Bird Conservation International (2017) 27:127–139. © BirdLife International, 2016
doi:10.1017/S0959270916000083

Abundance estimates for the endangered Green Peafowl *Pavo muticus* in Cambodia: identification of a globally important site for conservation

MATTHEW NUTTALL, MENGHOR NUT, VISES UNG and HANNAH O'KELLY

Summary

The catastrophic decline of the endangered Green peafowl *Pavo muticus* across its former range is well known, yet there are only a handful of reliable population estimates for this species from its remaining range, making global assessment challenging. We present the first rigorous population estimates for this species from Cambodia, and model the distribution and the relationships between this species and several environmental covariates from the Core Zone (187,900 ha) of Seima Protection Forest (SPF), eastern Cambodia. Using distance sampling the abundance of Green Peafowl in SPF in 2014 is estimated to be 541 (95% CI [252, 1160]). Density surface modelling was used to predict distribution and relative abundance within the study area, and there was some evidence that the species prefers areas of deciduous forest, non-forest, and to a lesser extent semi-evergreen forest. These results highlight the importance of the central and northern sections of SPF for this species. Furthermore, the analysis suggested that Green Peafowl abundance is higher in closer proximity to water, yet decreases in closer proximity to human settlement.

Introduction

The Green Peafowl *Pavo muticus* has attractive conspicuous plumage, a large body size and is ground-dwelling, an unfortunate evolutionary combination in areas with heavy hunting presence. Green Peafowl are particularly vulnerable to three threats – hunting, habitat loss, habitat degradation (Brickle *et al.* 2008, Goes 2009, Thornton *et al.* 2012) - that are pervasive in Cambodia and elsewhere throughout Green Peafowl range (Gray *et al.* 2012, O'Kelly *et al.* 2012). The historical record suggests a rapid extirpation of this species from much of its former range (Goes 2009). The Green Peafowl was described as "*the commonest bird in Indochina*" (Delacour and Jabouille 1925) and "*common everywhere*" (Delacour 1928) in the 1920s but by 1960 as "*rare near habitation, since it is conspicuous, easily shot, and its train is valuable*" (William Thomas, cited in Thomas and Poole 2003). More recently, the species has been listed as 'Endangered' (BirdLife International 2013) based on several studies across its range (e.g. Van Balen *et al.* 1995, McGowan *et al.* 1998, Brickle 2002, Brickle *et al.* 2008, Hernowo *et al.* 2011). The vulnerability of the species is unlikely to decrease in the near future as human populations within South-East Asia expand, and threats to the integrity of forested areas increase (Ghazoul and Evans 2004, Miles *et al.* 2006, Miettinen *et al.* 2011). Cambodia, Myanmar, and west-central Vietnam are potentially the last remaining strongholds for this species (BirdLife International 2013), although there has yet to be a detailed population study in Myanmar, and recent studies suggest a decline in west-central Vietnam (Sukumal *et al.* 2015). We report the first robust estimates of density and abundance of Green Peafowl from any site in these areas. In this paper we present the results of four years of line transect-based distance sampling for Green Peafowl, and report the only known abundance estimates for this species in

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

Cambodia. We also present a spatial model derived from the line transect data that presents the species' distribution and potential areas of high density as a function of several spatial variables. The overall objective of this study was to produce Cambodia's first site-level population estimate for this species, and to assist law enforcement managers in targeting patrol efforts and other protection measures. These results can also be used to highlight areas of potential recovery for this species.

Background to the study

The Eastern Plains of Cambodia – an area containing nine protected areas covering over 1 million ha - is considered one of the most important landscapes for the conservation of biodiversity in Indochina (Gray *et al.* 2012, O'Kelly *et al.* 2012, Evans *et al.* 2013) (Figure 1). This landscape, specifically Mondulkiri Province within which the majority of the protected areas lie, has been identified as a stronghold for Green Peafowl in Cambodia (Timmins and Ou 2001, Walston *et al.* 2001, Goes and Davidson 2002, Pech *et al.* 2002, Evans and Clements 2004), although this assertion is based on anecdotal evidence and relative indices (Goes 2009). No studies have produced population estimates for this species at the landscape level in Cambodia using scientifically defensible methods.

Green Peafowl were first recorded at the site in 2001 (Walston *et al.* 2001), and were surveyed using call counts from listening posts over a number of years (Evans and Clements 2004). A system of line transects was established in 2005 to allow an assemblage of key landscape species to be monitored over time using distance sampling techniques. This system was expanded and improved

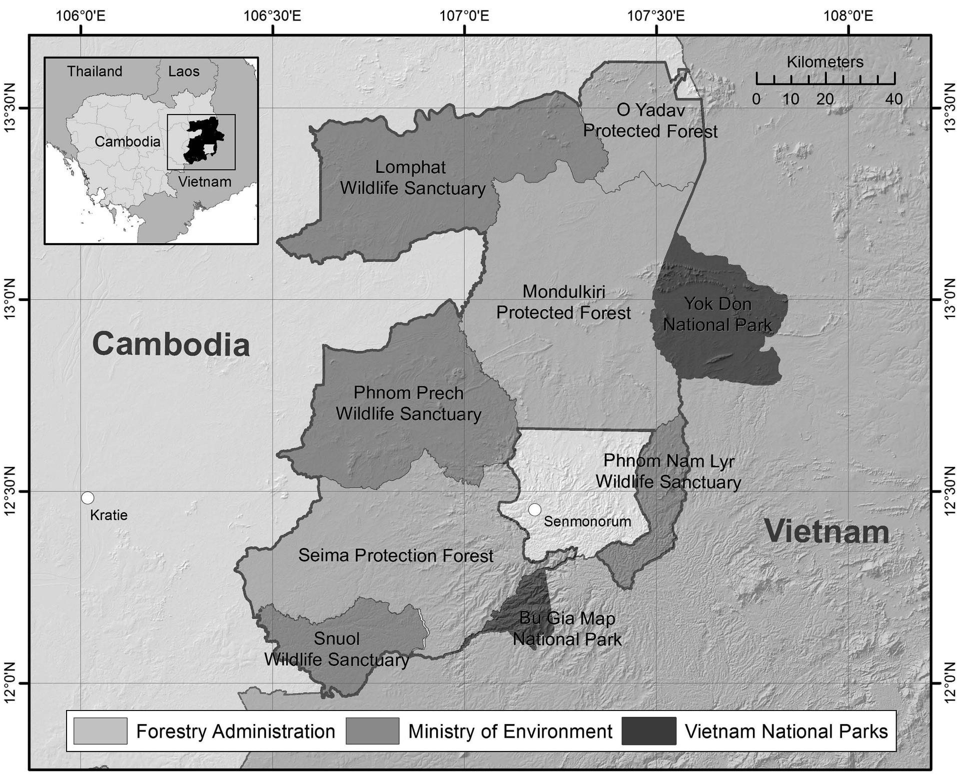

Figure 1. The Eastern Plains Landscape which falls within Mondulkiri, Rattanikiri, and Kratie Provinces. There are nine protected areas; seven in Cambodia and two in Vietnam.

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

in 2010 to facilitate more comprehensive monitoring of ungulate, primate, and avian species, including Green Peafowl (O'Kelly *et al.* 2012).

Methods

Study site

Seima Protection Forest (SPF) (106°55′1.573″E, 12°8′20.304″N) falls predominantly within Mondulkiri Province, and has a total area of 2,927 km², separated into two management sectors; the Core Zone (1,879 km²) and the Buffer Zone (1,048 km²) (Figure 2). The unique biogeography of SPF sees the Southern Annamite Mountain Range meet the Eastern Plains of Cambodia, resulting in a diverse mosaic of habitats that range from hilly evergreen forest in the south and east through to dry deciduous dipterocarp forests in the north and west (Evans *et al.* 2013, O'Kelly *et al.* 2012). Interspersed within this complex landscape are seasonal and permanent water sources, mineral licks, and areas of natural grassland, which together support an exceptionally diverse faunal community. The landscape has a tropical monsoon climate with a long dry season (December–April) and a wet season which sees rainfall of 2,200–2,800 mm/year (Evans *et al.* 2013). Green Peafowl have been seen relatively frequently in SPF since the initial surveys in 2001, yet during the initial line transect surveys (2005–2008) numbers of observations remained low (n = 3–12 per year). This was possibly a result of the elusive and cryptic nature of the species and the limited survey effort expended in the early years.

Line transect surveys

The survey design was based upon 40 square line transects each 4 km in length, placed systematically with a random start point (Figure 2). The effective survey area covered the entirety of the SPF Core Zone of (1,807 km²; Figure 2). Sampling was conducted in the dry season (February to May) in years 2010, 2011, 2013, and 2014. Effort levels were variable between years (Table 1) due to logistical and resource constraints. Observers walked the transects twice per day, once at dawn and once at dusk,

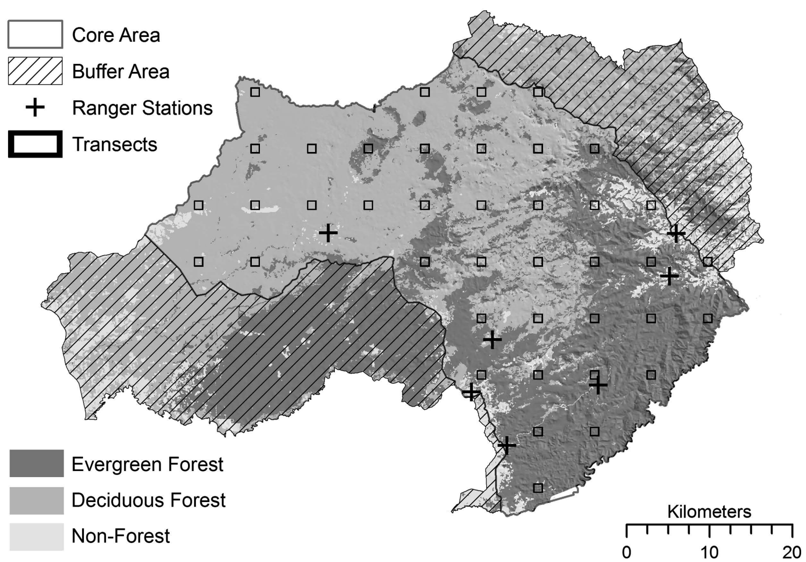

Figure 2. Seima Protection Forest (2927 km²) comprising the Core Zone (1879 km²) and the Buffer Zone (1048 km²).

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

walking either the full 4 km each time if the transect was located on flat ground or 2 km if the terrain was more challenging. Two observers walked in single file along the transect line with one observer concentrating on observations on or near the transect and one observer concentrating on the areas to the left and right of the transect. Only visual observations of Green peafowl were recorded. Auditory calls were not used because of the challenges of accurately estimating distances from unseen but calling individuals in tropical forests. Distances from the observer to the individual were measured using range finders and the bearings were estimated using sighting compasses. These measurements were then used to calculate perpendicular distances of the animals to the transect line. Standard distance sampling protocols were followed, as described by Buckland *et al. (*2001, Thomas *et al.* 2010). For further details of the methods used on the transects see O'Kelly *et al.* (2012).

Data analysis

Density and abundance estimates

The number of Green Peafowl observations per year were below the desired number (60–80), necessitating data pooling across years to improve the estimation of the detection function (Buckland *et al.* 2001). The estimates from years preceding 2014 have been generated retrospectively. Analyses were conducted using the software Distance (version 6.2; Thomas *et al.* 2010). Data were truncated after a visual assessment to eliminate outliers and to improve the model fit close to the line, and models were selected using a combination of visual assessment, goodness-of-fit tests, and Akaike's Information Criterion (AIC). Due to the low number of observations per year, a 'global' cluster size was used in order to reduce the variance associated with this parameter, and the presence of size-bias in the detections was tested using regression where significance was set at an α of 0.15. Where size-bias existed, cluster size was corrected by regression against probability of detection $g(x)$. Associated model parameters, standard errors, and confidence intervals were calculated by the software following methods described in Buckland *et al.* (2001).

Density surface modelling

In order to construct the spatial model, the line transects were divided into 100 x 100 m sub-transects or "segments". This size was selected so that the segment length broadly equated to $2w$ i.e. twice the length of the truncation distance, with the width being of the same distance, thus creating square segments (Buckland *et al.* 2001). This resulted in the creation of 40 segments per transect, totalling 1,600 segments across the study area. Green Peafowl observations from 2010, 2011, 2013, and 2014 were all incorporated into the model to provide a sufficient number of observations for the modelling process. Three environmental covariates; habitat, distance to water, and distance to human settlement were selected for inclusion based upon previous ecological studies of the species (Brickle 2002), and three broad hypotheses: 1) that water would be an important determinant of distribution, 2) the species would avoid areas of high human density at this site where hunting by humans is thought to be prevalent, and 3) that Green Peafowl would exhibit preference for deciduous forest over other forest types present in SPF. Distance to human settlement and distance to water were calculated as continuous variables measured from the centre of each segment to the nearest river or stream, and to the nearest village or town centre. Forestry Administration sub-stations were excluded as "human settlements" because the presence of law enforcement rangers and active patrolling from these sites may have had a confounding effect on the presence of peafowl. A habitat class was assigned to each segment based upon the dominant habitat type (> 50% of the segment). A prediction grid was created and placed over the study area. The size of the grid cells was decided through iteration in order to minimise the size of the cell as much as possible whilst taking account of computing capacity (Buckland *et al.* 2001). This process resulted in 7,986 500 x 500 m cells. Data were imported into the program Distance version 6.2 (Thomas *et al.* 2010). Density surface modelling (DSM) was done following the

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

two-step process outlined in Hedley and Buckland (2004) so that model checking could be done at both stages. The assumption that no significant variation in density exists across the individual segments (Miller *et al.* 2013) is unlikely to be violated in this case. The detection function was modelled within the mark-recapture Distance sampling engine, using a single observer fitting method (Buckland *et al.* 2001). A combination of visual assessment, goodness-of-fit tests and AIC values was inspected, resulting in the selection of a half normal key function with a constant scale parameter, and variance was estimated based on Innes *et al.* (2002). Estimated abundance per segment is treated as the response variable and was modelled as a function of the three covariates within the DSM engine in program Distance. A generalised additive model (GAM) with a logarithmic link and a quasi-Poisson response distribution was selected by comparing the generalised cross-validation scores, and was used to model abundance of clusters within each segment. The DSM engine was then used to predict abundance as a function of the covariates across the grid covering the study area. Variance associated with the estimation of abundance within the segments and across the unsampled areas was calculated by applying a moving block parametric bootstrap with 499 bootstrap resamples.

Results

Conventional distance sampling

The total number of observations across the four years was 85. The three key function models that were fitted (uniform, half-normal, hazard rate) produced plausible results but the half-normal key function with the cosine series expansion was selected based on a visual assessment, goodness-of-fit tests, and had a lower AIC value (half-normal = 600.52, uniform = 600.99, hazard rate = 602.76). The abundance estimates of Green Peafowl indicate a population of several hundred individuals (Table 1). Due to data being pooled during analysis, trend analysis is problematic and has not been attempted here.

Density surface modelling

The DSM predicted higher abundance in areas of deciduous forest, non-forest, and occasionally semi-evergreen forest, which are generally found in the central, north, and north-west of SPF (Figure 3). The southern portion of SPF was predicted low or zero abundance as this area is primarily higher elevation evergreen forest, and there were no observations on the transects in these areas. The strength of the relationship between peafowl presence and evergreen, semi-evergreen, and deciduous habitat categories can be seen in the component smooth plots (Figure 4) where the confidence intervals are narrow, however the small number of observations within bamboo areas reduced the precision for this habitat category. The modelled relationship between peafowl abundance and distance to water shows a roughly constant smooth until 500 m, after which abundance slowly decreases with increasing distance from water (Figure 4). Conversely, predicted

Table 1. Results from conventional distance sampling from line transects in 2010, 2011, 2013, and 2014.

Year[1]	Survey area (km^2)	L (km)	N[2]	Encounter rate (n/L)	Cluster size[3]	Density (individuals/km^2)	CV%	*n*	95% CI	
									Lower	Upper
2010	1807	1600	26	0.013	1.42	0.19	34	399	176	655
2011	1807	1460	18	0.012	1.42	0.18	50	323	123	851
2013	1807	1264	16	0.010	1.42	0.15	36	279	139	563
2014	1807	1292	25	0.020	1.42	0.30	39	541	252	1160

[1] – No line transect surveys were conducted in 2012.
[2] – Observations are clusters of animals.
[3] – Cluster size is the mean cluster size across all years adjusted for size bias.

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

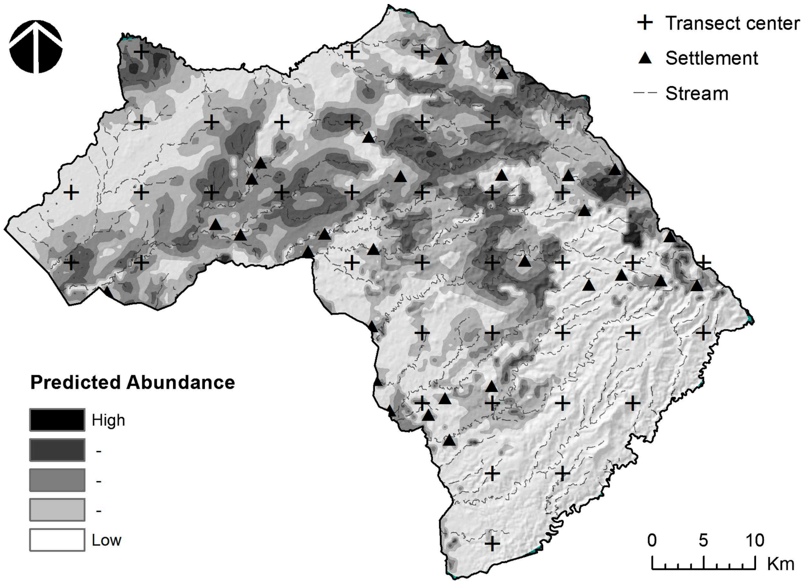

Figure 3. Relative abundance of Green peafowl modeled using line transect data and three covariates: habitat class, distance to nearest human settlement, and distance to nearest water body.

abundance increases as the distance from human settlements increases, albeit slightly, to a peak at approximately 3,000 m, after which predicted abundance steadily decreases with increasing distance. The precision of the prediction for both distance to water and distance from human settlement decreases with greater distance, which is reflected in the widening of the confidence intervals for the smooths (Figure 4).

The pattern of zero abundance that extends from the southern portion into the central-east of the study area is likely to be at least partly due to either large tracts of evergreen forest, a lack of water sources, or a combination of the two. Upon inspection, the patterns of high abundance that are present in the north of the study area tend to follow the pattern of water sources and avoid the patches of evergreen forest that are interspersed in the landscape.

Discussion

Monitoring Galliformes

A species or system of interest must be monitored if the effectiveness of conservation interventions is to be assessed (Green *et al.* 2005). Without empirical evidence conservationists cannot credibly claim success, nor indeed can they recognise failure (Sutherland *et al.* 2004, Ferraro and Pattanayak 2006). Yet in many bird monitoring regimes counts are often used, typically under the assumption that the count statistic correlates in a linear manner with density, which ultimately can lead to erroneous conclusions (Buckland *et al.* 2008). Previous studies focussed on Galliformes have used techniques such as transect-based and call count-based relative indices (e.g. Kaul and Shakya 2001, Dohling and Sathyakumar 2011, Jolli and Pandit 2011). Attempts have been made to move away from count-based indices through the use of camera traps and adapted capture-recapture (e.g. Winarni *et al.* 2004) and more recently through the use of occupancy frameworks (e.g. Jolli *et al.* 2012, Thornton *et al.* 2012). However, in order to reliably assess the status of a species and to monitor population trends over time, Conroy and Carroll (2002) suggest that where possible, variations of distance sampling or mark-resight/remove techniques should be

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

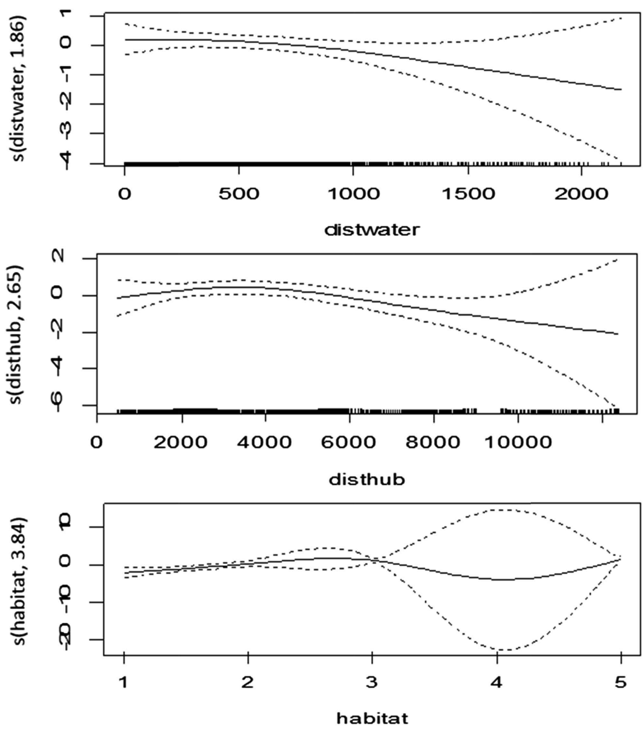

Figure 4. Plots of the smooth functions for the three variables; distance to water (top), distance to human settlement (middle), and habitat (bottom) that were used in the final density surface model for Green peafowl. Solid lines are the estimates of the conditional dependence between peafowl abundance and the variable, and dotted lines show the 95% confidence intervals for the smooth terms. Covariate values are displayed as rug plots at the bottom of the distance-related variable plots. The numbers on the Y-axis are the effective degrees of freedom of the smooth term. Distances are all in metres. Habitat categories are; 1 – evergreen, 2 – semi-evergreen, 3 – deciduous, 4 – bamboo, 5 – non-forest.

used, and only if these quantitative methods have been evaluated and discarded for logistical or biological reasons, should relative indices be considered.

Conventional distance sampling

All of the available methods mentioned above have limitations, but if it can be implemented properly, distance sampling offers considerable advantages over other techniques. Nevertheless, limitations and challenges exist with the use of distance sampling and therefore with the estimates for Green Peafowl presented here. The numbers of observations per year were too low to allow for annual detection functions and annual cluster sizes to be estimated during the analysis. One of the key benefits of a distance sampling framework is the ability to pool data across time (and space) and estimate a "global" detection function and cluster size whilst producing annual abundance estimates (Buckland *et al.* 2001). However this necessitates the assumption of homogeneous probability of detection and cluster size across time, precluding investigation of temporal variation within these parameters. This is undesirable for species that are potentially suffering the adverse effects of hunting, which may affect their behaviour or group composition and is of interest to wildlife managers. Furthermore, due to the extremely low encounter rates and a low number of

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

observations per year (Table 1), these initial estimates are imprecise and allow for only limited inference. This will, however, improve over time as more data accrue.

Implementing distance sampling surveys in tropical forest environments is a challenging endeavour. Ensuring an acceptable amount of effort is walked on each transect within an extensive, systematically placed transect grid across a site the size of SPF necessitates complex and costly logistics. Field teams are required to be extremely well trained in field protocols to ensure that theoretical assumptions that govern distance sampling are not violated, and to safeguard data quality and reliability of species identifications. Furthermore when the species of interest are naturally rare, cryptic, or artificially depressed long-term investment in survey effort is often required as one-off surveys are unlikely to produce a sufficient number of observations. In such cases where long-term monitoring is not possible the incorporation of auditory calls into a distance sampling framework – which will often increase the number of detections - is a possibility. In these cases distance "bins" can be used to group estimated auditory detections. In general, surveys using distance bins can produce unbiased estimates (Buckland *et al.* 2001). Nevertheless extreme caution must be employed, especially in tropical forest environments, to ensure the fundamental assumptions of distance sampling are not violated. Often the terrain and habitat of tropical forests distort auditory calls such that the accurate estimation of distance (and often compass bearing) within an analytically useful bin size and up to any meaningful effective strip width, is extremely difficult. The long-term monitoring programme in SPF demonstrates that this survey methodology can be successfully implemented in challenging environments in the context of low technical capacity, and is able to produce useful results for a suite of species with a low underlying density. For example, the SPF line transect system produces estimates for six species of primate and two ungulates in addition to Green Peafowl. The precision of the estimates for Green Peafowl is not optimal, limiting our ability to investigate population trends at this stage. However the use of distance sampling allows for the explicit estimation of the nuisance parameter – the probability of detection – which is so often ignored, for example in many index-based methods, to the detriment of the results (MacKenzie *et al.* 2002, Kery *et al.* 2008). Nevertheless, conservation biologists must critically assess the advantages and disadvantages of various monitoring schemes based on a plethora of variables, including human and financial resource constraints, available technical capacity, the biology of the species in question, the environmental conditions of the site, and most importantly, what the purpose of the research is. In the case of SPF, population estimates are required for a suite of species, and distance sampling using line transects is the most resource efficient way to do this. If however, density estimates are required only for Green Peafowl, there are certainly other methods which deserve exploration which are both robust and resource efficient. For example researchers from Western Siem Pang Protected Forest have successfully implemented auditory spatially explicit capture-recapture (Borchers and Efford 2008) for Green Peafowl (R. Loveridge 2015 *in litt*).

Density surface modelling

The purpose of this modelling exercise was to take advantage of four years of line transect data and the availability of environmental covariate data to better understand the distribution of Green Peafowl across SPF, and to combine this with analyses from other species to help inform the deployment of enforcement patrols. The predicted high abundance of peafowl in open deciduous forest was expected, as this is the favoured habitat identified both in previous studies (Brickle 2002) and by direct observations in SPF (authors' pers. obs.). It is clear that the species is also found regularly in semi-evergreen patches, but very rarely in evergreen areas. The use of bamboo- dominated habitat remains unclear as the precision of this modelled relationship is insufficient to make a reliable inference (Figure 4). The results of the modelling for the other two variables did broadly show the expected relationships; peafowl abundance decreased with an increasing distance from water sources, and peafowl abundance increased with increasing distance

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

from human settlement. The model has highlighted some important patterns of distribution across the Core Zone of SPF, and has reinforced the understanding of habitat preferences of this species. The fundamental difference between conventional distance sampling and DSM is that when estimating the abundance of a species using a line transect system within a distance sampling framework, the assumption is made that the areas sampled are representative of the wider, unsampled areas (providing survey design is robust). Conversely, the DSM process assumes that observations within the context of the predictor variables in the sampled area are representative of the wider study area. The decision to implement wildlife studies based upon design-based or model-based inference will be governed by many factors and will be site-specific, but should not be taken lightly.

Conservation status of Green Peafowl in Seima Protection Forest

Despite populations persisting in Thailand, Laos, China, Indonesia, and India, it is believed that sizeable populations remain only in Cambodia, and perhaps Myanmar, and west-central Vietnam (BirdLife International 2013, Sukumal *et al.* 2015). The Vietnamese population is found in Yok Don and Cat Tien National Parks and is extremely localised, and the species is probably extirpated from elsewhere in the country (S. P. Mahood 2015 *in litt.*). According to the IUCN Red List the global population is between 15,000 and 30,000 individuals, but this number should be considered extremely approximate, as there are very few reliable population estimates from anywhere in its remaining range. Within Cambodia, there are currently no published population estimates produced using robust methods, so a comparison of the SPF population with other sites from Cambodia is impossible at present. Goes (2009) assessed the conservation status of Green Peafowl across the whole of Cambodia. There are only a handful of historic records from the north-west, no specific records from the central plains or south-eastern provinces, and a few widely scattered historical records from the south-western provinces, including in Bokor National Park, Kirirom National Park, Phnom Samkos Wildlife Sanctuary, Phnom Aural Wildlife Sanctuary, and along the Sre Ambel river (Goes 2009), and incidental records from Central Cardamoms Protected Forest (S. Brook 2015 *in litt.*). Many of these records date back to the early 2000s, and the current status of the species in these areas cannot be assessed. There has been a recent study from Western Siem Pang Protected Forest in the north-east of Cambodia where a significant population has been assessed using spatially explicit capture-recapture (R. Loveridge 2015 *in litt.*), and this is likely to reveal another key site for the conservation of this species. Goes (2009) suggests that Southern Mondulkiri possibly holds the largest remaining population of this species in the world. The results of this study confirms that that the SPF population is of global importance and it seems highly likely that it is one of the most important populations in Cambodia. If this proves to be the case the global population estimate presented on the IUCN Red List is likely to be a significant overestimate.

The primary threats to this species in SPF are hunting and habitat loss due to land clearance. Hunting is a difficult threat to assess in tropical forest contexts (O'Kelly 2013). Law enforcement efforts in SPF have been recorded and monitored since 2004 via the Management Information System (MIST), and more recently the Spatial Monitoring and Reporting Tool (SMART) (www.smartconservationsoftware.org). Nevertheless hunting is still very difficult to assess as law enforcement teams have shifted their efforts over time to meet changes in immediate threats such as timber extraction and land clearance. This has resulted in fewer recorded observations of hunting incidents by patrol teams, despite increasing human populations in and around the Protection Forest and significantly improved road access, all of which are likely to increase levels of hunting. Nevertheless, Green Peafowl have been very rarely recorded in hunting or wildlife trade incidents in SPF (WCS unpubl. data), with the majority of poaching and live trade incidents involving sambar *Rusa unicolor*, red muntjac *Muntiacus vaginalis*, wild pig *Sus scrofa*, pygmy loris *Nycticebus pygmaeus*, black-shanked douc *Pygathrix nigripes*, common palm civet *Paradoxurus hermaphrodites*, banteng *Bos javanicus*, elongated tortoise *Indotestudo elongata*, and Burmese

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

python *Python molurus*. A possible explanation is that hunting of this species is primarily for subsistence rather than trade, thus causing hunting incidents to be less easily detected and therefore more underreported than other species. However, the density of Green Peafowl at the site is very small (0.3/km^2; Table 1). It is difficult to know what a natural population density would be given that hunting is suspected at all sites where Green Peafowl exist. Therefore in this case a coarse comparison can be drawn with the most similar species for which reliable density estimates exist. The density of Indian Peafowl *Pavo cristatus* in a reserve in India is 6.29/km^2 (Gurjar *et al.* 2013) and therefore based on the area of suitable habitat available in SPF it must be assumed that hunting is the primary cause of this severe population suppression.

Clearing of forested areas for agriculture is a major threat to wildlife species in SPF. Despite increasing investment in conservation activities and a significant increase in law enforcement efforts, the area of high quality habitat lost to deforestation continues to increase. This is not a unique problem, with much of South-east Asia suffering from high rates of forest loss (Miettinen *et al.* 2011). However SPF is rare in that it holds large areas of dry deciduous dipterocarp forests (DDF), and falls within one of three DDF hotspots identified for South-East Asia (Wohlfart *et al.* 2014). Land clearance for small and large-scale agriculture in and around SPF is increasing rapidly as a potent fusion of human population growth, rapid economic development, and booming infrastructure has exposed frontier provinces such as Mondulkiri to immigration and urbanisation (Evans *et al.* 2013). Although small-scale clearance for agriculture by individuals poses a serious threat to SPF, previous analyses have identified two legal mechanisms – Economic Land Concessions and the Government's Directive 01 individual land titling initiative - which are responsible for significantly more forest loss within the borders of SPF than illegal land clearance by small-holders (Nuttall *et al.* in prep). Illegal land clearance by individuals is increasing in speed and scale, and this type of clearance is heavily focused around the legal entities, as enforcement of these periphery areas is particularly difficult in the context of extremely limited resources and weak governance. Furthermore, an increase in human presence is likely with both industrial and smallholder forest loss, and is very often a precursor to an increase in negative human activities such as hunting (Wittemyer *et al.* 2008).

Despite the worrying scale of forest loss in the Buffer Zone of SPF, the Core Zone has suffered less, and the annual rate of deforestation is significantly less than neighbouring areas (WCS unpubl. data). The Core Zone still supports vast areas of mosaic habitat which contains a globally important assemblage of species (O'Kelly *et al.* 2012). Therefore we conclude that habitat loss is currently a secondary threat to Green Peafowl after hunting, but that it will undoubtedly become more serious in the near future.

Conclusions and recommendations

The Core Zone of SPF is potentially of global importance for the maintenance of viable Green Peafowl populations, and every effort should be made by both the Cambodian government and NGO partners to ensure this area is effectively protected. We have presented the only known population estimates for Green Peafowl from Cambodia and have identified the areas of SPF which are of greatest importance to this species. At sites where Green Peafowl are present and resources are limited, we strongly recommend that resources are targeted at reducing immediate threats, specifically hunting. Where resources are available for biological monitoring, wildlife researchers should endeavour to conduct well designed and robust studies that produce absolute estimates and distribution information so that the status of this species can be better understood, and law enforcement efforts and management interventions better targeted. Without such information, it will be a challenge for conservationists to coordinate an appropriate response to the rapid decline of this charismatic and highly threatened species. The recovery of this species in SPF will be dictated by the ability of the Cambodian government to invest sufficient resources into the management and protection of the site, so that the rate of forest loss and the impact of illegal hunting are significantly reduced in the near future. The areas that require urgent attention

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

include: 1) the provision of sufficient law enforcement staff who are managed strategically using the data available from SMART to focus on wildlife hotspots and to target hunting, 2) ensuring that land clearance in and around the Protection Forest results in prosecutions in order to create disincentives, 3) that boundary demarcation separating the Protection Forest and legally titled land is present, conspicuous, and immovable.

Acknowledgements

We would like to thank the Forestry Administration of the Royal Government of Cambodia for their support for the Seima Project over many years, and the project staff from both WCS and the Forestry Administration for their continued support. We would like to thank Ross Sinclair, Simon Mahood, Sarah Brook, and two anonymous reviewers for providing extensive comments which greatly improved earlier versions of this manuscript, Eric Rextad for patient guidance throughout the density surface modelling process, and Jeff Silverman for cartographic support and creation of the graphics. Special thanks go to the SPF biological monitoring team for their endless and tireless hard work in the field. Final thanks go to Jan and Henry Keeling. This work was supported by the USAID Supporting Forests and Biodiversity grant (Award number AID-442-A-13-00002); Winrock International (Sub-grant number 6499-12-03); and John D and Catherine T MacArthur Foundation (Grant number 09-92504-000-GSS)

References

BirdLife International (2013) *Pavo muticus. The IUCN Red List of Threatened Species. Version 2014.3*. www.iucnredlist.org

Borchers, D. L. and Efford, M. G. (2008) Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics* 64: 377–385.

Brickle, N. W. (2002) Habitat use, predicted distribution and conservation of green peafowl (*Pavo muticus*) in Dak Lak Province, Vietnam. *Biol. Conserv.* 105: 189–197.

Brickle, N. W., Duckworth, J. W., Tordoff, A. W., Poole, C. M., Timmins, R. and McGowan, P. J. K. (2008) The status and conservation of Galliformes in Cambodia, Laos and Vietnam. *Biodiv. Conserv.* 6: 1393–1427.

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 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: S91–S108.

Conroy, M. J. and Carroll, J. P. (2002) Estimating abundance of Galliformes: tools and application. Pp. 201–215 in M. I. A. Woodburn, P. J. K. McGowan, J. P. Carroll, A. Musavi and Z-W. Zhang, eds. *Galliformes 2000-Proceedings of the 2nd International Galliformes Symposium*. Reading, UK and Kathmandu, Nepal: World Pheasant Association, The King Mahendra Trust for Nature Conservation, and Bird Conservation Nepal.

Delacour, J. (1928) Quatrième expédition en Indochine. *L'Oiseau* 9: 257-269: 301–308.

Delacour, J. and Jabouille, P. (1925) On the birds of Quang–tri, central Annam; with notes on others from other parts of French Indo-China. *Ibis* 12: 209–260.

Dohling, L. M. and Sathyakumar, S. (2011) Relative abundance of Galliformes in Nongkhyllem Wildlife Sanctuary, Meghalaya. *NeBio* 2: 4–8.

Evans, T. and Clements, T. (2004) Current status and future monitoring of green peafowl in southern Mondulkiri. *Cambodia Bird News* 12: 18–20.

Evans, T. D., O'Kelly, H. J., Men, S., Hor, N. M., Pet, P., Pheakdey, S. and Pollard, E. H. B. (2013) Seima Protection Forest. Pp. 157–185 in T. C. H. Sunderland, J. Sayer and M. H. Hoang, eds. *Evidence-based conservation: Lessons from the Lower Mekong*. London, UK: Routledge.

Ferraro, P. J. and Pattanayak, S. K. (2006) Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLOS Biol.* 4(4) e105.

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

Ghazoul, J. and Evans, J. (2004) Causes of deforestation and forest fragmentation. *Sustainable Forestry Manage.* 4: 1367–1375.
Goes, F. (2009) The status and distribution of green peafowl *Pavo muticus* in Cambodia. *Cambodian J. Nat. Hist.* 1: 7–15.
Goes, F. and Davidson, P. (2002) Recent sightings. *Cambodia Bird News* 9: 47–59.
Gray, T. N. E., Phan, C., Pin, C. and Prum, S. (2012) Establishing a monitoring baseline for threatened large ungulates in eastern Cambodia. *Wildl. Biol.* 18: 406–413.
Green, R. E., Balmford, A., Crane, P. R., Mace, G. M., Reynolds, J. D. and Turner, R. K. (2005) A framework for improved monitoring of biodiversity: Responses to the World Summit on Sustainable Development. *Conserv. Biol.* 19: 56–65.
Gurjar, R. L., Singh, R. P. and Mishra, A. (2013) Density of the Indian peafowl *Pavo cristatus* in Satpura Tiger Reserve, India. *Podoces* 8: 12–18.
Hedley, S. L. and Buckland, S. T. (2004) Spatial models for line transect sampling. *J. Agric. Biol. Environm. Statistics* 9: 181–199.
Hernowo, J. B., Alikodra, H. S., Mardiastutti, A. and Kusmana, C. (2011) Population analysis of the javan green peafowl (*Pavo muticus muticus* Linnaeus 1758) in Baluran and Atlas Purwo National Parks, East Java. *Biodiversitas* 12: 99–106.
Innes, S., Heide-Jørgensen, M. P., Laake, J. L., Laidre, K. L., Cleator, H. J., Richard, P. and Stewart, R. E. A. (2002) Surveys of belugas and narwhals in the Canadian High Arctic in 1996. *NAMMCO Scientific Publications* 4: 169–190.
Jolli, V. and Pandit, M. K. (2011) Monitoring pheasants (*Phasianidae*) in the Western Himalayas to measure the impact of hydro-electric projects. *The Ring* 33: 37–46.
Jolli, V., Srivastav, A. and Thakur, S. (2012) Patch occupancy for cheer pheasant *Catreus wallichii* in the Great Himalayan National Park Conservation Area. *Internatn. J. Galliformes Conserv.* 2: 74–81.
Kaul, R. and Shakya, S. (2001) Spring call counts of some Galliformes in the Pipar Reserve, Nepal. *Forktail* 17: 75–80.
Kery, M., Royle, A. J. and Schmid, H. (2008) Importance of sampling design and analysis in animal population studies: a comment on Sergio et al. *J. Appl. Ecol.* 45: 981–986.
Mackenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, A. J. and Langtimm, C. A. (2002) Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83: 2248–2255.
McGowan, P. J. K., Duckworth, J. W., Xianji, W., Van Balen, B., Xiaojun, Y., Mohd, Khan, K. M., Yatim, S. H., Thanga, L., Setiawan, I. and Kaul, R. (1998) A review of the status of the Green Peafowl *Pavo muticus* and recommendations for future action. *Bird Conserv. Internatn.* 8: 331–348.
Miettinen, J., Shi, C. and Liew, S. C. (2011) Deforestation rates in insular Southeast Asia between 2000 and 2010. *Global Change Biol.* 17: 2261–2270.
Miles, L., Newton, A. C., DeFries, R. S., Ravilious, C., May, I., Blyth, S., Kapos, V. and Gordon, J. E. (2006) A global overview of the conservation status of tropical dry forests. *J. Biogr.* 33: 491–505.
Miller, D. L., Burt, M. L., Rextad, E. A. and Thomas, L. (2013) Spatial models for distance sampling data: recent developments and future directions. *Meth. Ecol. Evol.* 4: 1001–1010.
O'Kelly, H. J., Evans, T. D., Stokes, E. J., Clements, T. J., Dara, A., Gately, M., Nut, M., Pollard, E. H. B., Men, S. and Walston, J. (2012) Identifying conservation successes, failures and future opportunities; Assessing recovery potential of wild ungulates and tigers in Eastern Cambodia. *PLoS ONE* 7(10): e40482.
O'Kelly, H. J. (2013) *Monitoring conservation threats, interventions, and impacts on wildlife in a Cambodian tropical forest*. PhD thesis, Imperial College London, UK.
Pech, B., Chak, S., Ou, R., Dong, K. and Maxwell, A. (2002) *A rapid field survey of Phnom Kus Area in Mondolkiri Province*. Unpublished Report. Phnom Penh, Cambodia: Wildlife Conservation Society Cambodia Program and World Wide Fund for Nature Cambodia office.
Sukumal, N., McGowan, P. J. K and Savini, T. (2015) Change in status of green peafowl *Pavo muticus* (Family Phasianidae) inn Southcentral Vietnam: A comparison over 15 years. *Global Ecol. Conserv.* 3: 11–19.

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press

Sutherland, W. J., Pullin, A. S., Dolman, P. M. and Knight, T. M. (2004) The need for evidence-based conservation. *Trends Ecol. Evol.* 19: 305–308.

Thomas, W. W. and Poole, C. M. (2003) An annotated list of the birds of Cambodia from 1859 to 1970. *Forktail* 9: 103–127.

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

Thornton, D. H., Branch, L. C. and Sunquist, M. E. (2012) Response of large galliformes and tinamous (Cracidae, Phasianidae, Tinamidae) to habitat loss and fragmentation in northern Guatemala. *Oryx* 46: 567–576.

Timmins, R. J. and Ou, R. (2001) *The importance of Phnom Prich Wildlife Sanctuary and adjacent areas for the conservation of tigers and other key species*. Phnom Penh, Cambodia: WWF Cambodia Conservation Program.

Van Balen, S., Prawiradilaga, D. M. and Indrawan, M. (1995) The distribution and status of Green Peafowl (*Pavo muticus*) in Java. *Biol. Conserv.* 71: 289–297.

Walston, J., Davidson, P. and Men, S. (2001) *A wildlife survey of Southern Mondulkiri Province, Cambodia*. Phnom Penh, Cambodia: Wildlife Conservation Society Cambodia Program.

Winarni, N. L., Carroll, J. P., O'Brian, T. G. (2004) The application of camera traps to the study of Galliformes in southern Sumatra, Indonesia. Pp. 109–121 in R. A. Fuller, and S. J. Browne, eds. (2005) Galliformes 2004. *Proceedings of the 3rd International Galliformes Symposium*. Fordingbridge, UK: World Pheasant Association.

Wittemyer, G., Elsen, P., Bean, W. T., Coleman, A., Burton, O. and Brashares, J. (2008) Accelerated human population growth at protected area edges. *Science* 321: 123–126.

Wohlfart, C., Wegmann, M. and Leimgruber, P. (2014) Mapping threatened dry deciduous dipterocarp forest in South-east Asia for conservation management. *Tropical Conserv. Sci.* 7: 597–613.

MATTHEW NUTTALL*, VISES UNG
WCS Cambodia Program, House 21, Street 21, Sangkat Tonle Bassac, Phnom Penh, Cambodia.

MENGHOR NUT
Department of Wildlife and Biodiversity, Forestry Administration, Ministry of Agriculture, Forests, Fisheries, Royal Government of Cambodia.

HANNAH O'KELLY
WCS Laos Program, Unit 15, House No.173, Sisavath Tai Village, Chathabouly District, Vientiane, Lao PDR.

**Author for correspondence; e-mail: mnuttall@wcs.org*

Received 7 May 2015; revision accepted 12 February 2016;
Published online 23 May 2016

https://doi.org/10.1017/S0959270916000083 Published online by Cambridge University Press