First systematic survey of green peafowl *Pavo muticus* in northeastern Cambodia reveals a population stronghold and preference for disappearing riverine habitat

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មូលន័យសង្ខេប

ចំនួនសត្វក្ងោកបៃតងបានថយចុះយ៉ាងឆាប់រហ័សនៅអាស៊ីអាគ្នេយ៍ ដោយសារកត្តានៃការបាត់បង់ទីជម្រក និងការបរបាញ់។ សត្វក្ងោកបៃតងត្រូវបានគត់ត្រាថាជាសត្វជិតផុតពូជ ហើយចំនួនច្រើនបំផុត ដែលនូវសេសសល់ទំនងជាមានតែនៅភាគឦសាន នៃប្រទេសកម្ពុជាតែប៉ុណ្ណោះ។ ដូច្នេះ ការអភិរក្សសត្វក្ងោកបៃតងក្នុងតំបន់នេះគួរតែជាអាទិភាពក្នុងការអភិរក្ស។ ទោះជាយ៉ាងណា នៅមានចំនុចខ្វះចន្លោះជាច្រើនទាក់ទងទៅនឹងពត៌មានលំអិតអំពីអេកូឡូស៊ីរបស់ប្រភេទសត្វនេះ ការមិនមានទិន្នន័យជាមូលដ្ឋាននៃចំនួនសត្វក្នុងទីតាំងសំខាន់ៗជាច្រើនដែលមានប្រភេទសត្វនេះរស់នៅ និងនៅមានជម្រើសវិធីសាស្រ្តតិចតួច សម្រាប់ប្រើប្រាស់ក្នុងការធ្វើការវាយតម្លៃទាំងនេះ។ យើងធ្វើការសិក្សាវាយតម្លៃជាលើកដំបូង ដើម្បីប៉ាន់ប្រមាណពីចំនួនរបស់វាក្នុងដែនជម្រកសត្វព្រៃសៀមប៉ាង ដោយប្រើប្រាស់វិធីសាស្រ្តនៃការចាប់យក និងចាប់យកឡើងវិញ spatially explicit capture-recapture (SECR) ដោយផ្អែកលើការស្តាប់របស់អ្នកសិក្សា។ នៅចន្លោះខែកុម្ភៈ និងខែមេសា ឆ្នាំ២០១៥ យើងកត់ត្រាបានសំលេងសត្វយំចំនួន ៣៧៥ ដង ក្នុងនោះមានសត្វចំនួន ៩៩ក្បាល ត្រូវបានកំណត់ថាជាសត្វឈ្មោល ដែលត្រូវបានរកឃើញអំឡុងពេលនៃការសិក្សានៅ ១៧៦ ចំនុចសិក្សាផ្សេងគ្នា ដែលអាចប៉ាន់ស្មានបានថារបាយនៃសត្វឈ្មោលមានចំនួន ១.៧ក្បាល/គីឡូម៉ែត្រក្រឡា (៩៥% CI=១.០៨–២.៦៦) នៅក្នុងទីជម្រកនៃព្រៃទ្រនាប់ដងទន្លេ ដែលចំនួននេះខ្ពស់ជាងជិតប្រាំដងនៃរបាយសត្វឈ្មោលមានចំនួន ០.៣៥ក្បាល/គីឡូម៉ែត្រក្រឡា (៩៥% CI=០.២១–០.៥៩) ក្នុងទីជម្រកដែលមិនស្ថិតតាមដងទន្លេ។ ម្យ៉ាងទៀត ដង់ស៊ីតេរបស់វាក៏មានលក្ខណៈខ្ពស់ជាងចំពោះទីតាំង ដែលស្ថិតនៅឆ្ងាយពីលំនៅដ្ឋានរបស់មនុស្ស។ នេះបង្ហាញថា សត្វក្ងោកបៃតងអាចរងការគំរាមកំហែងពីការរំខានរបស់មនុស្ស ហើយសកម្មភាពអភិរក្សគួរតែផ្តល់អាទិភាពដល់ការការពារជម្រកតាមដងទន្លេនេះ។ ចំនួនដ៏ច្រើននៃសត្វក្ងោកបៃតងនៅក្នុងដែនជម្រកសត្វព្រៃសៀមប៉ាងត្រូវបានគេប៉ាន់ស្មានថាមានរហូតដល់ចំនួន ៥៧៩ក្បាល (៩៥% CI=៣៤៩–១២០៣) ហើយយើងគិតថាតំបន់នេះជាតំបន់ដែលទ្រទ្រង់ប្រភេទសត្វក្ងោកបៃតងនេះច្រើនជាងគេក្នុងប្រទេសកម្ពុជា។ វិធីសាស្រ្តនៃការស្តាប់សំលេងនេះ (SECR) ត្រូវបានវាយតម្លៃ ហើយយើងអាចផ្តល់ជាយោបល់ថាប្រសិនជាមានអ្នកជំនាញបច្ចេកទេសគ្រប់គ្រាន់ វាជាវិធីសាស្រ្តមួយមានប្រសិទ្ធិភាពខ្ពស់ និងចំណាយថវិកាតិចក្នុងការប៉ាន់ស្មានចំនួនរបស់វានៅតាមទីតាំងនីមួយៗ។

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Abstract

The green peafowl has undergone a rapid decline across Southeast Asia as a consequence of habitat loss and hunting. The species is listed as Endangered and the largest remaining population likely occurs in northeastern Cambodia. Conservation of the species in this region should therefore be a priority, yet significant knowledge gaps remain. These include an inadequate understanding of peafowl ecology, the absence of population baselines for many sites across the species' range and insufficient methods to assess ecology and population size. We provide the first assessment and abundance estimate of green peafowl in Siem Pang Wildlife Sanctuary using a novel application of spatially explicit capture recapture (SECR) methods based on an array of listening stations. Between February and April 2015, 375 vocalisations attributed to 49 calling males were detected during 176 listening station survey periods, providing an estimate of 1.7 males/km^2 (95 % CI= 1.08–2.66) in riverine habitat, nearly five times higher than the estimate of 0.35 males/km^2 (95% CI=0.21–0.59) in non-riverine habitat. Peafowl density was also higher further from human settlements. This suggests that the green peafowl population in the wildlife sanctuary may be threatened by human disturbance and that future conservation actions should prioritize protection of riverine habitat. We estimate the abundance of green peafowl in Siem Pang Wildlife Sanctuary at 574 birds (95% CI=349–1,203) and suggest the site is a national stronghold for the species. We also evaluate the acoustic SECR methodology employed and suggest that with sufficient expertise it is a cost-effective means of generating site-based abundance estimates.

Keywords

Abundance, Cambodia, green peafowl, riverine habitat, SECR.

Introduction

The green peafowl *Pavo muticus,* with its striking, long and colourful train feathers, has strong cultural importance in Southeast Asia. The species is an ancient symbol of wealth and power in Myanmar, was used as the icon of the Burmese monarchs, was printed on Burmese banknotes until 1966 and is the emblem of the National League for Democracy. In Thailand, Laos and Cambodia, the green peafowl is frequently depicted in religious temples such as Angkor (Goes, 2009) and in Java, the species is a symbol of traditional dance (McGowan *et al.*, 1998). Its ecological values are less well known, but as the diet of the species includes seeds, it may have ecological importance as a seed disperser (Owens & McGowan, 2011).

Once described as "the commonest gamebird in Indochina" (Delacour & Jabouille, 1925), green peafowl have declined rapidly in range within the greater Mekong region, and the only sizeable remaining populations are found in forests in Cambodia (Evans & Clements, 2004), Myanmar (Hla *et al.*, 2015) and Vietnam (Brickle *et al.*, 1998; Brickle, 2002). However, Sukumal *et al.* (2015) resurveyed the same area of Vietnam as Brickle *et al.* (1998) and Brickle (2002) and showed that this population has drastically declined. Outside of this region, small populations of the species persist in western and northern Thailand, southern Laos (Vongkhamheng *et al.*, 2012), Yunnan in China (Han *et al.*, 2009) and on Java in Indonesia (van Balen *et al.*, 1995; BirdLife International, 2016).

Cambodia experienced the fastest acceleration in the rate of deforestation in the world between 2001 and 2014 (Petersen *et al.*, 2015). The decline of the once revered green peafowl is partly due to deforestation and poorly regulated exploitation of forests and wildlife in the region. Habitat fragmentation has isolated many small populations. As a ground-dwelling bird, the green peafowl is particularly vulnerable to habitat fragmentation and susceptible to local extinction (Goes, 2009). Limited evidence also suggests the species is hunted for meat and feathers, and collection of eggs and chicks for illegal sale into the pet trade (BirdLife International, 2016). The conspicuous appearance of the species and its regular use of the same roosting trees make it easily hunted. As a consequence of inferred population declines, the green peafowl is listed as Endangered on the IUCN Red List of Threatened Species (BirdLife International, 2016).

In their status review for green peafowl, Brickle *et al.* (2008) suggest that "northern and eastern Cambodia probably hold the largest single population of the species" and the national population has been estimated at 2,000 to 3,000 birds (Goes, 2009). However, this figure is poorly substantiated because the status of the species at sites across Cambodia has been largely inferred or extrapolated using data from incidental records, ornithologists' trips and relative indices (Goes, 2009). Only one systematic survey has been undertaken in a single protected area to date (Nuttall *et al.*, 2017). As a consequence, we aimed to contribute to filling this data gap by surveying the species in Siem Pang Wildlife Sanctuary (SPWS) in northeastern Cambodia.

Nuttall *et al.* (2017) surveyed green peafowl using line transects and distance sampling analysis of visual detections to estimate the abundance of the species in Keo Seima Wildlife Sanctuary. Encounter rates with green peafowl were low and so a large amount of surveys across multiple years were needed to robustly estimate abundance (Nuttall *et al.*, 2017). Because male green peafowl produce a characteristic and loud 'wail' call that can be heard up to one kilometre away (Indrawan, 1995), auditory detections provide an alternative means of studying the species (Brickle, 2002). For instance, Brickle (2002) used point distance sampling of auditory detections of the wail call to survey green peafowl in Vietnam. This yielded a higher number of green peafowl detections per survey event than Nuttall *et al.* (2017). Because species density and abundance are estimated more accurately with a larger number of detections (Buckland *et al.*, 2001), we opted to survey green peafowl using auditory detections.

Density estimation by point distance sampling of auditory detections relies on distances to detected individuals being observed (Buckland *et al.*, 2001) and has been shown to be sensitive to random error in distance estimation, even when distance is estimated without bias (Borchers *et al.*, 2015; Kidney *et al.*, 2016). However, advances in Spatially Explicit Capture Recapture (SECR) methods have enabled estimation of the effective sampling area of a capture-recapture experiment based on supplementary field data collection (Royle & Young, 2008) such as estimated angles and distances to detected animals (Borchers *et al.*, 2015). By assuming distributional forms for the distance and angle estimation error and estimating their parameters, SECR methods are able to produce unbiased estimates of density (Borchers *et al.*, 2015; Kidney *et al.*, 2016). Another advantage of SECR methods over conventional distance sampling is that they allow the stochastic availability of animals to be modelled in the form of calling probabilities and accounted for in density estimation (Borchers & Efford, 2008). As a result, acoustic SECR methods are increasingly employed for studying cryptic species and were adopted in the present study.

Previous surveys of green peafowl in Vietnam, China and Cambodia have found that the species is associated with permanent water sources (Brickle, 2002; Liu *et al.*, 2008; Nuttall *et al.*, 2017). Our study therefore focused on riverine habitat, which we recognize as including all habitats within a river channel and adjacent riparian or "gallery forest" that fall within its floodplain (Allen *et al.*, 2009; Maxwell, 2009). The aims of our study were to: 1) model the habitat preferences of green peafowl to inform future conservation management actions in SPWS; 2) provide a first abundance estimate for the species at the site to assess its conservation significance and provide a baseline for monitoring conservation efforts; 3) evaluate a novel approach for surveying green peafowl based on recent advances in acoustic SECR methods, thereby addressing the need for flexible survey methods for the species.

Methods

Site description

Our study was conducted between February and April 2015 in SPWS, a ca. 670 km^2 protected area within the Western Siem Pang Important Bird Area (centred on 14°17′N, 106°27′E) in Stung Treng Province, northeastern Cambodia (Fig. 1). Siem Pang Wildlife Sanctuary is dominated by semi-evergreen forest with smaller pockets of deciduous dipterocarp forest and riverine habitat (Fig. 1), all of which is at low elevations (<350 m asl). The Sekong River runs approximately north to south through the site, is navigable all year round, approximately 100–200 m wide and has a braided channel in the northern portion of the site, dotted with small bars and rocky outcrops. Three smaller rivers present at SPWS—the O'kampa, Stung Malu and Stung Ting Hing—are only partially

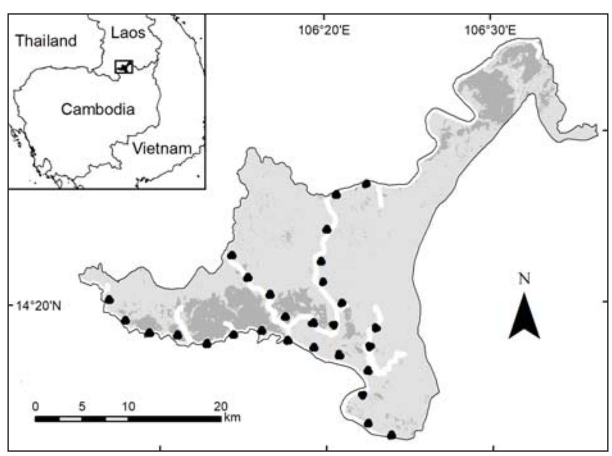

Fig. 1 Locations of listening stations (black circles) in triangle formations in relation to deciduous dipterocarp forest (dark grey), semi-evergreen forest (light grey) and riverine habitat (white) within Siem Pang Wildlife Sanctuary.

navigable during the wet season. Riverine habitats in the region experience intense seasonality, with river levels changing up to 10 m (Maxwell, 2009). As a consequence, seasonally flooded forests included in riverine habitat can extend some distance from a river's edge. In our study, a river channel and adjacent riparian forest within 100 m of the river edge were defined as riverine habitat. This distance was based on pilot transects from the river edge into the forest interior which quantified the presence/absence of structural criteria and species indicative of riparian and gallery forests including a closed canopy, signs of seasonal inundation, and presence of *Ficus* spp. and giant bamboo *Gigantachloa* spp. (Gardner *et al*., 2000; Maxwell, 2009).

Siem Pang Wildlife Sanctuary became part of the Western Siem Pang Important Bird Area (IBA) in 2003, following the discovery of five Critically Endangered bird species there (Hout *et al*., 2003). Since this time, surveys of deciduous dipterocarp forests in the southern sector of the IBA have confirmed the occurrence of >300 bird species (BirdLife International Cambodia Programme, 2012), including significant populations of the Critically Endangered slender-billed vulture *Gyps tenuirostris*, white-rumped vulture *G. bengalensis* and red-headed vulture *Sarcogyps calvus* (Clements *et al.*, 2013; Sum & Loveridge, 2016). Approximately 35% of the global population of the Critically Endangered white-shouldered ibis *Pseudibis davisoni* and 10% of the Critically Endangered giant ibis *Thaumatibis gigantea* also occur at the site (Wright *et al.*, 2012; Ty *et al.*, 2016). Confirmed sightings of Endangered mammal species including Indochinese silvered langur *Trachypithecus germaini*, yellow-cheeked crested gibbon *Nomascus gabriellae*, Eld's deer *Rucervus eldii*, dhole *Cuon alpinus* and banteng *Bos javanicus* have also been recorded (BirdLife International Cambodia Programme, 2012; Eames, 2014).

Survey design

We applied a modified form of the multi-occasion SECR model presented in Borchers *et al.* (2015) which includes an additional parameter giving the probability that an individual will be available for detection on a given sampling occasion (Kidney, 2014; Kidney *et al*., 2016). In the case of vocalising species, this can be interpreted as the probability that an individual makes a call during a given observation period. The detectors in this case were the listening stations, which were arranged in 28 separate arrays. Each array consisted of three listening stations in a triangular formation with one observer per station (equalling three observers per array). Listening stations were arranged 300 m apart, with the two southerly stations positioned at equal latitude. The location of listening arrays within the survey area was systematic and followed principles outlined by Buckland *et al.* (2001) to achieve a spatially representative design of the target area (Fig. 1). This was achieved by converting the survey area to a raster grid of 1 km^2 numbered cells using ArcGIS vers. 9.3 (Environmental Systems Research Institute, USA). The centroid of the first array was then located in a randomly selected cell using a random number generator. The centroids of subsequent arrays were then located at 3-km intervals using the ArcGIS spatial measurement tool, following the permanent courses of the Sekong, Stung Malu, O'Kampa and Stung Ting Hing rivers. Where both sides of the river fell within the boundaries of the wildlife sanctuary, adjacent arrays were located on opposite sides of the river. Due to border disputes over river access along the northeastern boundary of the sanctuary, it was considered too unsafe to survey the upper reaches of the survey area.

Surveys were conducted between February and April 2015 to coincide with the breeding season and peak period for wail call vocalisations produced by male green peafowl (Indrawan, 1995; Brickle, 2002). Following Brickle (2002), all wail vocalisations were noted. To capture the most active calling periods of the day, the survey period for each array was defined as 16:30–18:30 hrs, with a repeat survey the following morning between 05:30–07:30 hrs (i.e. a two-occasion survey). The observer at each listening station noted the time, direction and estimated distance to calling individuals.

Data processing and density modelling

We undertook one week of trial data collection and review to develop a rigorous and replicable method for categorising whether green peafowl calls originated from one male or another. During this phase, observers recorded the distance and bearing of calling males each time they were heard. This allowed us to identify variation in: 1) estimated distance and directional bearing to a call; and, 2) movement of calling birds during the trial period. In almost all cases (14 of 16 calling individuals registered during the trial phase), the first detections of calling birds in the morning survey periods were from the same location as calls registered during the evening survey of the previous day. This suggested that birds vocalised from roost sites in the evening and again from the same roost site before moving on to display or foraging areas, and so in turn that individuals could be accurately re-identified between these two survey periods. When birds moved during a survey period, they often made repeat calls while travelling. This allowed us to track moving individuals and, through repeated surveys, estimate the total distance that individuals were likely to travel within a survey period. Based on these observations, detections were defined as originating from the same individual if they occurred within an estimated distance of 300 m from where the observer first heard the calling male or if they varied in bearing by less than 45°. An exception to this rule was made when more than one male was heard calling simultaneously. Brickle (2002) noted that green peafowl calls are socially facilitated and we noted occasional bursts of calling activity from multiple males simultaneously. This enabled identification of multiple males, located nearby. These spatial and angular protocols provide a conservative method for grouping multiple calls from the same male which avoids over-estimation of the number of different males, while allowing for minor movements in calling individuals and additional variation introduced by recorder error.

In preparation for SECR modelling, data were processed so that repeat recordings of individuals during the same survey period were averaged to generate a maximum of one detection per male per listening station per survey period (Fig. 2). A multi-occasion SECR model was considered appropriate for the survey data because recaptures between survey occasions could be identified with a high degree of confidence. In SECR modelling, the centre of activity for each animal over the course of multiple survey periods (days) was treated as a random effect. Estimates of model parameters (such as density) were derived by maximising the likelihood after marginalising over all possible values of the random effect (i.e. averaging across all possible activity centre locations). So while the bearing to detected animal locations within occasions were obtained by averaging bearings within occasions, animal activity centres across occasions were treated as random effects.

All models were fitted in R (R Core Team, Austria) using the gibbonsecr package (Kidney, 2015) which uses an integration grid called a 'habitat mask' (Efford *et al.*, 2009) to obtain maximum likelihood estimates (Appendix 1). Density estimation parameters used were an intercept-only sub-model for the detection function scale parameter, hazard rate detection function, gamma distribution for estimated distances and wrapped cauchy distribution for estimated bearings (Appendix 1). Density surface modelling was undertaken to explore the relationship between green peafowl density and habitat and anthropogenic disturbance covariates collected by field teams at listening stations (Loveridge *et al.*, 2016; Appendix 2). Because all of the habitat and threat covariates had potential biological significance for green peafowl, they were all modelled. Model simplification was carried out using the Akaike information criterion (AIC) (Akaike, 1974) and we report all models within two AIC (Anderson & Burnham, 2002).

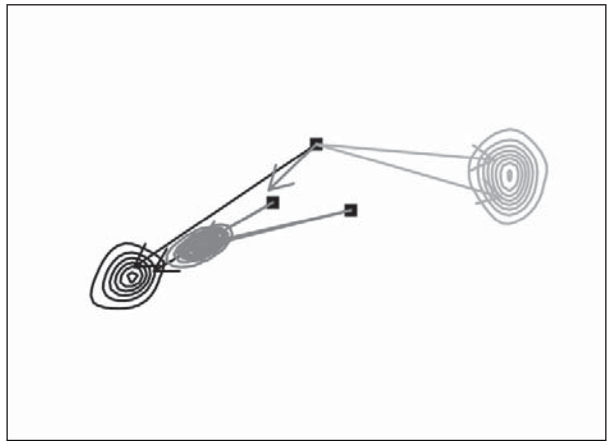

Fig. 2 Example spatial detections data recorded for listening array number 19. Black squares represent listening station locations. Arrows and green peafowl location probability contours (circles) are categorised by individual calling males. Arrow direction equals the bearing recorded by the observer and length of arrow represents the distance estimated by the observer.

Abundance estimation

Because green peafowl were detected using vocalisations made only by adult males (Indrawan, 1995), we estimated males/km^2 as the unit of density (Brickle, 2002). Estimated 95% confidence intervals for density were obtained using a parametric bootstrap by taking one million draws from the estimated sampling distributions of the model parameters for density and using the 2.5% and 97.5% percentiles from the derived sampling distributions of the density estimates. A conservative estimate of green peafowl abundance for SPWS was obtained by multiplying the density estimate of males by two (assuming a 1:1 sex ratio) and multiplying the density estimate for riverine habitat by the area of riverine surveyed (38.6 km^2). To the same end, all other habitats in the site were designated as non-riverine (631 km^2) and this area was multiplied by the lower density estimate for non-riverine habitat. Confidence intervals for abundance estimates were determined using the 95% confidence intervals of density estimates for riverine and non-riverine habitat.

Results

A total of 375 detections of the green peafowl's wail call were recorded over the course of 176 listening station survey periods. Of these, 131 were recorded during the evening survey period and 244 during the morning survey period. These detections were classified as originating from 49 different calling males, equalling 1.75

calling males per listening array. Of the 28 acoustic array locations, calling males were detected at 16. The placement of the arrays provided an effective survey area for riverine and non-riverine habitat of 38.62 km^2 and 227.73 km^2, respectively.

Density surface modelling of habitat and threat covariates determined that the model with the lowest AIC had a single binary covariate for riverine / non-riverine habitat (Fig. 3). One other model was within two AIC of this preferred model and was composed of the same riverine habitat covariate and a covariate for increasing distance to settlements (AIC=0.96). The latter explained less variation in green peafowl density than the former because a univariate model containing only the distance to settlements covariate had an AIC value of 14.68. Models containing other covariates for habitat and anthropogenic disturbance were not within two AIC of the most parsimonious model.

The density of green peafowl in riverine habitat was estimated as 1.7 males/km^2 (95% CI=1.08–2.66) from an effective sample area of 38.62 km^2. The density in non-riverine habitat was estimated as 0.35 males/km^2 (95% CI=0.21–0.59) from an effective sample area of 227.73 km^2. The abundance of green peafowl in SPWS was estimated at 574 birds (95% CI=349–1,203).

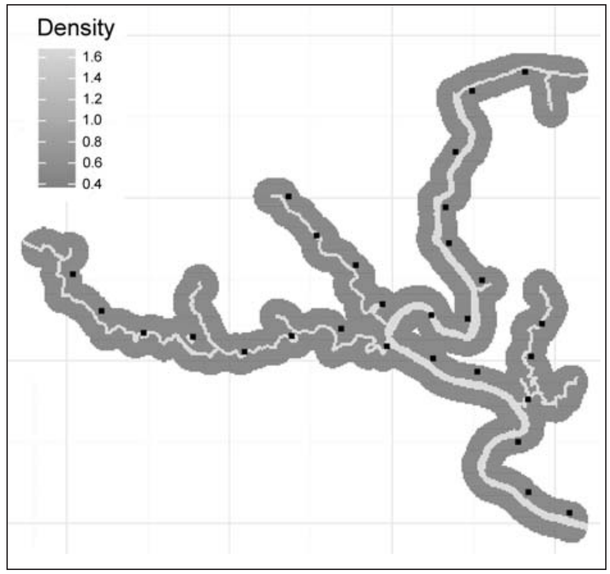

Fig. 3 Fitted density surface model for the lowest AIC model containing the binary riverine / non-riverine covariate. Black squares indicate centre points of the listening post arrays.

Discussion

Habitat preferences and conservation management

Our assessment of habitat preferences for green peafowl found that species density was nearly five times higher in riverine compared to non-riverine habitats. To a lesser extent, densities were also influenced by distance to settlements. In previous research on the habitat preferences of the species, Brickle (2002) subsumed all forest habitats under a 'deciduous forest' category. Our study builds on these findings by using remotely sensed and ground-truthed habitat data to generate finer-scale habitat classifications. Brickle (2002) found that detections were higher closer to water and our results concur with this finding. However, our study also shows that models including the binary riverine vs. non-riverine habitat variable predicted green peafowl density better than models that included the continuous variable of distance to rivers. This adds to the work of Brickle (2002) by identifying a specific association with riverine habitat, rather than simply proximity to rivers.

The fertile alluvial soils of riverine habitat provide a rich variety of food resources suitable for green peafowl, including *Ficus* spp. (Allen *et al*., 2009; Brun, 2013) which likely contribute to their preference for this habitat. The richness of riverine habitat contrasts greatly with the more open deciduous dipterocarp forests, which in Cambodia are often dominated by only four species of dipterocarpaceae and lack fruit-bearing trees species (Eames, 2014). However, riverine habitat is under significant threat due to its accessibility, presence of desirable resources including highly fertile soils for agriculture and proximity to fish stocks and hardwood species, all of which have resulted in greater species losses and elevated rates of degradation compared to other environments (Dudgeon, 2002; Allen *et al*., 2009). Green peafowl density was also higher further from settlements in our study, suggesting that its population at SPWS may be depressed by human disturbance. Given the species' close association with riverine habitat, iconic appearance and susceptibility to fragmentation and disturbance (Goes, 2009), green peafowl could provide a suitable flagship and/or indicator species for riverine habitat. Efforts to conserve the species should prioritize this habitat.

Conservation significance of SPWS for green peafowl

We estimate that 574 (95% CI=349–1,203) green peafowl occur in SPWS. This is comparable to the 541 birds estimated in Keo Seima Wildlife Sanctuary by Nuttall *et al.* (2017) who consequently identified the site as globally important for the species. In Vietnam, Sukumal *et al.* (2015) recorded a density of calling birds of 0.253 /km^2 in Yok Don National Park, and 3.025 /km^2 and 4.694 /km^2 in two separate zones of Cat Tien National Park. Our estimated density of 1.7 males/km^2 is low relative to comparable habitats in the latter. As density of the species is lower closer to settlements in SPWS, it is possible that it has been depressed by human disturbance at the site. Because large tracts of suitable riverine habitat still remain in SPWS, however, we suggest the site is a stronghold for the species in Cambodia, with a population comparable to other key sites for the species.

The global population of green peafowl is currently estimated at 15,000–30,000 birds (BirdLife International, 2016). This figure is approximate and likely represents an overestimate because it is based on few rigorous studies. Northern and eastern Cambodia have been identified as a priority zone for green peafowl conservation (Brickle *et al*., 2008; Owens & McGowan, 2011). Yet many protected areas exist within this region where the species is poorly known (Fig. 4). To improve the accuracy of global population estimates, surveys for green peafowl should be accorded high priority within these areas and could provide a platform for developing a national action plan to conserve the species in Cambodia.

Evaluation of acoustic SECR methodology

The trade-off between scientific rigour and financial resoruces is a major challenge in biodiversity monitoring (Sutherland *et al*., 2004). We used recent empirical advances in acoustic SECR to implement a cost-effective assessment for one species within a single field season. To achieve this, we selected a survey method that ensured a sufficient number of detections for robust statistical analysis. The total cost of our field survey was US$ 5,980. This comprised $3,095 for field expenses including boat hire, staff per diems and field equipment, $2,695 for staff salaries during the survey and $200 for travel expenses. These costs are lower than the cost of the multi-year study

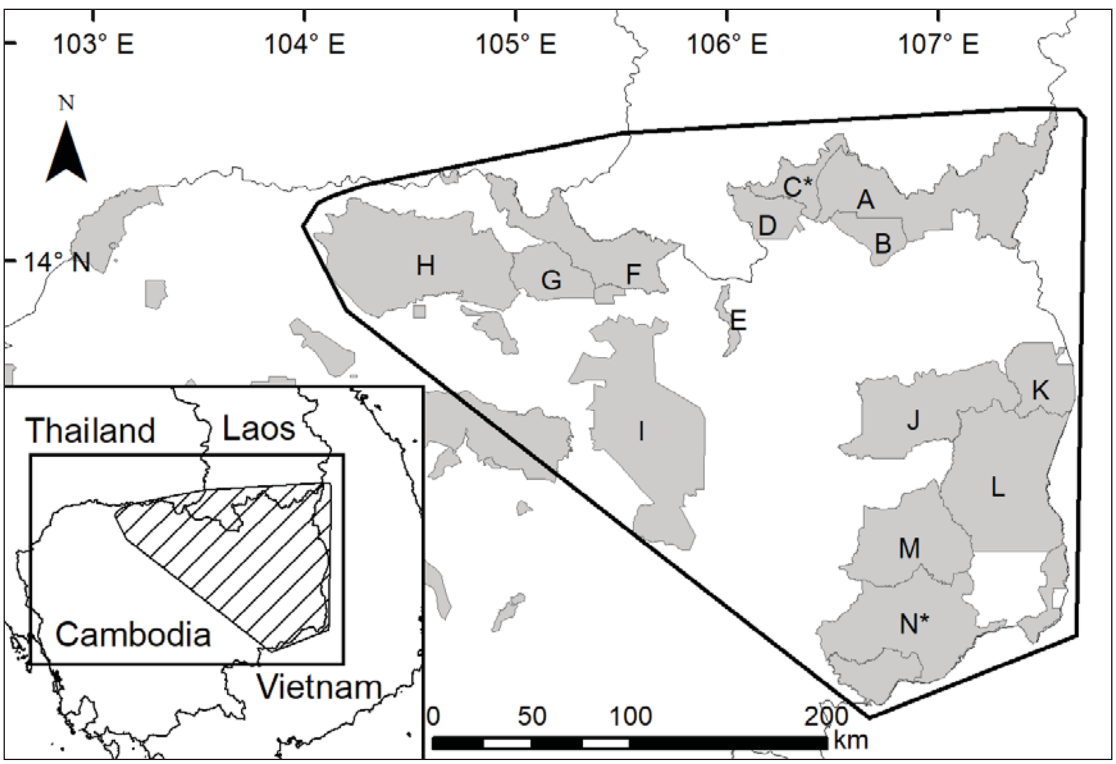

Fig. 4 The northeastern forest arc and proposed priority zone for green peafowl conservation (thick line on main map, cross hatched area on inset map) in Cambodia. Protected areas (grey shading) within the proposed priority zone include: A) Virachey National Park, B) Veun Sai-Siem Pang National Park, C) Siem Pang Wildlife Sanctuary, D) Prey Siem Pang Kang Lech Wildlife Sanctuary, E) Stung Treng Ramsar Site, F) Chepp Wildlife Sanctuary, G) Preah Rokar Wildlife Sanctuary, H) Kulen Promtep Wildlife Sanctuary, I) Prey Lang Wildlife Sanctuary, J) Lomphat Wildlife Sanctuary, K) Ou YaDav National Park, L) Srepok Wildlife Sanctuary, M) Phnom Prich Wildlife Sanctuary, N) Keo Seima Wildlife Sanctuary. * Indicates sites with a rigorous abundance estimate for green peafowl.

of Nuttall *et al.* (2017), which employed visual detections and distance sampling for multiple species.

The acoustic SECR method we employed has several analytical advantages over conventional distance sampling. These include accommodation of random error in distance estimation: a major issue in studies where the true distance to detected animals cannot be observed directly. The potentially least rigorous aspect of our approach was accurately distinguishing between calling individuals. To address this, we classified all detections within 300m or less than a 45° difference in bearing from an initial call as the same individual. These cut-off points were adopted to accommodate observer error in recording detected animals and allow for minor movements of detected animals during the survey period. However, as it remains unclear how strictly male green peafowl defend territories, several males not vocalising concurrently within a 300 m area could possibly be classified as a single male. It should be noted that our study is the first application of the acoustic SECR method to the green peafowl and required significant time to become acquainted with the analytical methods. However, we believe that the approach is suitable for esimating the abundance of this species in other poorly surveyed locations across its range and could also be applied to other vocal species, such as the Critically Endangered giant ibis.

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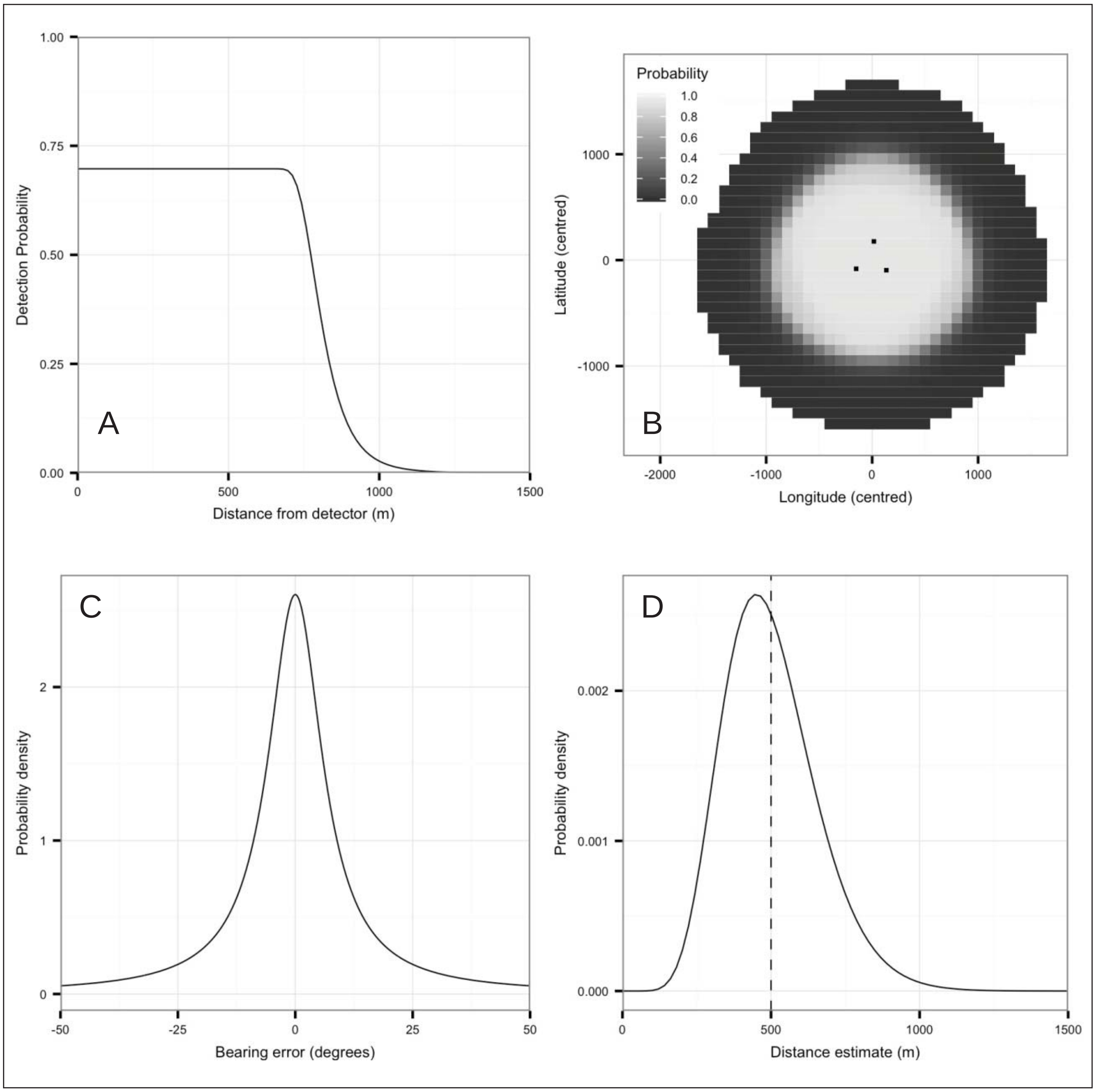
Appendix 1 Fitted observation sub-models from SECR analysis

Plot (A) shows the hazard rate detection function, which gives the detection probability for a calling individual at a single detector as a function of distance from the detector. Plot (B) shows the detection surface for array number 1 (black squares denote listening stations), which gives the overall probability of detection for an individual during the survey, given the spatial location of the activity centre (and taking account of the calling probability and detection function at each detector). Plot (D) shows the distribution of bearing errors, which were assumed to be unbiased, and plot (D) shows the distribution of distance estimates for an example case where the true distance is 500m (shown by the dotted line).



Appendix 2 Habitat covariates recorded at each listening station location

Covariate	Description
Tree density	A relascope (Gove *et al.*, 2001) was held at eye level 53 cm from the researcher whilst a 360° rotation was made about the central position of the listening station. The number of trees viewed as larger than the 1 cm opening in the relascope was counted and the number multiplied by two to give an estimate of tree basal area (m^2/ha).
Average tree height	A laser rangefinder (Nite Hawk Pin Predator 400) was used to estimate the height of four trees at each listening station. Tree selection was randomized by selecting tree stems closest to bearings of north, south, east and west from the centre of the plot. The average of these trees was then calculated.
Ground density	Ground density was considered as a cylinder of space with a circular area of 5 m radius, with the observer as the mid-point and vertical height from 0 to 0.5 m above ground. This was then scored as: 1 = 0–25% vegetation cover, 2 = 26–50% vegetation cover, 3 = 51–75% vegetation cover, 4 = 76–100% vegetation cover.
Understory density	Understory density was considered as a cylinder of space with a circular area of 5 m radius, with the observer as the mid-point and vertical height from 0.5 to 3 m above ground. This was then scored as: 1 = 0–25% vegetation cover, 2 = 26–50% vegetation cover, 3 = 51–75% vegetation cover, 4 = 76–100% vegetation cover.
Mid-story density	Mid-story density was considered as a cylinder of space with a circular area of 5 m radius, with the observer as the mid-point and vertical height from 3 m up 1 m below the canopy. This was then scored as: 1 = 0–25% vegetation cover, 2 = 26–50% vegetation cover, 3 = 51–75% vegetation cover, 4 = 76–100% vegetation cover.
Canopy density	Canopy density was considered as a cylinder of space with a circular area of 5 m radius, with the observer as the mid-point and vertical height as the top one meter of forest strata. This was then scored as: 1 = 0–25% vegetation cover, 2 = 26–50% vegetation cover, 3 = 51–75% vegetation cover, 4 = 76–100% vegetation cover.
Presence of cattle	0 = No evidence of cattle, 1 = evidence of cattle (dung / animals) observed in the plot.
Human disturbance	1 = No evidence of recent logging, 2 = Occasional single tree stumps and single trees felled, 3 = Frequent felled trees in the study plot, some evidence of trails cleared for vehicle access (hand tractors), 4 = Frequent felled trees grouped into piles, recent trail clearance for vehicle access (hand tractors/ trucks), land clearance for land grabbing, recent/ active logging camps.
Habitat type	Four habitat types recognised as follows: semi-evergreen forest, deciduous dipterocarp forest, bamboo stands, dry river beds. Each categorised as a seperate binary variable (present/absent).
Distance to settlements (km)	Straight line distance to the nearest permanent settlement.

