Coefficient of variation (%)	95% Confidence interval
BKNP	100.55	65	0.64	0.61	2.65	47.75	0.92–7.62
CCNP	252.37	15	0.59	0.55	0.26	65.28	0.06–1.15
PSWS	265.76	68	0.25	0.40	1.60	44.67	0.61–4.16
GD**	618.69	148	0.23	0.48	1.23	32.21	0.63–2.39

*Total length of line transect (line length in km multiplied by observation times)
**Global density estimation

reasonable discrimination between *A. cambodiana* presence and absence (AUC = 0.79). The AUC threshold cut-off value was 0.4 based on the minimised difference between sensitivity and specificity with the highest correct classification at 78%.

Using the best regression model, we estimated there to be 2,308 km² of *A. cambodiana* habitat in Cambodia's Cardamom Mountain range remaining in 2016. This comprises around 45% of the estimated total area of evergreen forest above 400 m and 96% (2,221 km²) of this habitat is located inside protected areas (Figure 3).

Habitat loss

In 2016 15,007 km² of evergreen forest covered the Cardamom Mountains in Cambodia, which comprised (65%) of the total area. Of this, 2,308 km² (15%) was suitable for *A. cambodiana* being located above 400 m and with a slope between 11° and 43°. Over the past 20 years (1996–2016) the area of evergreen forest across the Cardamom Mountains has decreased by 20% (3,551 km²) including a 11% reduction in suitable habitat for *A. cambodiana*. This is equal on average to a rate of loss of around 100 km² every 10 years. Previously the amount of available habitat was larger and had declined by 173 km² (7%) between 1996 and 2006, a further 118 km² (5%) between 2006

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Table 2. Detail of parameters in accepted *Arborophila cambodiana* habitat use models with beta coefficient and 95% CI.

Model	Variable	K	AIC	Δ AIC	AIC-w	Coefficient	95% CI	
							Lower	Upper
1	Elevation	4	872	0	0.7	4.17	2.69	5.64
	Slope					0.78	0.003	1.56
2	Elevation	3	874	1.69	0.3	4.23	2.73	5.74
3	Distance to Water	3	910	38.13	0	0.79	0.20	1.38
4	Slope	3	911	38.97	0	0.88	0.18	1.59
5	Null	2	915	42.84	0	-113.37	-241	14.98

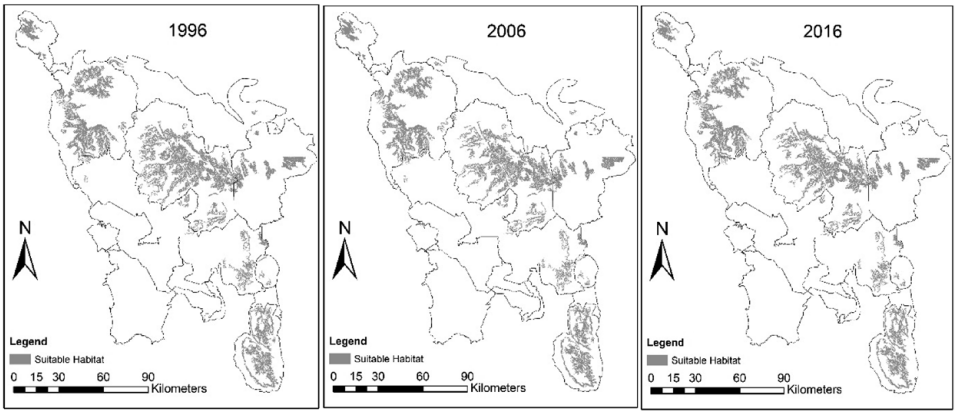

Figure 3. Change in suitable habitat for *Arborophila cambodiana* in the Cardamom Mountains over 20 years (1996–2016).

and 2016. Comparing the three study areas, in 20 years (1996–2006 and 2006–2016), total evergreen forest loss was highest in CCNP (127 km², 11 km²) followed by PSWS (25 km², 7 km²) and BKNP (10 km², 6 km²) (Figure 3 and Table 3).

Discussion

Bird density

Our *A. cambodiana* density estimates were low when compared to similar partridge species. For example, the estimated density of *A. davidi* in southern Vietnam was 3.63/km² (Vy *et al.* 2017), *A. chloropus* (now *Tropicoperdix chloropus* Chen *et al.* 2015) in Khao Yai National Park, northeastern Thailand was ~ 18/km² (Ong-in unpubl. data) and *A. arde* on Hainan Island, China was 6.54/km² (Gao 1999). However, our estimate was higher than the estimated 0.48/km² density of *A. rufipectus* in Sichuan, China where much of the natural habitat had been replaced by non-native conifer plantations and what remained was highly fragmented (Dai *et al.* 1998).

The higher density of *A. cambodiana* at BKNP was likely due to the low level of habitat loss at this site when compared to the others. The suitable habitat that remains at BKNP is isolated and largely inaccessible to humans, as much occurs on a plateau, surrounded by high, steep cliffs. As a result habitat fragmentation is low, which is favourable for many bird species (Ewers and Didham 2006, Chan 2010). This is unlike the other study areas which are much more accessible and fragmented. In 2007, much of the southern part of BKNP was granted to a private company to develop

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Table 3. Predicted *A. cambodiana* habitat (steeply sloping evergreen forest above 400 m from sea level) in 1996 to 2006 and 2016.

Study areas	1996	2006	2016
BKNP	379	378	370
CCNP	1,079	940	903
PSWS	697	682	661
Cardamom*	2,599	2,426	2,308

*Total predicted suitable habitat of *A. cambodiana* which including three study areas plus Phnom Aural Wildlife Sanctuary, Peam Krosob Wildlife Sanctuary, Southern Cardamom National Park, Kirirum National Park and new established wildlife corridors.

ecotourism (Open Development Cambodia 2014). This area is now better protected, with the collection of NTFPs having been banned. Ecotourism can also benefit galliform conservation, for example birdwatching in Cat Tien National Park, Vietnam (Sukumal *et al.* 2015) has reduced the hunting pressure on Green Peafowl *Pavo muticus* as villagers now value this iconic species for its ability to attract tourists. The increase in tourism and consequent increase in financial revenue for the area, might have encouraged the adjacent rural communities to avoid disturbing the forest (i.e. hunting and grazing cattle in the park) as well as increased the park's management effectiveness (Sukumal *et al.* 2015).

During the survey we also recorded male *T. chloropus* calling along line transects We estimated their density at approximately 15 calling males /km² in BKNP (unpubl. data) which is like the 18 calling males/km² recorded for the same species in the well protected Khao Yai National Park, Thailand (Ong-in unpubl. data). *T. chloropus* was also found at low density in the other two study areas (three calling males/km² in CCNP and six calling males/km² in PSWS).

The lower densities recorded for both partridge species in the CCNP are likely to be the result of habitat fragmentation. In the CCNP evergreen forest is interspersed with woodlands with a grassland understorey (Stuart and Emmitt 2006) which is unsuitable habitat for several *Arborophila* species (Dai *et al.* 1998, Gao 1999, Ong-in *et al.* 2016, Vy *et al.* 2017). For instance, we did not detect *A. cambodiana* along the two transects located in open pine forest with grassy understorey. Similarly, Sichuan Hill-partridge (*A. rufipect*) in China were also absent from coniferous forest despite occurring in adjacent areas of plantation (Dai *et al.* 1998).

Habitat use

In the Cambodian Cardamom Mountains *A. cambodiana* was most commonly recorded in evergreen forest at elevations above 400 m and on steep slopes. This shows the importance of the structure of the terrain for this species. Similar micro-habitat preferences were also found for other *Arborophila* species including the Common Hill-partridge *A. torqueola* (Liao *et al.* 2007a) and Sichuan Hill-partridge *A. rufipectus* (Dai *et al.* 1998, Liao *et al.* 2007b) in China and Orange-necked Partridge *A. davidi* (Vy *et al.* 2017) in southern Vietnam. Based on the habitat use model we predicted that density of *A. cambodiana* should be highest in the CCNP, followed by PSWS and lowest in BKNP (Figure 2, D). However, our survey data showed the opposite (Table1). This contradictory finding is most likely the result of human disturbance (e.g. Hiller *et al.* 2004, Rimbach *et al.* 2013). We observed both small (targeted valuable timber) and large-scale (land clearance for agricultural purpose) logging almost everywhere within CCNP, including numerous paths crossing the area used to export timber from the CCNP through Phnom Aural Wildlife Sanctuary.

In addition, there were numerous ELCs and less government patrolling in areas controlled by private companies. Illegal logging increases hunting, as loggers opportunistically target small terrestrial animals including galliforms (Samnang *et al.* 2009, Poulsen *et al.* 2011, Rimbach *et al.* 2013). *Arborophila* species have been shown to actively avoid or occur at lower densities in areas

with human disturbance (Nijman 2003, Liao *et al.* 2007a, 2007b, Vy *et al.* 2017). The low-density estimates for *A. cambodiana* may also result from the presence of other species such as *T. chloropus* in the area. The effect of potential competitors was also predicted for *A. davidi*, which was found at lower densities in the presence of *T. chloropus* in South Vietnam (Vy *et al.* 2017). *A. cambodiana* did not extend through much of the Southern Cardamom National Park south to the Gulf of Thailand, where the topography is mostly flat and thus less suitable for the species. Human disturbance such as logging, hunting and land clearance may also be the cause of low *A. cambodiana* and *T. chloropus* densities (Samnang *et al.* 2009).

Habitat loss

A. cambodiana is vulnerable to habitat loss and disturbance, as it occurs mostly in well-developed forest with deep litter and complex ground structure (Nijman 2003, BirdLife International 2016). Logging and hunting remain a cause for concern, despite the protected status of most of its remaining habitat (Samnang *et al.* 2009). Addressing these issues is largely a legal matter, although developing and implementing less harmful forestry practices may prove beneficial. The threat from unregulated and unplanned development remains. For example, there are five ELCs in BKNP (Open Development Cambodia 2014). Within PSWS two giant pepper farm ELCs cover 10% of its total area. The concern is that as the revenue from the area increases, the ELCs will be enlarged (e.g. Sodhi *et al.* 2010)

Approximately 47% (Table 3) of the remaining *A. cambodiana* habitat is in CCNP. Unfortunately, CCNP has the lowest *A. cambodiana* densities which is likely to be due to high fragmentation and human disturbance. Protecting *A. cambodiana* in the CCNP is also hampered by a lack of human capacity and protected area management planning (Conservation International 2016).

Reassessment of A. cambodiana's Red List assessment

We have shown that *A. cambodiana* is range- and habitat-restricted (Brickle *et al.* 2008), its habitat has been fragmented (Figure 3), and human disturbance and development activities negatively affect the species. We also believe that these threats and pressures will only increase across the species' range with time. Under Red List criterion A2c there has been an inferred reduction in population size with its extent of occurrence having declined by 11% over 20 years. This is less than the 30% decline required over 10 years for the species to be classified as 'Vulnerable' (IUCN Standards and Petitions Subcommittee, 2017). Under criterion B1, *A. cambodiana's* 2,308 km² extent of occurrence meets the 'Endangered' criterion (< 5,000 km²) along with the condition (bi) as the extent of occurrence continues to decline. However, this study does not provide information to adequately address either of the other conditions under B1, relating to severe fragmentation (a) or extreme fluctuations (c). Under criterion C the number of mature individuals is estimated at 2,800–11,000, therefore possibly exceeding 'Vulnerable' requirement for < 10,000 individuals. As *A. cambodiana* appears to approach the thresholds for threatened status under criteria A, B and C, we feel that this informed analysis warrants a revision of its status to 'Near Threatened' from 'Least Concern'. A more detailed analysis of *A. cambodiana's* extinction risk should be undertaken given its restricted extent of occurrence and the continuing threats to its survival.

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References

Akaike, H. (1973) Information theory and an extension of the maximum likelihood principle. Pp. 267–281 in B. N. Petrovand and F. Csàki, eds. *2nd International Symposium on Information Theory*. Budapest, Hungary: Akadémiai Kiàdo.

BirdLife International (2016) *Arborophila cambodiana*. The IUCN Red List of Threatened Species 2016. Retrieved May 17, 2017, from http://dx.doi.org/10.2305/IUCN.U˙K.2016-3.RLTS.T22679057A92801643.en

Bolker, B. (2016) Getting started with the glmmTMB package. https://cran.r-project.org/web/packages/glmmTMB/vignettes/glmmTMB.pdf

Brickle, N. W., Duckworth, J., Tordoff, A. W., Poole, C. M., Timmins, R. and McGowan, P. J. (2008) The status and conservation of Galliform in Cambodia, Laos and Vietnam. *Biodivers. Conserv*. 17: 1393–1427.

Brook, B. W., Sodhi, N. S. and Ng, P. K. (2003) Catastrophic extinctions follow deforestation in Singapore. *Nature* 424(6947): 420.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2001) *Introduction to distance sampling estimating abundance of biological populations*. Oxford, UK: Oxford University Press.

Buckland, S. T., Marsden, S. J. and Green, R. E. (2008) Estimating bird abundance: making methods work. *Bird Conserv. Internatn*. 18(S1): S91–S108.

Butchart, S. H., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J. P., Almond, R. E., . . . Bruno, J. (2010) Global biodiversity: indicators of recent declines. *Science*, 328(5982): 1164–1168.

Chan, S. (2010) *Land encroachment and community dependence on the forest in Bokor national park: understanding the issues*. Phnom Penh, Cambodia: The Department of International Convention and Biodiversity, General Department of Administration for Nature Conservation and Protection, Ministry of Environment of Cambodia.

Chen, D., Liu, Y., Davison, G. W., Dong, L., Chang, J., Gao, S., . . . Zhang, Z. (2015) Revival of the genus Tropicoperdix Blyth 1859 (Phasianidae, Aves) using multilocus sequence data. *Zool. J. Linn. Soc*. 175: 429–438.

Clements, G. R., Lynam, A. J., Gaveau, D., Yap, W. L., Lhota, S., Goosem, M., . . . Laurance, W. F. (2014) Where and how are roads endangering mammals in Southeast Asia's forests? *PLoS ONE* 9(12): e115376.

Conservation International. (2016) Central Cardamoms Protected Forest Project, News from the Field. Pnomh Penh, Cambodia.

Corlett, R. T. (2014) *The ecology of tropical East Asia*. Oxford, UK: Oxford University Press.

Dai, B., Dowell, S. D., Rodney, P. M. and Robert, S. R. W. (1998) Conservation status of the Sichuan Hill-partridge Arborophila rufipectus in China. *Bird Conserv. Internatn*. 9: 349–359.

Daltry, J. and Momberg, F. (2000) *Cardamom Mountains: biodiversity survey 2000*. Cambridge, UK: Fauna and Flora International.

Delacour, J. (1929) On the birds collected during the Fourth Expedition to French Indo-China. *Ibis* 71: 192–220.

Duckworth, J., Batters, G., Belant, J., Bennett, E., Brunner, J., Burton, J., . . . Harris, J. (2012) Why South-east Asia should be the world's priority for averting imminent species extinctions, and a call to join a developing cross-institutional programme to tackle this urgent issue. *SAPIENS (Surveys and Perspectives Integrating Environment and Society)* 5(2).

Eames, J. C., Steinheimer, F. D., and Bansok, R. (2002) A collection of birds from the Cardamom Mountains, Cambodia, including

a new subspecies of *Arborophila cambodiana*. *Forktail* 18: 67–86.

ESRI (2011) *ArcGIS Desktop, Release 10.1*. Redlands, CA: Environmental Systems Research Institute.

Ewers, R. M., and Didham, R. K. (2006) Confounding factors in the detection of species responses to habitat fragmentation. *Biol. Reviews* 81: 117–142.

Franklin, J. (2010) *Mapping species distributions: spatial inference and prediction*: Cambridge, UK: Cambridge University Press.

Freeman, E. A., and Moisen, G. (2008) PresenceAbsence: An R package for presence absence analysis. *J. Statis. Softw*. 23(11): 1–31.

Gao, Y.-R. (1999) Conservation status of endemic Galliform on Hainan Island, China. *Bird Conserv. Internatn*. 9: 411–416.

Gelman, A. (2008) Scaling regression inputs by dividing by two standard deviations. *Statistics in Medicine* 27: 2865–2873.

Gelman, A. and Hill, J. (2006) *Data analysis using regression and multilevel/hierarchical models*: Cambridge University Press.

Goes, F. and Furey, N. (2013) The birds of Cambodia-an annotated checklist. *Cambodian J. Nat. Hist*. 5.

Grainger, M. J., Garson, P. J., Browne, S. J., McGowan, P. J. and Savini, T. (2018) Conservation status of Phasianidae in Southeast Asia. *Biol. Conserv*. 220: 60–66.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., . . . Loveland, T. (2013) High-resolution global maps of 21st-century forest cover change. *Science* 342(6160): 850–853.

Heino, M., Kummu, M., Makkonen, M., Mulligan, M., Verburg, P. H., Jalava, M. and Räsänen, T. A. (2015) Forest loss in protected areas and intact forest landscapes: a global analysis. *PLoS ONE* 10(10): e0138918.

Hiller, M. A., Jarvis, B. C., Lisa, H., Paulson, L. J., Pollard, E. H. and Stanley, S. A. (2004) Recent trends in illegal logging and a brief discussion of their causes: a case study from Gunung Palung National Park, Indonesia. *J. Sust. Forestry* 19: 181–212.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H., . . . Cox, N. A. (2010) The impact of conservation on the status of the world's vertebrates. *Science* 330(6010): 1503–1509.

Hosmer, D. and Lemeshow, S. (2000) *Applied logistic regresssion*. Second edition. New York: Wiley.

IUCN Standards and Petitions Subcommittee (2017) *Guidelines for using the IUCN Red List categories and criteria*. Version 13. Prepared by the Standards and Petitions Subcommittee. Downloadable from http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Liao, W.-B., Cao, L., Jin-chu, H. and Xin, L. (2007b) Habitat utilization of the Sichuan Hill Partridge (*Arborophila rufipectus*) in the non-breeding period in Laojunshan nature reserve. *Zool. Res*. 28: 172–178.

Liao, W.-B., Hu, J. C. and Cao, L. (2007a) Habitat utilization during the pairing season by the common hill partridge Arborophila torqueola in Baiposhan Natural Reserve, Sichuan, China. *Ornithol. Sci*. 6: 87–94.

Miettinen, J., Shi, C. and Liew, S. C. (2011) Deforestation rates in insular South-East Asia between 2000 and 2010. *Global Change Biol*. 17: 2261–2270.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., and Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature* 403(6772): 853.

Nijman, V. (2003) Distribution, habitat use and conservation of the endemic Chestnut-bellied Hill-partridge (Arborophila javanica) in fragmented forests of Java, Indonesia. *Emu: Austral Ornithol*. 103: 133–140.

Ong-in, T., Pierce, A. J., Gale, G. A., Browne, S. J. and Savini, T. (2016) Nesting ecology and nest site selection of green-legged partridge. *Raffles Bull. Zool*. 64: 89–97.

Open Development Cambodia (2014) Forest cover. Retrieved May 16, 2017, from https://opendevelopmentcambodia.net/profiles/forest-cover

Poole, C. M. (1999) Little known Oriental bird: Chestnut-headed Partridge. Retrieved May 16, 2017, from http://orientalbirdclub.org/chestnut-h-partridge/

Poulsen, J. R., Clark, C. J. and Bolker, B. M. (2011) Decoupling the effects of logging and hunting on an Afrotropical animal community. *Ecol. Applic*. 21: 1819–1836.

R Development Core Team. (2017) *R: A language and environment for statistical computing*. Vienna, Austria : R Foundation for Statistical Computing.

Rimbach, R., Link, A., Heistermann, M., Gómez-Posada, C., Galvis, N., and Heymann, E. W. (2013) Effects of logging, hunting, and forest fragment size on physiological stress levels of two sympatric ateline primates in Colombia. *Conserv. Physiol.* 1(1). doi: 10.1093/conphys/cot031

Samnang, C., Sary, O, and Browne, S. J. (2009) Galliform surveys throughout the Cardamom Mountains, Cambodia, with particular reference to the Vulnerable Chestnut-headed Partridge (*Arborophila cambodiana*). Report to Rufford Small Grants, Cambodian Galliform Conservation Programme.

Sodhi, N. S., Posa, M. R. C., Lee, T. M., Bickford, D., Koh, L. P. and Brook, B. W. (2010) The state and conservation of Southeast Asian biodiversity. *Biodivers. Conserv*. 19: 317–328.

Stuart, B. L. and Emmett, D. A. (2006) A collection of amphibians and reptiles from the Cardamom Mountains, southwestern Cambodia. *Fieldiana Zoology* 109: 1–27.

Sukumal, N., McGowan, P. J. and Savini, T. (2015) Change in status of green peafowl *Pavo muticus* (Family Phasianidae) in Southcentral Vietnam: A comparison over 15 years. *Global Ecol. Conserv*. 3: 11–19.

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L. and Burnham, K. P. (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *J. Appl. Ecol*. 47: 5–14.

Vy, N. T., Ngoprasert, D., Browne, S., and Savini, T. (2017) Status and range decline of two galliform species in South-East Asia. *Bird Conserv. Internatn*. 28: 423–438.

World Pheasant Association. (2017) Retrieved 23 October, 2017, from https://www.pheasant.org.uk/southeastasia

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