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Micro-habitat selection and population recovery of the Endangered Green Peafowl *Pavo muticus* in western Thailand: implications for conservation guidance

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Summary

The endangered Green Peafowl *Pavo muticus* is one of the most threatened vertebrate species in South-East Asia and has undergone a rapid decline in both distribution and population density. The remaining populations are mostly limited to protected areas where an understanding of their ecological requirements is required to ensure that conservation management is effective. To clarify this, we investigated their population status and ecological requirements in Huai Kha Khaeng Wildlife Sanctuary, western Thailand. Line transect surveys across five sections of the Sanctuary revealed variation in population density, apparently linked to recent levels of human activity and management. Comparison of encounter rates along transects with those recorded in similar surveys conducted 21 years previously showed an increase in numbers in most of the peripheral areas of the sanctuary whilst numbers in the core area have remained stable. Using camera trapping and radio tracking to investigate habitat selection all year round, our results showed that the Green Peafowl preferred areas with an open understorey but a high percentage cover of ground vegetation. During the breeding season they preferred to cluster near streams to establish a display site, whilst in the non-breeding season they ranged more widely but still preferred areas of open understorey and high ground cover. We present some evidence of temporary avoidance of areas recently frequented by large predators (tiger and common leopard). Our results suggest that increased patrols to control hunting help to allow Green Peafowl populations to recover. We suggest that measures that allow recovery of populations of species such as Green Peafowl will ultimately enhance large predator conservation through increasing their prey base.

Introduction

Global biodiversity has decreased in the face of increasing human pressure over the past 40 years (Butchart *et al.* 2010). This is known to be particularly acute in South-East Asia where vertebrate species have shown bigger declines than in any other region (Hoffmann *et al.* 2010). Overexploitation of natural resources has contributed to the declining status of many vertebrate species (Butchart *et al.* 2010), and the establishment and management of protected areas would seem to be an essential tool to protect biodiversity loss and prevent extinction (Hoffmann *et al.* 2010).

Conservation and management action plans developed at the micro-habitat level have been shown to strongly influence bird population recovery (Reed *et al.* 2011). Therefore, understanding the components of habitat quality influencing ecological characteristics such as food availability and foraging behaviour for selected species is essential to ensure that conservation action is effective (Garabedian *et al.* 2014). Microhabitat structure is known to influence bird populations (Mallari *et al.* 2011). Changes in habitat structure as a result of natural forest succession influence the abundance and number of bird species through change in microhabitat structure (Holmes *et al.* 2001). These changes in microhabitats influence food availability, reproductive success, and predation rate.

The Green Peafowl is one of the most threatened large bird species in South-East Asia. They were uplisted from 'Vulnerable' to 'Endangered' on the IUCN Red List in 2009 (BirdLife International 2014) due to high hunting pressure and habitat disturbance that reduced and fragmented their population (McGowan *et al.* 1999, BirdLife International 2001). Formulating a recovery plan for this endangered species is hampered by the fragmented nature of the remaining population. One of the initial actions required in the recovery plan is to assess status and ecology in order to understand the species' habitat requirements, including response to habitat alteration (McGowan *et al.* 1999).

Huai Kha Khaeng Wildlife Sanctuary is part of the western forest complex in Thailand which supports the largest tiger *Panthera tigris corbetti* population in the country (DNP 2010, cited in Simcharoen *et al.* 2014). The sanctuary is also believed to hold the largest Green Peafowl population remaining in Thailand and perhaps South-East Asia (McGowan *et al.* 1999), although the population size has not been monitored and until now information on their ecology has been limited. This lack of information makes it difficult to understand how the population reacts to protection and conservation management activity and there is a need for ecological information for this species in order to inform conservation of the species elsewhere across its range.

The aims of this study, therefore, were: (1) to determine the population density of Green Peafowl in core protected forest and investigate the response of the population to different levels of protection and management activity; (2) to establish the basic habitat requirements of the Green Peafowl and identify their pattern of habitat use in both the breeding and non-breeding seasons; (3) to establish the predator community inhabiting the area used by the study species; and (4) to consider the broader implications of the findings for conservation management in order to contribute to a recovery plan for the population of the species at this site and across its range.

Study area

This study was conducted in Huai Kha Khaeng Wildlife Sanctuary, western Thailand (15°36'N 99°19'E) (Figure 1). The sanctuary is connected to Thung Yai Naresuan Wildlife Sanctuary and this Western Forest Complex is designated as a UNESCO World Heritage Site. Huai Kha Khaeng covers a total area of 2,780 km^2 within an altitudinal range of 200–1,600 m. The annual temperature range is 8-38 °C and the mean annual rainfall is 1,375 mm (Simcharoen *et al.* 2014). The dry season occurs between November to April with a mean rainfall of 298 mm, and the wet season starts in May and extends to October with a mean rainfall of 1,088 mm. The sanctuary consists of mixed deciduous forest (48%), dry evergreen forest (25%), hill evergreen forest (13%) and dry dipterocarp forest (7%) (WEFCOM 2004, Simcharoen *et al.* 2014). This study was mainly focused on mixed deciduous and dry dipterocarp forest at altitudes ranging between 170 and 385 m, reported to be the optimal habitat and elevation of the Green Peafowl (Johnsgard 1999, BirdLife International 2001). For the purposes of this study, we divided the area for data collection into five sections: north, north-east, south-east, centre, and south, based on the historical range of the Green Peafowl population in the sanctuary (Simcharoen *et al.* 1995).

Methods

Habitat use

Habitat use was defined using three methods; line transect, camera trapping, and radio tracking.

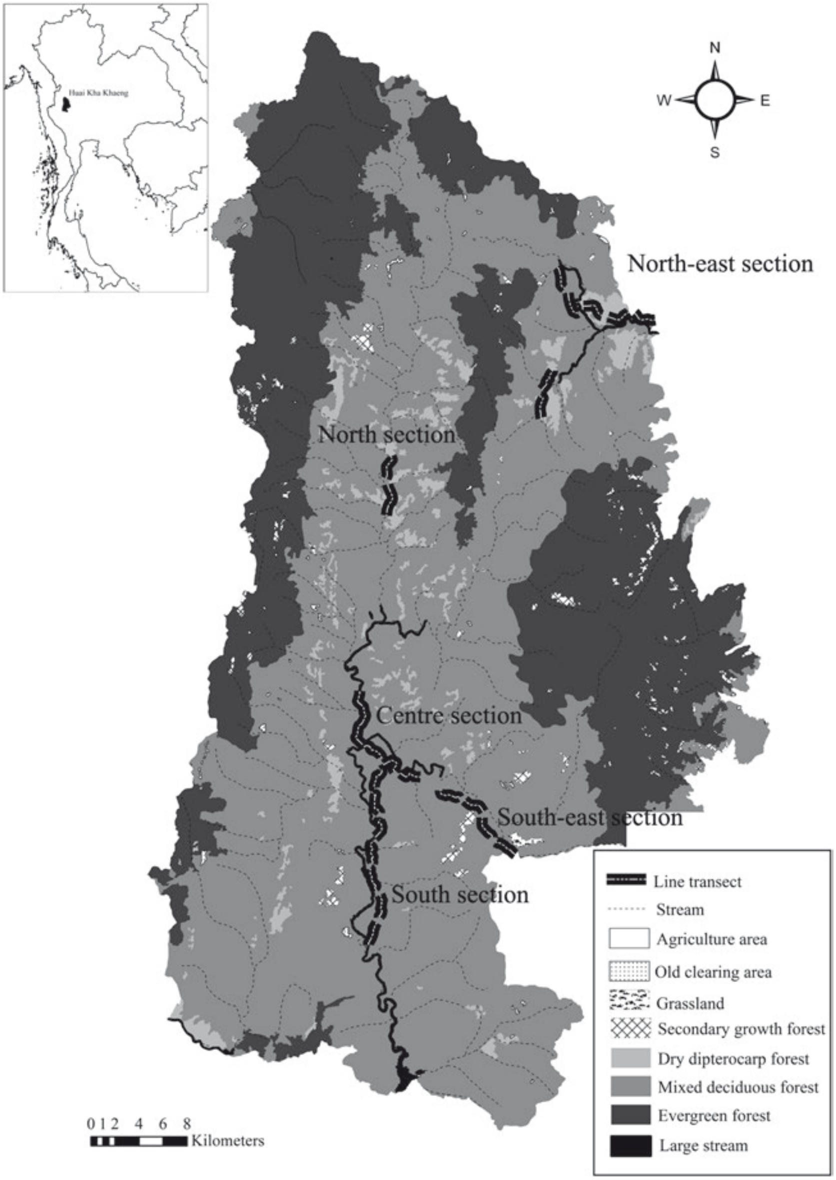

Figure 1. Map of Huai Kha Khaeng Wildlife Sanctuary showing 24 line transects covering the five survey sections. Thick black lines indicate both 2 and 5 km length transects.

Line transect surveys

In order to investigate population change in Green Peafowl since the last survey in 1992 reported by Simcharoen *et al.* (1995), we attempted to repeat their survey. Survey results in 1992 were expressed as encounter rates (calling birds/km^2), because efficient tools for measuring density (for example distance sampling techniques) were poorly developed at the time. We have taken the opportunity to provide density estimate data based on distance sampling techniques. We followed the same transects as those used in the historical survey to allow direct comparability, though we

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realise that these were not randomly located and therefore violate one of the assumptions of distance sampling. However, following Buckland *et al.* (2008) the assumption referring to the random distribution of survey points could be relaxed when habitat characteristics are too difficult. Based on the above, our density estimations should therefore be treated with caution.

Density was estimated using line transects set along accessible roads (forest interior) and streams during three breeding seasons (February–March 2013, January–March 2014, and January 2015) when the birds frequently call (Ponsena 1988a, Brickle *et al.* 1998, Johnsgard 1999) (Figure 1). Transects covered five sections of the sanctuary: north (two 2-km transects), north-east (seven 2-km transects), centre (five 2-km transects and one 5-km transect), south-east (four 2-km transects) and south (five 2-km transects) (Figure 1). Vocal and visual records were recorded within 1 km on both sides of the transect (calls beyond 1 km were excluded). A minimum number of 60–80 detections at each transect was deemed to be suitable for distance sampling analysis (Buckland *et al.* 2001). Each transect was walked six times (twice a day for three consecutive days). We increased effort to 10 times (twice a day for a total of five consecutive days) where there were fewer than 60 detections. This replication was used in order to reach the generally recommended minimum number of detections (60–80 but as few as 40 might be adequate) at each section which will allow a good level of precision in the density estimation (Buckland *et al.* 2001). Each transect was walked by different observers during the daily peak calling period (06h30–08h30 in the morning and 16h45–18h45 in the evening) (Sukumal *et al.* 2015). Before data collection started, all observers conducted a preliminary survey together to standardise estimates of distance to calling birds in order to minimise errors between observers (Buckland *et al.* 2001). The distance to each calling bird was assigned to 100 m distance categories or 50 m distance categories for closer records.

Camera trapping

Micro-habitat selected by Green Peafowl was investigated using camera traps across different habitat characteristics. Camera trapping was carried out at two sites: i.) In the north-east section of the sanctuary (Hor Ton Pueng) where the Green Peafowl population has recovered during the past 10 years, and ii.) in the centre section (Khao Ban Dai) where the population is believed to have remained stable over the last 10 years and where the last remaining population persisted when disturbance in the sanctuary was high (during 1988) (Figure 2). Camera trapping at each site was conducted within the breeding (November to March) and non-breeding (April to October) seasons in both areas: north-east section July–October 2012 (non-breeding season, 1,563 trap nights) and November 2012–February 2013 (breeding season, 1,580 trap nights); centre section April–August 2013 (non-breeding season, 2,811 trap nights) and December 2013–April 2014 (breeding season, 2,585 trap nights). Thirty-five camera trap locations were set in each section (70 locations in total). Camera trap locations were set across a grid, using the stream as the centre (10 locations at each site) to determine the extent to which the Green Peafowl used habitats alongside the stream in both the breeding and non-breeding seasons. Two further lines of traps were set at a distance of 350 m (11 locations at each site) and 700 m (14 locations at each site) away from the stream on both sides (Figure 2). This distance was based on the ranging behaviour of a radio-collared male studied by Ponsena (1988b) who determined that the distance between ranging edge and stream during the breeding season (January–March) was on average 350 m. The interval between each camera trap location was at least 350 m and one camera trap was set at each location. Camera traps were mounted on tree trunks at a height of 65 cm. We used passive infrared cameras with flash. Cameras were programmed to run continuously (24 hours a day) for at least 20 days and take three consecutive pictures per trigger with a one-minute delay between triggers.

At each camera trap location, a circular plot was established for vegetation analysis which was carried out when camera traps were set. Within a radius of 10 m of each plot, the percentage of grass and/or ground vegetation cover was estimated by recording presence/absence at every 1-m distance in 8 directions (north, north-east, east, south-east, south, south-west, west, and north-west), and calculating as a presence percentage within a 10 m radius. Within a 20 m radius,

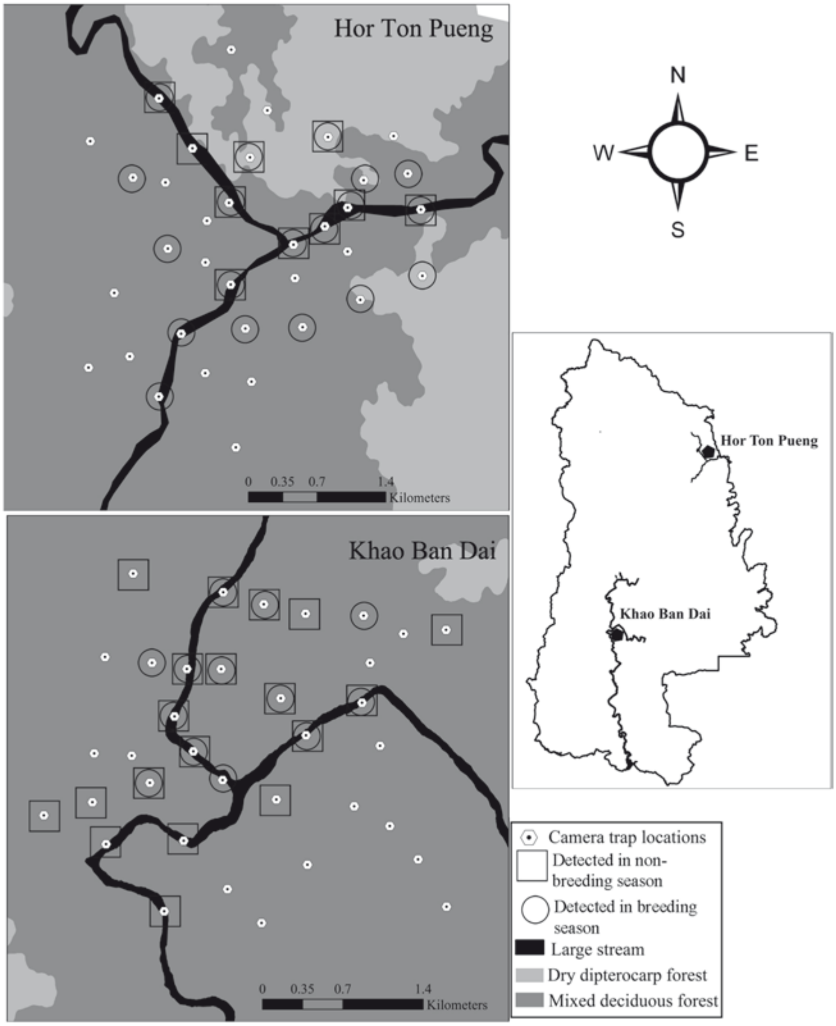

Figure 2. Camera trap locations in north-east and centre sections of the Wildlife Sanctuary. Camera traps were set in a grid pattern with the stream at the centre and lines at 350 and 700 m from the stream. Squares indicate locations where Peafowl were detected in the non-breeding season, circles indicate locations where they were detected in the breeding season.

trees with DBH < 5 and > 5m were counted to estimate their density. The percentage cover of understorey vegetation and canopy cover were estimated in each plot. The percentage cover of understorey vegetation was estimated by using a 2-m PVC pipe which was painted with two colours in 20 blocks (10 cm per block). One observer held the PVC pipe horizontally at 1 m height and stood at every 5 m distance in 4 directions (north, east, south, and west) while another observer stood at the centre to record the number of blocks that were obscured by vegetation at different distances. The number of obscured was calculated as a percentage cover of understorey vegetation in the area. The canopy cover was estimated by recording presence/absence of canopy cover at every 5 m distance in 4 directions (north, east, south, and west), and calculating as a presence percentage within 20 m radius. The distances from camera trap locations to the nearest stream were estimated using ArcGIS 10.3 software.

Radio tracking

Additional data on micro-habitat selection were collected using radio tracking. Bird capture was attempted during the breeding season when males set their small territories around well-known display sites. During 10 to 15 days per month, 20–30 leg snare traps (Winarni *et al.* 2009, Sukumal *et al.* 2010) were set on the ground around the display site and checked constantly. Once caught, birds were removed from the traps as soon as possible to avoid injury and reduce stress. On capture, a bird was fitted with a necklace-mounted radio-collar model RI-2B made by Holohil Systems Ltd. The collar weighed 15 g with a life span of 24 months. Collar weight ranged between 0.3 and 0.4% of the reported male body weight (3,850–5,000 g, Johnsgard 1999) which is well below the recommended limits set by radio collaring protocols (≤ 3% is generally considered adequate) (Ministry of Environment, Lands and Parks Resources Inventory Branch for the Terrestrial Ecosystems Task Force Resources Inventory Committee (1998).

Five locations two hours apart for the collared bird were collected on 14 consecutive days per month. Locations were collected at least two hours apart to ensure independence, based on a previous study of Siamese Fireback *Lophura diardi* where two hours was regarded as sufficient to eliminate any potential disturbance generated from the previous observation (Sukumal *et al.* 2010). In total 45 radio locations of the tagged bird in the breeding season (January–March) and 68 radio locations in the non-breeding season (April–November) were used to estimate the range size for the two seasons. The characteristics of the micro-habitat used by the radio-collared bird were estimated by taking each radio location as the centre of a 20-m radius vegetation plot, and taking the same vegetation measurements as those used for camera trap plots (as described in the previous section above). The distance of each location to streams was estimated using ArcGIS 10.3 software. In order to provide a suitable comparison with overall habitat availability, we compared habitat characteristics at radio locations with those at camera trap locations from the north-east section, as these camera trap locations were representative of the available habitat across the whole range of the radio-collared bird (Figure 3).

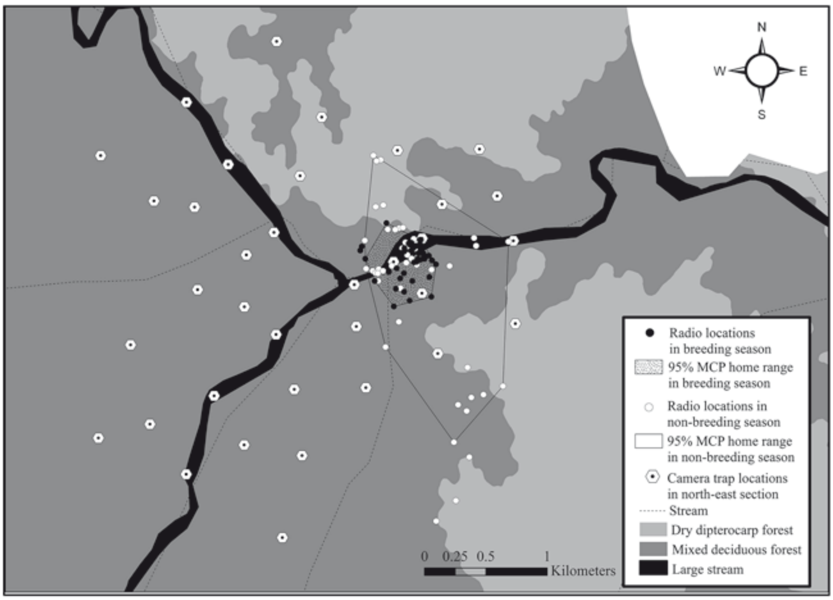

Figure 3. Radio locations and range size of the radio-collared Peafowl compared with camera trap locations in the north-east section of the Wildlife Sanctuary. The white spots and open polygon indicate the locations and home range size during the non-breeding season, the black spots and stippled polygon indicate the locations and home range size during the breeding season.

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Data analysis

Density estimation was obtained using DISTANCE version 6.0 from 24 line transects (Thomas *et al.* 2010). Separate analyses were done for the five sections by pooling the detections from the different transects within each section. Double counting of the same bird by the observers during the survey was avoided by excluding records likely to be of the same bird based on direction and distance from transect of each call to avoid overestimation. Detections were derived from aural records of calling birds. We excluded visual detection due to lack of data and to standardise the detection probability before conducting the analysis. The data were truncated to remove outliers before conducting the analysis. All key functions of uniform, half-normal, hazard, and negative exponential with all series adjustment of cosine, simple polynomial, and hermite polynomial were examined to select the best detectability function and model with lowest AIC following Buckland *et al.* (2001).

To investigate the relationship between Green Peafowl density and habitat type, we classified the habitat type within the transect area by creating a 1-km buffer either side of each transect. The buffer polygon was created using ArcGIS 10.3 program. The correlation between mean numbers of calling birds per survey along each transect and the area of each habitat type was examined using spearman correlation. The GIS database was derived from the Western Forest Complex Ecosystem Management Project, Department of National Parks, Wildlife and Plant Conservation (WEFCOM 2004).

A generalized linear model (GLM) with logit links and binomial error distributions was used to study the relationship between a given variable and habitat use. Camera trap data from the two sites were analysed using the presence/absence of Green Peafowl as the response variable. The predictor variables were ground vegetation coverage, understorey vegetation cover, canopy cover, understorey vegetation (DBH < 5 cm) density, tree (DBH > 5 cm) density and distance to stream. All predictor variables were checked for correlation; variables that were highly correlated ($r > 0.5$) with other variables were removed. Each percentage predictor variable was arcsine transformed (Sokal and Rohlf 1995) and the continuous predictor variable was standardised by dividing the values by twice the standard deviation (Gelman 2008) in order to transform the data to the same scale. The best model was selected based on the lowest Akaike's Information Criterion (AIC) value (Burnham and Anderson 1998). The analysis was conducted using program R (R Development Core Team 2014). Analysis of breeding and non-breeding season data was carried out separately.

The habitat selection pattern from the single radio-collared bird was investigated using a generalized linear model (GLM) with logit links and binomial error distributions. Radio locations of the tagged bird at two hour intervals ($n = 45$ in breeding season and $n = 19$ in non-breeding season) and camera trap locations from the north-east section ($n = 35$) were used as the response variables. The predictor variables were ground vegetation cover, canopy cover and distance to stream. All predictor variables were transformed to the same scale before analysis. Ranging size was estimated using 95% minimum convex polygons (MCP). The analysis was conducted in ArcGIS 10.3. The analysis of habitat selection pattern and ranging size was separated between breeding and non-breeding seasons.

In the north-east section, where one male was collared, we compared microhabitat variables between radio location and camera trap location for both breeding and non-breeding seasons. To investigate a correspondence of those variables, non-parametric Mann-Whitney *U*-tests were used.

To investigate the impact of the presence of predators, we focused on large predator species (tiger *Panthera tigris* and common leopard *P. pardus*) as this group of predators are known to attack adult birds (Johnsgard 1999). Using Mann-Whitney *U*-tests, we compared the median time between Green Peafowl pictures (from a minimum of one hour) for locations without records of large predators with those where large predators had been recorded.

Results

Density estimation and relation to habitat types

Density estimates for calling male Green Peafowl are shown in Table 1. We also attempted to assess population change during the past 21 years by comparing our data with historical data from

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Table 1. Density estimates for the Green Peafowl in Huai Kha Khaeng Wildlife Sanctuary during the breeding season. Data are based on line transect surveys conducted in February-March 2013, January-March 2014, and January 2015.

Sites	Number of transects	Total length (km)	Survey effort (time of observations)	Density estimates (calling birds/km²)	95% confidence intervals	Number detected
North (Yang Dang)	2	4	10	2.89	0.426–19.654	37
North-east (Head Quarter)	7	14	70	4.834	1.671–13.983	557
South-east (Huai Mhae Dee)	4	8	40	1.13	0.359–3.554	67
Centre (Khao Ban Dai)	6	15	56	1.142	0.270–4.827	88
South (Huai Mod Dang)	5	10	30	11.343	4.287–30.008	520

a study using line transects in Huai Kha Khaeng by Simcharoen *et al.* (1995) in 1992. This historical survey measured the total number of birds/total length of transect, as distance sampling techniques at that time were poorly developed. By considering only encounter rates that do not account for detection probability between two periods, we therefore compared number of calling birds/km from the historical survey with our current survey as a proxy index of relative abundance. The numbers of Green Peafowl recorded in this study were significantly different ($\chi^2 = 114.0128$, $P < 0.0001$) and higher compared with the survey carried out in the Sanctuary in 1992 (Figure 4).

There was a significant positive correlation between water body area and mean number of calling males recorded on each transect ($r_s = 0.405$, $P = 0.049$) (Figure 5). However, this correlation was only just statistically significant and therefore the conclusion that the species prefers calling near rivers should be treated with caution and we would recommend further investigation to corroborate. Other habitat variables were not significantly correlated.

Habitat selection in the non-breeding season

Green Peafowl were detected at 30 out of a total of a total of 70 camera trap locations during the non-breeding season (Figure 2). The model shows that understorey vegetation (DBH < 5 cm) density ($\beta = -3.276$, $P < 0.05$) and distance to stream ($\beta = -2.817$, $P < 0.05$) were significantly

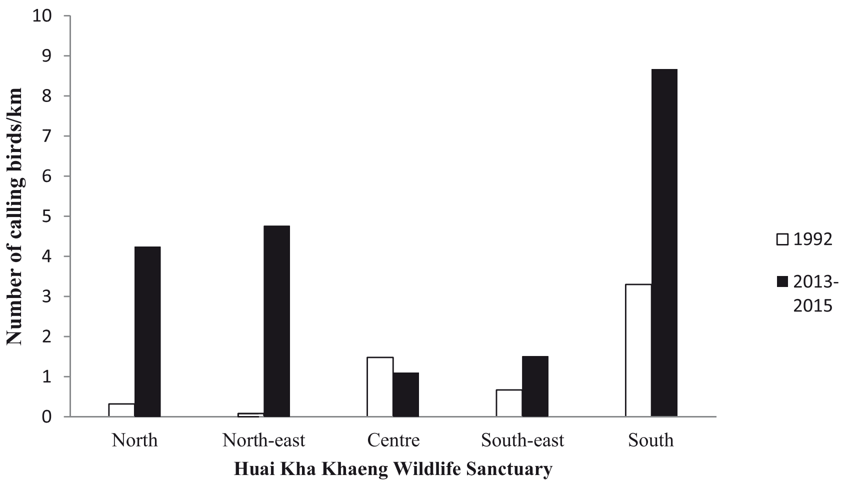

Figure 4. Comparison between the number of calling birds/km recorded along line transect surveys in 1992 (Simcharoen *et al.* 1995) and 2013–2015 (this study).

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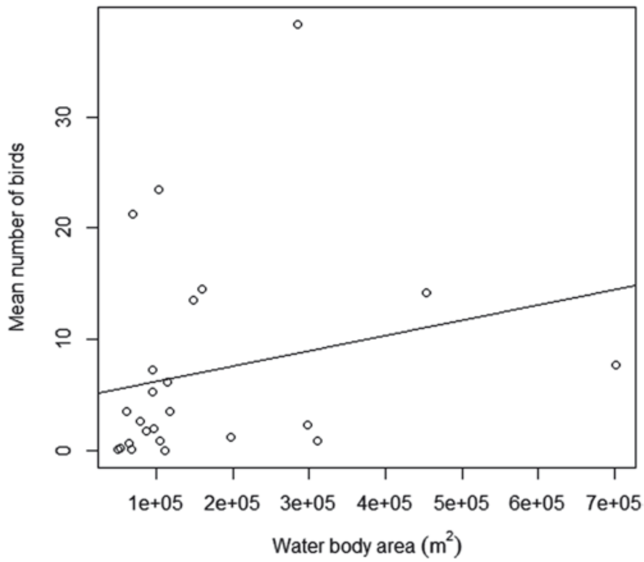

Figure 5. Relationship between the mean number of calling birds from each transect and the water body area (m^2) inside the survey effort area of each transect.

correlated with the presence of Green Peafowl in the area. The birds were mostly found in the area with more open understorey vegetation close to streams (Table 2, Figures 7a and 7b).

Habitat selection of the single radio-collared bird was investigated by comparing the habitat characteristics at radio locations with available habitat of camera trap locations where radio-collared birds were not detected. The model showed that only ground vegetation cover had a significant influence on habitat selection ($\beta = 3.054$, $P < 0.001$), although caution should be applied to this result as the data are from a single bird and therefore all observations are pseudo-replicates. Nevertheless, the results suggest that the radio-collared bird was more likely to use the area with high cover of ground vegetation during the non-breeding season (Table 2 and Figure 7c) and the bird had a larger home range during the non-breeding season (177.23 ha) than during the breeding season (25.72 ha) (Figure 3). Radio locations were sited in areas of higher coverage of ground vegetation than camera trap locations (Mann-Whitney U-test, $w = 25$, $P < 0.0001$).

Habitat selection in the breeding season

From 70 camera trap locations, 32 locations detected the Green Peafowl (Figure 2). The model shows that only distance to stream significantly influenced ($\beta = -1.433$, $P < 0.05$) the presence of Green Peafowl in the area, whereby peafowl were more likely to be detected nearer the stream than further away (Table 2 and Figure 7d).

Habitat selection by the radio-collared bird also showed a similar pattern with distance to stream having a significant influence on location of this bird ($\beta = -4.593$, $P < 0.005$). This radio-collared bird was mostly detected close to the stream (Table 2 and Figure 7e). The ranging investigation (January–March 2014) showed that the range size of the radio-collared bird was 25.72 ha which clustered in a small area around the stream (Figure 3).

However, distance to stream was significantly different between radio locations and camera trap locations where the bird was present (Mann-Whitney U-test, $w = 287$, $P < 0.005$), with radio locations being closer to the stream than camera trap locations.

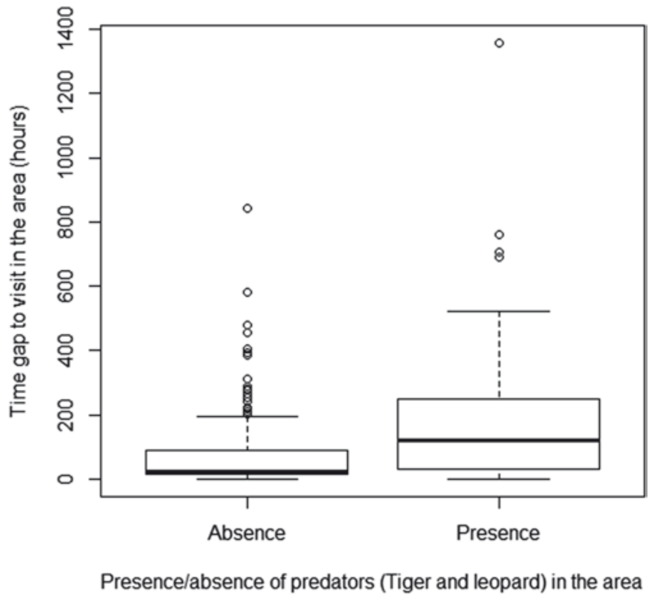

Figure 6. The median time between Green Peafowl pictures (from a minimum of one hour) for locations without records of large predators (tiger and leopard) compared with those where large predators had been recorded.

Interaction with predators

The camera trap data showed a high area of overlap between Green Peafowl and tiger and leopard pictures. The median time between Green Peafowl pictures (from a minimum of one hour) for locations without records of large predators was significantly shorter than for those after large predators had been recorded (Mann-Whitney *U*-test, $w = 2583$, $P < 0.0001$) (Figure 6), suggesting that Green Peafowl might change their behaviour and avoid areas frequented by large predators for some time after the predator had passed.

Discussion

This study has provided information on basic ecology and population status of endangered Green Peafowl in a well-protected area of South-East Asia. Data from both radio tracking of a single individual and systematic camera trapping surveys revealed that during the non-breeding season (April–October), the species mostly selected more open understorey vegetation with high ground cover. This habitat characteristic was mostly found close to streams but can also be present in mature forest far from streams. Both data collection methods also revealed that during the breeding season (November–March), the birds spent most of their time occupying the area close to streams. The presence of large predators, as indicated by camera trap records, reduces the movement of Green Peafowl past camera traps within their range. Monitoring of change in numbers compared with available historical data indicated that the number of Green Peafowl which were encountered in our study area in Huai Kha Khaeng Wildlife Sanctuary has increased during the past 21 years.

Density

In order to monitor long term changes in the Green Peafowl population at each section of the sanctuary, we located our survey transects based on the location of the different historical surveys.

Table 2. Parameters of the habitat selection model from camera trapping and radio-telemetry in non-breeding and breeding seasons.

Parameters	β	z-value	p-value
Non-breeding season			
Camera trapping (AIC = 62.054)			
(Intercept)	0.622	0.553	0.580
Understorey vegetation (DBH<5cm) density	-3.276	-2.148	0.032*
Tree (DBH>5cm) density	-2.625	-1.687	0.092
Ground vegetation cover	2.505	1.833	0.067
Canopy cover	0.662	0.455	0.649
Distance to stream	-2.817	-2.243	0.025*
Radio-collared bird (AIC = 95.933)			
(Intercept)	-1.338	-1.257	0.209
Ground vegetation cover	3.054	3.472	<0.001***
Canopy cover	-1.594	-1.902	0.057
Distance to stream	-0.257	-0.397	0.691
Breeding season			
Camera trapping (AIC = 96.476)			
(Intercept)	1.054	1.667	0.095
Understorey vegetation (DBH<5cm) density	-0.531	-0.793	0.428
Tree (DBH>5cm) density	-0.188	-0.276	0.783
Ground vegetation cover	0.322	0.582	0.560
Canopy cover	-0.258	-0.439	0.660
Distance to stream	-1.433	-2.032	0.042*
Radio-collared bird (AIC = 52.720)			
(Intercept)	-1.105	-1.500	0.134
Ground vegetation cover	0.130	0.163	0.871
Canopy cover	-0.539	-0.613	0.540
Distance to stream	-4.593	-0.397	<0.005**

$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.0001$

The main area surveyed in 1992 was located along the Huai Kha Khaeng River as this area was known for a long time to host the last remaining population of Green Peafowl. Therefore we decided to run a 5-km transect along the river. We are aware, however, that the non-random location of this transect might violate important assumptions of distance-based data and might generate a bias in the results as rivers have been reported to show high densities of this species. Despite this, our results in this area do not show a particularly high density perhaps because when using vocal instead of visual detection, we can record animals as far as 1 km from the river which might not use it in their range. As we present separate densities for each of the five sections in our study we suggest that if there was any bias due to one of the transects being located along the river this should not seriously undermine overall estimates found in this work. Moreover, part of this study focuses on the monitoring of population change over time through a comparison of the number of calling birds/km with the historical survey using the same locations. Some of the transects in this study were located along roads but these roads did not provide a structural barrier to the birds because they are relatively narrow (2–3 m) and very seldom used by vehicles (during 10 surveys over five days not more than two vehicles were encountered).

Our data appear to show that the Green Peafowl population in the Huai Kha Khaeng Wildlife Sanctuary has increased over the past 21 years, compared with data collected in 1992 (Simcharoen *et al.* 1995). The higher estimated density between surveys was determined in the peripheral south, north and north-east sections of the Sanctuary, whilst populations in the central core zones appear to have remained stable (Figure 4). In 1989, the logging concession in the southern part of the sanctuary was stopped due to the importance of this area for the 'Endangered' wild water buffalo *Bubalus arnee*, which has here one of the four remaining populations in South-East Asia

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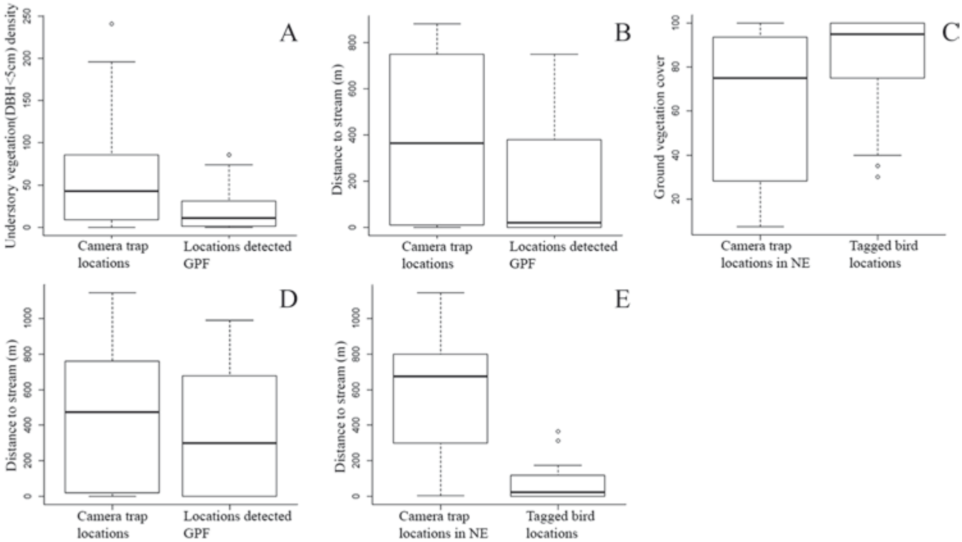

Figure 7. The comparison in non-breeding season of understorey vegetation (DBH < 5cm) density and distance to stream between total camera trap locations and locations where we detected Green Peafowl (GPF) (a and b), ground vegetation cover between total camera trap locations in north-east section (NE) and radio locations of tagged bird (c), and comparison in breeding season of distance to stream between total camera trap locations and locations where we detected Green Peafowl (d), distance to stream between total camera trap locations in north-east section (NE) and radio locations of tagged bird (e).

(IUCN-SSC Asian Wild Cattle Specialist Group 2010) and the Green Peafowl, which has here the only known remaining population for the sanctuary soon after logging was banned. In the north-eastern section the human populations of the villages were moved out in 1991 to reduce disturbance to wildlife (Simcharoen *et al.* 1995). During the past 21 years, the sanctuary has also seen a significant increase in the frequency of patrolling activity which covers the whole area of the sanctuary. These management activities in the area have decreased hunting pressure and are believed to have improved the populations of species such as banteng *Bos javanicus*, tiger and Green Peafowl. Our survey data would appear to confirm this for Green Peafowl.

It is still unclear whether the population recovery is the result of an expansion from the known remaining population along the Huai Kha Khaeng river or whether there were smaller unknown source populations remaining in unsurveyed areas of the Sanctuary. Elsewhere, a large decline in population density over 15 years has been reported in Yok Don National Park, south-west Vietnam, despite a large patch of suitable habitat remaining. Here it is believed that the population decreased due to increased levels of human disturbance and hunting pressure (Sukumal *et al.* 2015). Our results from Huai Kha Khaeng appear to demonstrate a recovery in the population of this species following a reduction in disturbance and hunting.

Microhabitat

The comparison of variables influencing habitat selection in both the breeding and non-breeding seasons show differences between areas investigated using radio locations and camera trap locations. Those results might be due to the fact that camera trap locations covered a larger area and represent the habitat selected by several birds, while radio locations were from a single radio-collared male inhabiting a relatively small area.

Most surveys are carried out during the breeding season when birds make frequent calls that are easy to detect (Brickle 1998, Bezuijen *et al.* 2008). Consequently, the results point out the importance of water sources where birds are mostly detected (Brickle 1998, Bezuijen *et al.* 2008). Studies in the non-breeding season have been limited as the birds have a low calling rate and are more cryptic in their behaviour which makes them difficult to detect.

From camera traps set across a grid running at right angles to a stream, our data from both camera trapping and radio telemetry have shown that during the breeding season Green Peafowl are mostly detected in areas around larger water bodies. A single radio-collared male showed a cluster of radio locations close to water bodies and this was supported by camera trap locations where the bird was present. This is consistent with the view that Green Peafowl aggregate close to water bodies in the breeding season where they use open areas for their display sites and to enhance territorial proclamation (Johnsgard 1999). However, we have presented evidence that during the non-breeding season Green Peafowl range more widely and utilise a mosaic of open areas and grassland patches in open forest habitat (dry dipterocarp or deciduous forest) (Figure 3 and Table 2), often away from water bodies. We have shown a preference for high cover of ground vegetation that might provide a variety of food in the area (Ponsena 1988b). Agricultural areas adjacent to protected areas may also provide similar conditions and account for records of Green Peafowl in cultivated areas (Johnsgard 1999), though this requires further investigation.

The diet of the Green Peafowl has been reported as mostly plant material such as seeds, buds and young shoots of grasses (*Daclyoctenium aegytium*, *Apluda mutica*, *Sorghum nitidum*, *S. halepense*, *Eragrostis diplachnoides*, etc.) that are found in high abundance and coverage in the ground layer of open areas within its habitat (Ponsena 1988b). This is consistent with our finding that the species prefers more open habitat with a high cover of ground vegetation. This characteristic can be found close to water sources but also in open forest away from water.

Predation

This study was conducted in a sanctuary with very high wildlife protection mostly targeting the large resident tiger population and its preferred prey. The efficiency of those activities results in the area containing the highest tiger population in Thailand (Simcharoen *et al.* 2007, 2014) as well as substantial populations of other threatened species such as banteng and wild water buffalo (IUCN-SSC Asian Wild Cattle Specialist Group 2010). The main predators of adult Green Peafowl have been reported as big cat species (Johnsgard 1999), medium sized carnivores such as civets and probably also common mongoose *Herpestes edwardsii*, jungle cat *Felis chaus* and feral dogs *Canis familiaris*. The small and medium sized carnivores that were observed in our study site include the yellow-throated marten *Martes flavigula*, Asian golden cat *Pardofelis temminckii*, dhole *Cuon alpinus*, golden jackal *Canis aureus*, common palm civet *Paradoxurus hermaphroditus*, large Indian civet *Viver razibetha*, large spotted civet *V. megaspila*, and small Indian civet *V. indica*. This carnivore guild could be considered potential predators of peafowl chicks and roosting adults.

During fieldwork for this study we observed a leopard attempting to hunt Green Peafowl (N. Sukumal pers. obs.), and a similar event was also reported by the ranger during patrols in the Sanctuary. On the other hand, a tiger was observed in close proximity to a group of foraging peafowl but no hunting attempt was made and no disturbed behaviour was observed in the birds (N. Sukumal pers. obs.). The highest density of Green Peafowl was recorded in areas with the greatest recent human disturbance where numbers of large predators are very low or absent. Moreover, camera trap results show that the presence of large predators (tiger and leopard) negatively influence the movement of Green Peafowl which avoid areas where predators are active. Therefore the presence of large predators can lead, at least temporarily, to a low density of Green Peafowl. It is interesting to note that the population density of Green Peafowl in the core area remains low (Figure 4) whilst our camera trap data detected the highest number of tiger (nine individuals, 128 independent events from 43 locations) and leopard (not possible to determine the number of individuals from camera trap photos but 35 independent events were detected from 25 locations). This compares with only three individual tigers (18 independent events from 14 locations) and fewer records of leopard (13 independent events from 9 locations) in the north-east section (N. Sukumal unpubl. data) where Green Peafowl density was substantially higher. It is possible that high density of large predators in the core area could depress density of peafowl which instead expand in the peripheral areas of the sanctuary. In time, this could represent an increase in the prey base which might support higher densities of large predators in due course.

The association with other wildlife species also needs to be considered, for example large herbivore species such as banteng that are mostly found in the same habitat as Green Peafowl in our study site. It is possible that the occurrence of this large herbivore could lead to the natural maintenance of open understorey vegetation, thus influencing habitat suitability for Green Peafowl (Sukumal *et al.* 2015). This requires further investigation.

Implications for conservation management

We have provided evidence of an increasing population of Green Peafowl in the Huai Kha Khaeng Wildlife Sanctuary associated with higher levels of protection in areas of the Sanctuary where disturbance and hunting pressure has been reduced through removal of human populations and a regular patrolling system over a large area. This contrasts with the decline over the past 15 years recorded in an existing patch of relatively good quality habitat in the Yok Don National Park in Vietnam where there is no effective management and disturbance from human activities such as illegal logging, excessive fire and cattle grazing and high hunting pressure has increased (Sukumal *et al.* 2015). This would seem to suggest that current management at Huai Kha Khaeng is working.

Our results have also revealed that Green Peafowl require habitat characterised by an open understorey but high coverage of ground vegetation, both near water courses (favoured during the breeding season) and in the wider forest away from water courses (important during the non-breeding season). Habitat protection and management for Green Peafowl should therefore focus on the areas showing these characteristics in the natural habitat. The priority action plan therefore should focus on protecting open patches with high ground vegetation coverage which is the foraging and breeding area for Green Peafowl and also for large herbivore species such as banteng, Asian elephant *Elephas maximus* and sambar *Rusa unicolor*.

In Huai Kha Khaeng Wildlife Sanctuary, the north-east section is connected to agriculture areas and a forest buffer zone area where villagers are allowed to collect non-timber forest products. This area is vulnerable to fire caused by the high level of human activities in the area, and this can spread into the sanctuary and become difficult to control. The establishment of a fire break around this area might relieve expansion of fire into the Sanctuary.

Forest fires, observed yearly during the dry season in many dry forest areas in South-East Asia, can have a negative effect on wildlife populations, especially ground dwelling species such as Green Peafowl (Sukumal *et al.* 2015). To mitigate this, prescribed burning is sometimes conducted to relieve excessive fire fuel accumulation within protected areas as well as fire expansion from outside. However, prescribed burning should be avoided during the nesting period for ground-nesting birds (for Green Peafowl between January-March; N. Sukumal pers. obs.) but rather be conducted earlier in the season depending on different of reproductive periods in each region. Moreover, the establishment of fire breaks around nesting and foraging habitat can be an optional solution, which requires human management by controlling and limiting fire expansion into this habitat. The agricultural areas adjacent to the sanctuary in the north-east and south-west sections may be important to the peafowl and they have been reported to use this area for their foraging and display sites especially during the breeding season (N. Sukumal pers. obs.). In these areas pesticide use needs to be controlled and intrusion of agriculture into the forest edge prevented through raising awareness of the needs of wildlife. Control of illegal hunting through continued patrols is also necessary.

The north, west and south sections of sanctuary are adjacent to other protected areas including, the Thung Yai Naresuan (East) Wildlife Sanctuary in the west and the Khuean Srinagarindra

National Park in the south. Further studies are needed to determine whether these provide a network of interconnected Peafowl populations.

The relationship between Green Peafowl and large herbivore species such as banteng requires further investigation as they are mostly found in association with the same habitats. Indeed, banteng could play an important role in maintaining the preferred conditions for Green Peafowl. Restoration of this ecosystem may therefore require maintenance of the wildlife community associated with these habitats. In the northern section of Huai Kha Khaeng where it is connected to Mae Wong National Park, natural expansion of the Green Peafowl population may be prevented by the geographic barrier of a mountain range. Here a reintroduction programme has been set up to restore the population of Green Peafowl in Mae Wong National Park. However, a preliminary survey in the area revealed very low numbers of Green Peafowl (N. Sukumal pers. obs.) and a habitat comprising dense, tall grass and herbs in the understorey. This habitat characteristic might limit the recovery of the Green Peafowl population in the area. It will be important to investigate the reasons for the differences in habitat structure at this site before reintroduction is attempted. If Green Peafowl population recovery is to be successful at this site, it might be necessary to open the understorey level either through human management or restoring the natural grazing community including wild cattle or other wild herbivores. This aspect could be used as the basis for experimental work looking at the simultaneous reintroduction of both peafowl and large herbivore species. Restoration of wildlife communities in specific habitats could help generate and maintain the ecosystem in the long term.

Several species of Galliformes have been shown to respond well to reductions in hunting pressure and it would seem from our results that Green Peafowl are no exception. A primary conservation objective at Huai Kha Khaeng is the increase of populations of large predators, especially tiger and leopard. For this to happen, it is necessary for populations of their prey animals to recover: so conservation action that improves population density of species such as Green Peafowl will also have a beneficial effect on populations of large predators.

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