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Living with human encroachment: Status and distribution of Green Peafowl in northern stronghold of Thailand

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ABSTRACT

Green Peafowl have declined significantly across much of their historical range mostly due to habitat loss and degradation following intensive agricultural expansion, logging and infrastructure development. In Thailand, two strongholds remain, in the west and the north. While the western stronghold has been extensively investigated and is well protected, the status of the species in the northern stronghold remain unknown. This stronghold is distributed over at least four contiguous protected areas surrounded by agricultural landscapes, where conflict with farmers has recently been reported. The aims of this work are to 1) investigate the species' status in this northern stronghold, 2) define the species' habitat use within and outside protected areas, and 3) to provide management suggestions for the species' long-term survival. Our results showed a high probability of species occurrence (>0.5) in the stronghold within the four protected areas. Using Distance sampling over 54 transects, 2 km long, located in the interior, edge and agriculture landscape, we estimated a density of 15.82 calling males/km^2 over the whole stronghold with densities ranging from 13.55 to 19.89 calling males/km^2 in the four protected areas separately. A general linear models showed that species distribution was affected positively by dry dipterocarp forest, the main species' habitat over its range, and negatively by human settlements. A higher number of the species was predicted within the protected areas than outside, highlighting the significance of the protected contiguous forest patches in the stronghold for the long-term conservation of the species combined with the supporting agro-ecotourism through the species existence in the surrounding agricultural landscapes. Beside protected areas management, cooperation by local communities has to be included in any conservation program to avert human-wildlife conflict.

1. Introduction

Over the past decades, Southeast Asia has seen its rich biodiversity collapse primarily due to habitat loss following agricultural and infrastructural expansion (Sodhi et al., 2009). Agricultural expansion causes widespread habitat loss and degradation, mostly through fragmentation and edge effects (Laurance et al., 2014) forcing resident wildlife into closer contact with humans (Scanes, 2018). This forced interaction between humans and wildlife can result in active conflict with adverse consequences that lead to wildlife decline and

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eventual extinction from important parts of their distribution ranges (Nyhus, 2016), focusing on identifying critical drivers and defining short- and long-term spatiotemporal solutions, and different conceptual models and frameworks for managing resource use and coexistence have been proposed (König et al., 2020), but limited studies are available for smaller species, particularly in the region.

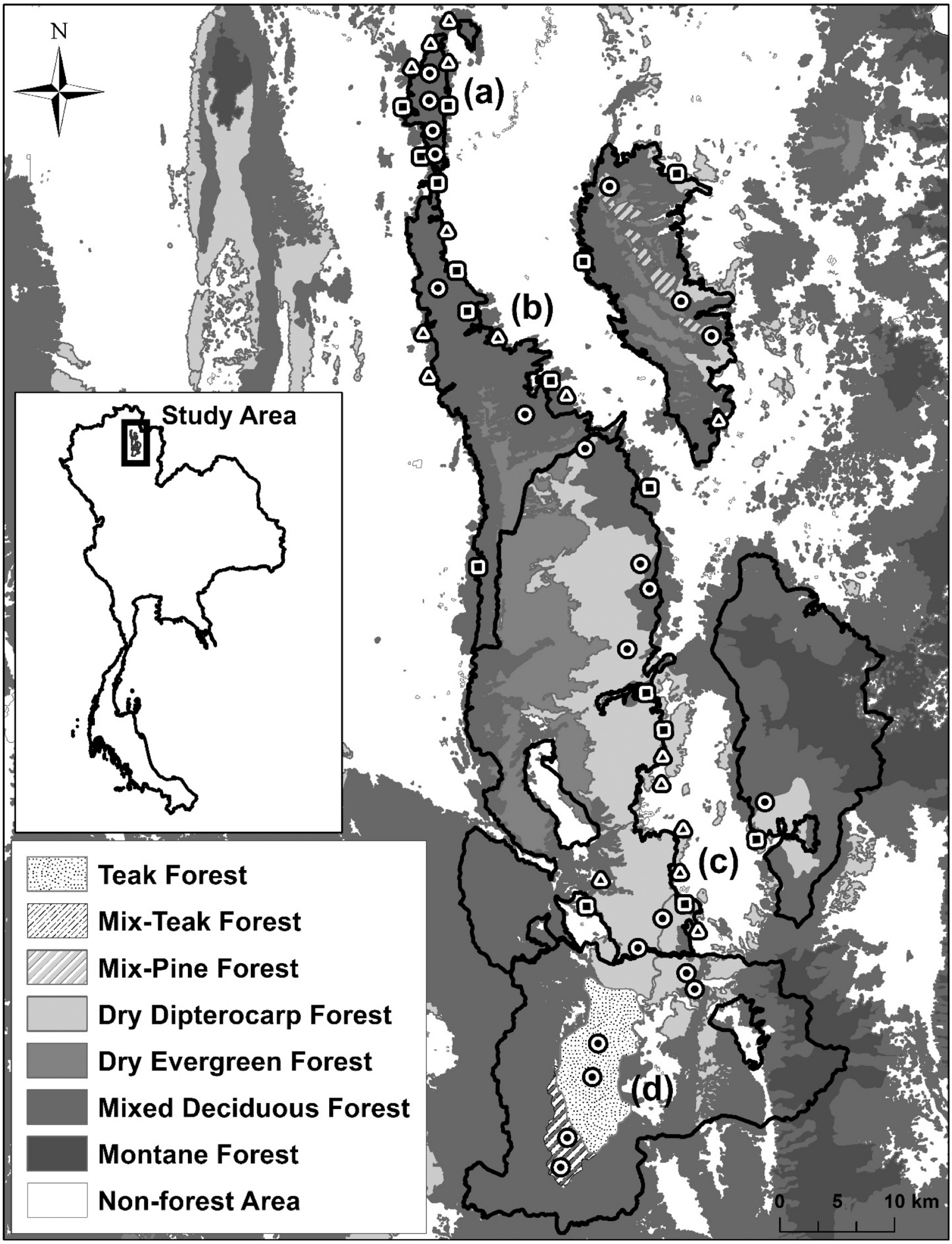


Fig. 1. The whole study area covered by four protected areas:(a) Tub Phaya Lor Wildlife non-hunting area, (b) Wiang Lor Wildlife Sanctuary, (c) Doi Phu Nang National Park and (d) Mae Yom National Park. The round shapes represent transects within protected, square shapes represent transects at the edge and triangular shapes represent transects in agricultural areas.

Among the highly-threatened species in Southeast Asia, the order Galliformes, and in particular the family Phasianidae, shows a high proportion of species under extinction risk due to hunting, habitat loss and degradation (Grainger et al., 2018). The growing human population in the region (Sodhi et al., 2009) increases pressure on subsistence resources and human-wildlife interaction (Shwe et al., 2021). Moreover, limited data on the species' response to the increasing human presence is a challenge in designing effective management plans for Phasianidae (Grainger et al., 2018).

The endangered Green Peafowl (*Pavo muticus*) was historically distributed in the open dry habitats of Southeast Asia, i.e. dry dipterocarp forest, teak forest and grassland with small trees. Due mainly to habitat degradation, the species distribution has shrunk with large populations only found in 6 strongholds over its range (Sukumal et al., 2020a). Green Peafowl are relatively tolerant to low-intensity, multi-crop agriculture near their natural habitat (Shwe et al., 2021) but sensitive to intensively farmed landscapes (Sukumal et al., 2015). In Thailand, only two strongholds of this species have been reported (Sukumal et al., 2020a), one within the well-protected Huai Kha Khaeng Wildlife Sanctuary in the west, where the population is well studied and monitored over the long term (Sukumal et al., 2017), and another within the protected areas network of Phayao province in the north, where the species inhabits at least four contiguous protected areas, showing different protection levels and surrounded by agricultural landscapes (Saridnirun et al., 2017). The area shows a large variety of dry forest habitats reported to be used by Green Peafowl. Besides the well-investigated dry dipterocarp and mixed deciduous forest (Saridnirun et al., 2015; Sukumal et al., 2015, 2017) the species also uses mixed pine forest and one of the last remaining patches of teak forest still found in the region. However, in this stronghold, no estimates are available on the Green Peafowl population status, nor details on their use of different dry habitats, and more importantly, their use of the surrounding agricultural landscape, where conflict has been reported.

It is therefore the aim of this study to investigate the distribution and status of Green Peafowl in the Thai northern stronghold, focusing on the four protected areas differing in protection priorities and management. We started by defining the probability of occurrence of Green Peafowl in the stronghold based on known information about the species (Sukumal et al., 2020a). Second, we estimated Green Peafowl density in each of the four protected areas. Third, we investigated their use of forest interior, edge, and particularly the surrounding agricultural landscape where conflict with local villagers could result in the decline of the species. Fourth, we investigated habitat use over the area with a particular focus on one of the last remaining wild teak areas. In the end, we provide an overview of management strategies for the species in the area.

2. Study area

This project will focus on the northern Thailand stronghold in the Phayao province as highlighted by Sukumal et al. (2020a). The stronghold is composed of a complex of four continuous protected areas (namely Tub Phaya Lor Wildlife Non-hunting Area, Wiang Lor Wildlife Sanctuary, Doi Phu Nang National Park, and Mae Yom National Park), surrounded by 2 km buffer within the surrounding agriculture landscape and covering a total area of about 1500km^2 (Fig. 1). See Table 1 for details on each protected area size and forest cover. The area has an elevation range between 300 and 1200 masl and is mostly covered by open forest including dry dipterocarp and mixed deciduous forests, around 85% (DNP, 2020), the preferred habitats of Green Peafowl (Sukumal et al., 2020a), as well as mixed pine, teak and mixed teak forests, which have also been reported to be used by the species. The surrounding agricultural areas consist of several crop types, mostly rice fields, mountain rice, corn, rubber, and fruit trees such as mango, orange, tamarind and longan (*Dimocarpus longan*). The area experiences a dry season from September to May, with an average monthly rainfall of 79 mm, and a rainy season from June to October, with an average monthly rainfall of 134 mm. The annual rainfall is 1095 mm (TMD, 2020), and temperature ranges from 14° to 31 °C.

Table 1
The four protected areas location, coordinate, habitat types and relative area covered in km^2 and percentage.

Protected area	Location	Habitat type	Area cover km^2	Percentage Cover
Tub Phaya Lor Wildlife Non-hunting Area	19°26'56.40"N 100°4'28.22"E	Mixed deciduous forest	40.5	64
		Dry dipterocarp forest	24.6	36
		Total	65.1	
Wiang Lor Wildlife Sanctuary	19°16'45.17"N 100°9'8.34"E	Mixed deciduous forest	232.2	62
		Dry evergreen forest	54.4	15
		Dry dipterocarp forest	64.2	17
		Mixed pine forest	20.6	6
		Total	371.4	
Doi Phu Nang National Park	18°51'22.73"N 100°10'55.70"E	Mixed deciduous forest	457.6	53
		Dry evergreen forest	207.3	24
		Dry dipterocarp forest	196.4	23
		Total	861.3	
Mae Yom National Park	18°42'45"N 100°10'42.24"E	Mixed deciduous forest	432	72
		Dry dipterocarp forest	21.7	5
		Hill evergreen forest	21	4
		Teak forest	69	15
		Mixed teak forest	19	4
		Total	562.7	

3. Methods

3.1. Green Peafowl probability of occurrence

We predicted the probability of occurrence of Green Peafowl in the study area following Sukumal et al. (2020a). The probability of occurrence model was constructed using an infinite weight logistic model to investigate the relationship between given habitat covariates and the probability of occurrence from the used versus available habitat selection model. Used locations were based on presence-only data of recent record locations (from 2009 to 2015). Available locations were generated from systematic random sampling by placing locations at 5 km intervals within the rectangular extent covering used locations. We created a 1 km circular plot around each used and available location to determine habitat covariates of altitude and land-cover type for each plot. The best-performing model was selected by the lowest Akaike Information Criterion (AIC) (Burnham and Anderson, 2002). This model provides the best estimate of coefficient values for each habitat covariate. We then generated a map of the predicted probability of occurrence, based on this model, covering mainland South-east Asia, focusing only on our study area.

3.2. Green Peafowl density estimate

The density survey was conducted between January and April 2018 during the breeding season when males frequently make loud calls as part of their mating strategy (Sukumal et al., 2015). The survey was conducted along the 54 transects, each measuring 2 km, located along accessible trails inside, at the edge and outside the four protected areas (Fig. 1). In detail, Tub Phaya Lor had 4 transects in the interior, edge and agricultural areas, Wiang Lor and Doi Phu Nang had 6 transects in the interior, edge and agricultural areas, while Mae Yom had 6 transects only in the interior of teak and mixed teak forests as Green Peafowl were only reported in this area (Fig. 1). Each transect was walked by 2 observers for 3–5 consecutive days. Transects were walked twice daily during daily peak calling periods in the morning (06.00–08.30 AM) and in the evening (04.00–06.30 PM). For each calling bird detected, the observer recorded the calling time, observer's location along the line transect, estimated angle and distance to the calling bird assigned within 50 m distance categories. The farthest detection distance was set at 1 km from the observer for both auditory and visual detections (Loveridge et al., 2017).

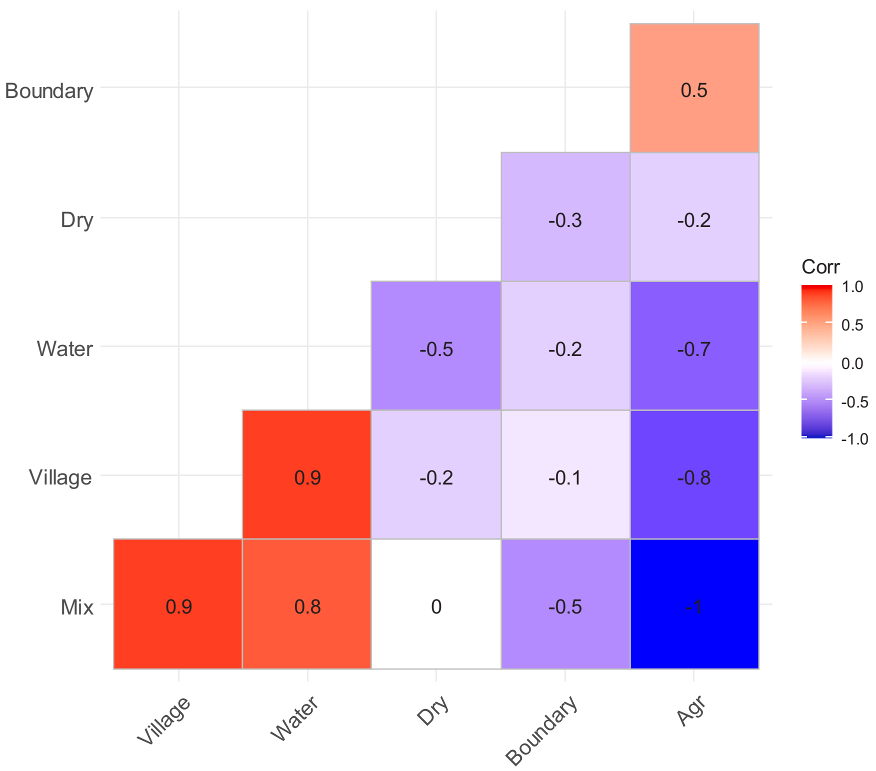


Fig. 2. The correlation matrix of landscape variables with correlation coefficients value labelled within each square. Including: Village = Distance to the nearest permanent human settlement, Water = Distance to the nearest water source, Boundary = Distance to boundary, Mix = Area covered by mixed-deciduous forest, Dry = Area covered by dry-dipterocarp forest, Agr = Area covered by agriculture field.

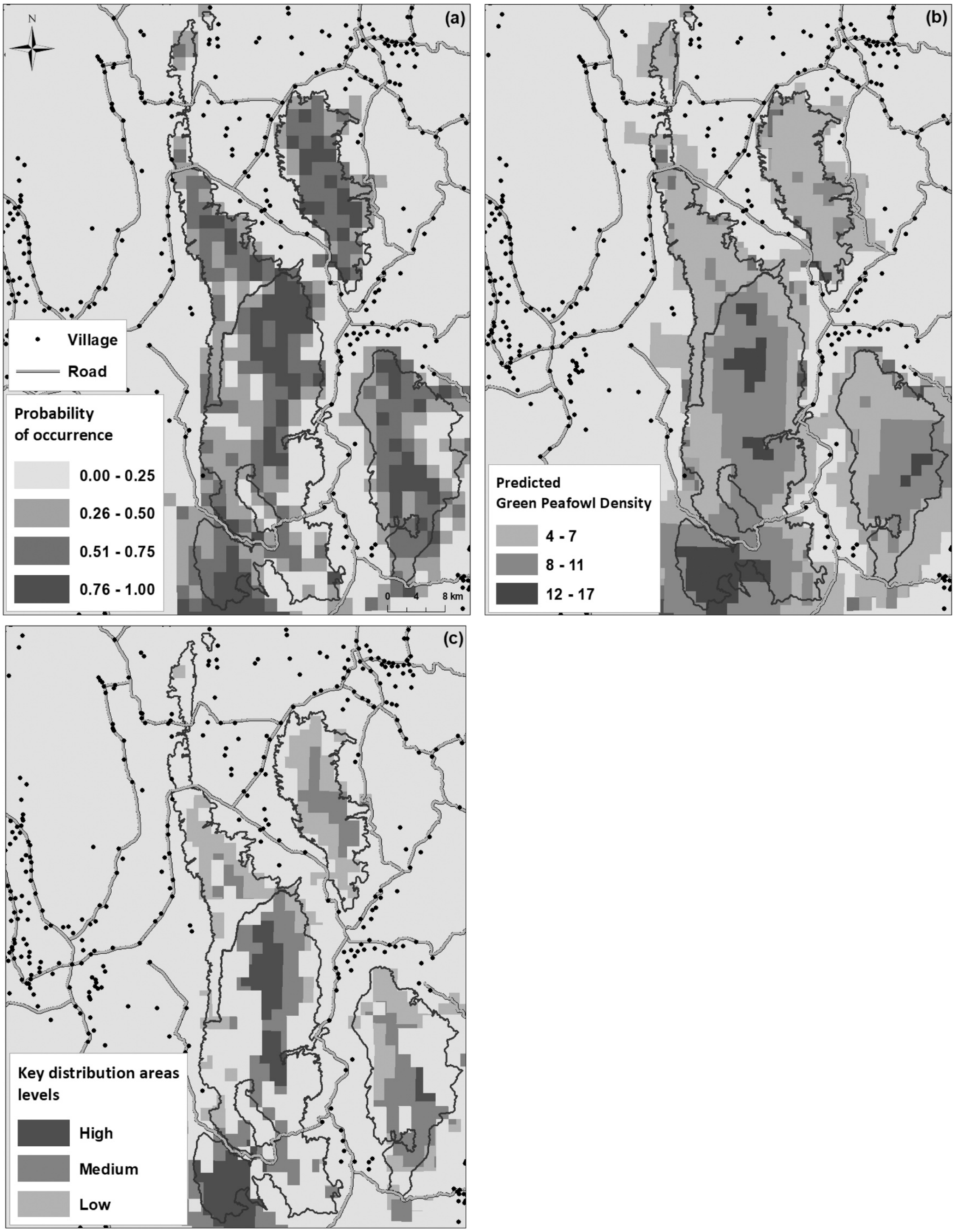


Fig. 3. (a) Predicted probability of occurrence of Green Peafowl generated from recent record locations (from 2009 to 2015) in mainland Southeast Asia, focusing only on our study area. (b) Predicted distribution number of Green Peafowl in three protected areas based on the best model of relationships between the number of calling birds from each transect and given landscape variables. (c) Defining the key distribution areas and levels by the overlap between a and b.

3.3. Data analysis

The density of calling males was estimated for each protected area, for the forest interior, edge and agricultural landscape, as well as for each habitat type. We used the program DISTANCE (Buckland et al., 2015) and excluded visual detections as they included both sexes while calls only detected males. The probability of double counting was reduced by excluding calls from the same direction and distance (Sukumal et al., 2015). Key functions such as the uniform, half-normal, hazard rate, and negative exponential functions with cosine, simple polynomial and Hermite polynomial adjustments were examined to select the best detectability function, and the best model was selected based on the lowest AIC value (Buckland, 2001).

3.4. Distribution modelling

We used the highest number of birds detected from each transects to model the distribution over the study area. A generalized linear model (GLM) with a logit link function and Poisson error distribution was used to investigate the relationship between the number of calling birds and given landscape variables. The number of birds from the transect survey was used as the response variable. The predictor variables were: 1) distance to the nearest permanent human settlement, 2) distance to the nearest water source, 3) distance to the edge, 4) area covered by mixed-deciduous forest, 5) area covered by dry-dipterocarp forest and 6) area covered by the agricultural field. Before running the analysis, all variables were checked for correlation. When two variables were highly correlated ($r > 0.7$) we eliminated one of the two variables and kept the one that appeared to be of relevance for the species following reference from previous studies (e.g. Sukumal et al. 2017). We considered the $r > 0.7$ threshold as it indicates two paired variables to be too linearly related and therefore will affect the model result (Fig. 2). Each percentage predictor was arcsine-transformed (Sokal et al., 1995), and the continuous predictor variable was standardized by dividing the value by twice the standard deviation (Gelman, 2008) in order to transform the data to the same scale.

We tested the variables individually as well as models comprised of the combinations of variables. The variables selection and model combinations were considered based on knowledge of Green Peafowl ecology from the relevant literature (Saridnirun et al. 2015; Sukumal et al. 2015; 2017; Loveridge et al. 2017). We compared the constant models (intercept-only-model) to models containing variables of interest with difference in Akaike's Information Criterion (AIC) and AIC weights. We focus on the top models with the lowest AIC. Confidence intervals of 85% combined were used to consider variables influencing peafowl density.

The analysis was conducted using program R (R Core Team, 2019). The selected model provided the best estimate of coefficient values for each predictor variable. We created 1265 rectangular grids of 1.4-km^2 covering the protected areas, excluding Mae Yom, with the surrounding agricultural areas and then generated a map of the predicted distribution of Green Peafowl number in each grid cell. We excluded Mae Yom National Park due to differences in habitat characteristics, especially a high proportion of natural teak forest, and the survey design used which focused only on the area within the protected area. This analysis was conducted in ArcGiS 10.3.1.

3.5. Defining key distribution areas

The key distribution areas were defined based on how our density estimates for Green Peafowl coincided with the probability of occurrence. We overlaid the map of Green Peafowl probability of occurrence for the study area, focusing only on areas showing a probability of occurrence ($P > 0.5$), with the obtained map of the predicted density of the species. We divided the key areas into three categories, 1) high-level key distribution areas, overlapping areas with a probability of occurrence $P > 0.5$ and high predicted density (> 11 calling males/km^2), 2) medium-level key distribution areas, overlapping areas with a probability of occurrence $P > 0.5$ and medium predicted density (8–11 calling males/km^2), and 3) low-level key distribution areas, overlapping areas with a probability of occurrence $P > 0.5$ and low predicted density (< 8 calling males/km^2).

3.6. Investigating threats to Green Peafowl

We investigated the different threats to Green Peafowl in the study area using GLM with a logit link function and Poisson error distribution. The threats identified at the transect level, namely the presence of 1) cattle, 2) natural predators, 3) domestic dogs, 4) humans, and 5) incidence of fire, were used as the predictor variable, while the number of birds detected from each survey was used as the response variable. Data on the vegetation structure and percentage of ground vegetation, collected at 100 m intervals along each transect, was also included in the analyses. This variable was standardized by dividing the values by twice the standard deviation in order to transform the data to the same scale. The best model was selected based on the lowest AIC value.

4. Results

4.1. Probability of occurrence and density estimate

At the species range scale over mainland Southeast Asia, Sukumal et al. (2020a) reported as "high" a probability of occurrence > 0.5 for Green Peafowl. When using such value for our study site we estimate that 25.73% of the stronghold show a "high" probability of occurrence (Fig. 3a).

The overall density estimate for the whole study area (combining all four protected areas), based on a total of 1615 detections, was

15.82 calling males/km^2. The highest density was found in Wiang Lor with 19.89 calling males/km^2, following by Tub Phaya Lor with 15 calling males/km^2, Doi Phu Nang with 14.88 calling males/km^2 and Mae Yom with 13.55 calling males/km^2.

The highest density was in the forest interior with 18.58 calling males/km^2, followed by 17.2 calling males/km^2 at the edge and 14.5 calling males/km^2 in the agricultural landscape. Regarding the different habitat types, the highest density was recorded in the mixed pine forest with 24.77 calling males/km^2, followed by mixed deciduous forest with 19.84 calling males/km^2, dry dipterocarp forest with 15.76 calling males/km^2, agricultural areas with 14.287 calling males/km^2, teak forest with 12.684 calling males/km^2 and mixed teak forest with 9.93 calling males/km^2 (Table 2).

4.2. Predicted distribution of Green Peafowl

Over three protected areas, the model showed that the dry-dipterocarp forest area and distance to the nearest permanent human settlement significantly influenced the Green Peafowl number. The birds were more likely to be detected in the dry-dipterocarp forest area and farther away from the village (Appendix Table 2) (Fig. 4). As distance to water resource was highly correlated with distance to the nearest permanent human settlement we excluded it from the model as the distance to the nearest permanent human settlement has been previously selected to explain peafowl density (Saridnirun et al., 2015, 2017; Loveridge et al. 2017).

High species distribution was predicted within the protected areas, with the number declining the closer one gets to the exterior. However, the model also predicted that the bird could be found in protected areas covered by open forest, e.g. dry-dipterocarp forest and mixed deciduous forest, in adjacent agriculture areas, up to 1000 m from the forest edge although most detections were within 500 m, and farther away from the village (Fig. 3b).

4.3. Status in key distribution areas

The key distribution areas covered a total of 829 km^2 (63.30% of the total protected area), located within the protected areas (653 km^2, 79%) and outside (176 km^2, 27%) (Fig. 3c). In Tub Phaya Lor Wildlife Non-hunting Area, only one low-level key distribution area was found, covering 7 km^2 (10% of protected area). In Wiang Lor Wildlife Sanctuary, two levels of key distribution areas were found, a low-level area covering 148 km^2 (39% of protected area) and a medium-level area covering 57 km^2 (15% of protected area). In Doi Phu Nang National Park, three levels of key distribution areas were found, a low-level area spanning 102 km^2 (11% of protected area), a medium-level area spanning 214 km^2 (25% of protected area) and a high-level area spanning 129 km^2 (15% of protected area).

4.4. Micro-habitat and threats influencing Green Peafowl number

The GLM model identified five-variables with significant influence on the Green Peafowl density. Birds were more likely to be detected in areas with ground cover ($\beta = 0.14080$, $P < 0.05$) and fire incidence ($\beta = 0.42919$, $P < 0.001$), but less likely in areas showing three main disturbances, the presence of humans ($\beta = -0.33214$, $P < 0.01$), cattle ($\beta = -0.35155$, $P < 0.001$) and domestic dogs ($\beta = -0.41774$, $P < 0.001$; Table 3) (Appendix Table S2) (Fig. 5).

Table 2
Density estimates for Green Peafowl in their northern stronghold of Thailand. Data are based on line transect surveys conducted in January – April 2019 and March 2020.

Categories		Number of transect	Number of observation	Total length (km)	Survey effort (time off observations)	Density estimates (calling males/km^2)	95% confidence intervals
Protected Area	Tub Phaya Lor	12	288	38	19	15.006	12.009–18.751
	Wiang Lor	18	476	42	21	19.897	16.984–23.268
	Doi Phu Nang	18	689	66	33	14.884	11.644–19.024
	MaeYom	6	162	36	18	13.550	10.519–17.453
	Pooled Estimates			182	91	15.829	14.258–17.574
Zone	Agriculture	16	505	58	29	16.153	13.324–19.581
	Edge	16	482	52	26	17.432	14.737–20.619
	Interior	22	628	72	36	18.134	15.376–21.388
	Pooled Estimates			182	91	17.240	15.663–18.975
Habitat	Agriculture	22	672	78	39	14.287	11.469–17.796
	Dry Dipterocarp	13	441	46	23	15.762	12.221–20.328
	Mixed Deciduous	12	323	28	14	19.846	15.834–24.875
	Mix-Pine	3	78	6	3	24.771	19.831–30.940
	Mix-Teak	2	41	12	6	9.938	6.8754–14.365
	Teak	2	60	12	6	12.684	9.0165–17.844
	Pooled Estimates			182	91	16.215	14.652–17.944

5. Discussion

5.1. Peafowl density

Our density estimates are in line with those in other parts of the species' range. In agricultural landscapes in Myanmar, densities were estimated to be between 1.13 and 2.63 males/km^2 (Shwe et al., 2021). In southcentral Vietnam, the density is estimated at 0.25 calling birds/km^2 in the highly disturbed dry forest of YokDon National Park and at 3.03 calling males/km^2 in CatTien National Park, where ecotourism is well developed (Sukumal et al., 2015). In Cambodia, the estimates are relatively low, mostly due to high threats, at 1.70 calling males/km^2 in Siem Pang Wildlife Sanctuary (Loveridge et al., 2017), 0.30 calling males/km^2 in Seima Protection Forest (Nuttall et al., 2017) and 1.61 calling males/km^2 in Srepok Wildlife Sanctuary (Chandara, 2017). Figures from HuaiKhaKhaeng Wildlife Sanctuary in western Thailand range from 1.13 to 11.34 calling males/km^2 due to the high protection level implemented in the area (Sukumal et al., 2017). Our average of 15.82 calling males/km^2, therefore, is on the high side, indicating a good population status. The species distribution is similar throughout the four protected areas mostly due to the continuity of the primary forest patches, making them likely to be inhabited by the same population (Fig. 1). Moreover, the species appeared to be well established in the surrounding agricultural landscape, which provided them with seasonal and temporally high yield food sources.

Tub Phaya Lor Wildlife Non-hunting Area is the smallest, newest and least protected among the four areas. The landscape is highly fragmented from past deforestation and agricultural expansion, resulting in the confinement of resident wildlife populations into isolated patches, with several species extirpated by overexploitation. Although the protected area is mostly covered by mixed deciduous and dry dipterocarp forests, the species still showed a high estimated density (15 calling males/km^2). Moreover, the surrounding low-intensity agricultural area with diverse crops can be as supportive as their natural habitat (Hendershot et al., 2020). In addition, its small size will enable extensive ranger-patrolling, despite meager resources, and facilitate collaborative conservation efforts with villagers.

Wiang Lor Wildlife Sanctuary has the highest protection priority among the study areas with intensive patrolling and a ban on all human activities, including tourism. This explains the highest density of almost 20 calling males/km^2. Moreover, not only is the protected area composed of a very large continuous forest patch suitable for Green Peafowl (dry dipterocarp and mixed deciduous forests), it is also surrounded by a diverse agricultural landscape with crops such as rice, logan, rubber and teak with an open understory suitable for the species (Sukumal et al., 2017).

Both Doi Phu Nang and Mae Yom National Parks have high protection priority and are partly open for tourism, causing intensive human activities in specific areas often modified to accommodate such activities. Doi Phu Nang is mainly covered by dry dipterocarp and mixed deciduous forests and is occupied by mountain tribes, who have hunted wildlife, including Green Peafowl, as a primary source of protein, even before the establishment of the National Park. Notwithstanding the deforestation and agricultural encroachment that has taken place in the area, a high species density, about 14 males/km^2, was recorded, probably because its connection to other protected areas allowed the species to disperse. Mae Yom National Park is renowned for its unique habitat, the largest remaining natural teak and mixed teak forest in Thailand. The remoteness of the teak forest combined with the strict protection and patrolling by park rangers make it inaccessible even by the local mountain tribes, which explains the relatively high density of 13.5 calling males/km^2.

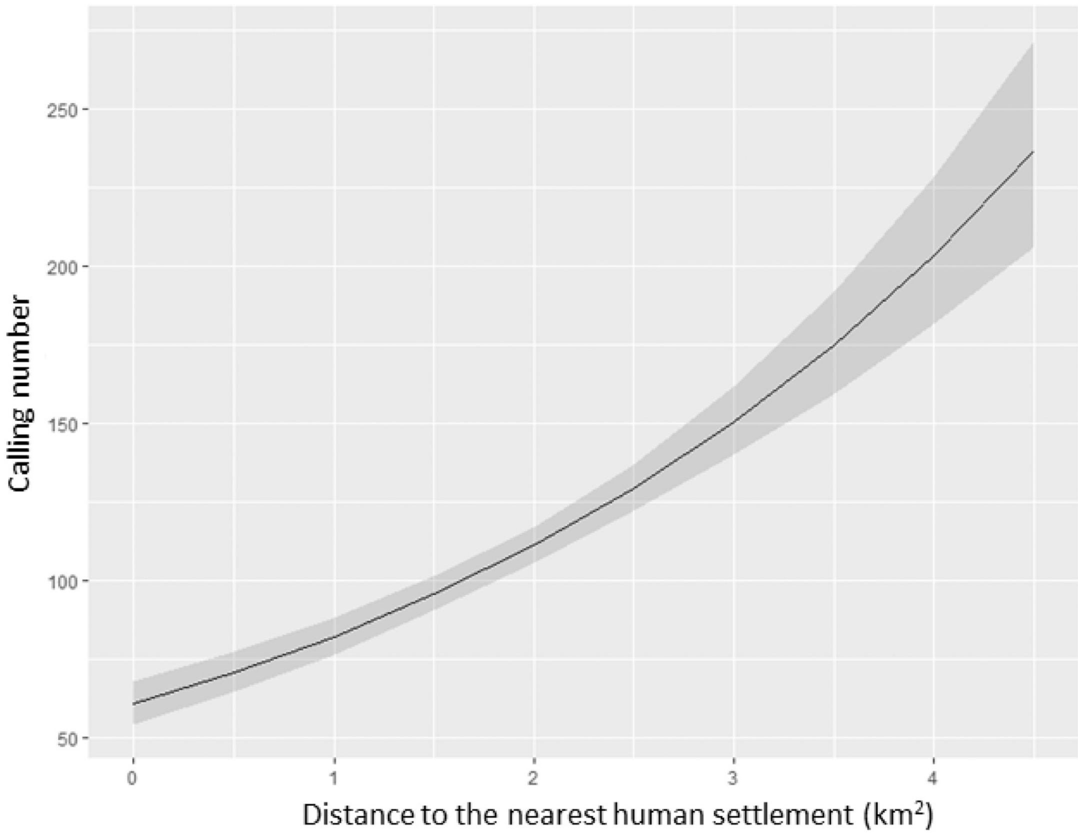
5.2. Effect of habitat types on density estimates

Green Peafowl prefer open forest combined with shrubs and saplings as recorded in dry dipterocarp, mixed deciduous, teak, mixed teak and mixed pine forests (Sukumal et al., 2015, 2017). These habitats provide effective breeding grounds and suitable grass understory used as food resources by the species (Saridnirun et al., 2017). Our results showed that Dry Dipterocarp forest is the preferred habitat type in the best model predicting peafowl density. However, its wide confidence interval range reported in Fig. 4 could be the consequence of the fact that this habitat covers both interior areas, with high estimated densities, and edges, with lower estimated densities.

At the very center of Mae Yom National Park, an area called Dong Sak Ngam, teak *Tectona grandis* covers a vast area spanning 260 km^2 along the Yom River, where the density of mature teak can range from 126 stems/km^2 at the fringes to 200 stems/km^2 toward the center. The Yom River, due to the lowland basin topographical structure, was proposed in 1980 as a possible site for the construction of a dam. However, due to the presence of the endangered Green Peafowl and the uniqueness of its botanical composition, the project was suspended in 1999 (EIA Report, 1999). Our results highlight the importance of this teak forest patch and this specific area for the conservation of Green Peafowl, making a possible future reconsideration of the dam project a conservation concern.

The area surrounding the teak forest is primarily composed of mixed teak forest, a combination of dry dipterocarp forest with a low teak density (<120 stems/km^2). The low estimated density in this habitat could be due to its closeness to the edge of the protected area and susceptibility to human disturbance, including from agriculture and tourism-related activities, with an access road to tourist and camping areas.

The mixed pine forest, mostly dry dipterocarp forest with pine as the dominant tree, is distributed along mountain ridges at the center of the protected area. The limited accessibility caused by the hilly and mountainous landscapes and its connection to the main forest patch make it attractive to Green Peafowl. The estimated density ranged between 9.01 and 17.84 calling males/km^2. This value is higher than the estimate of 0.63–1.13 calling males/km^2 for the species in the high-elevation mixed pine forest, evergreen forest dominated by pines, in Shan State, Myanmar (Shwe et al., 2021).



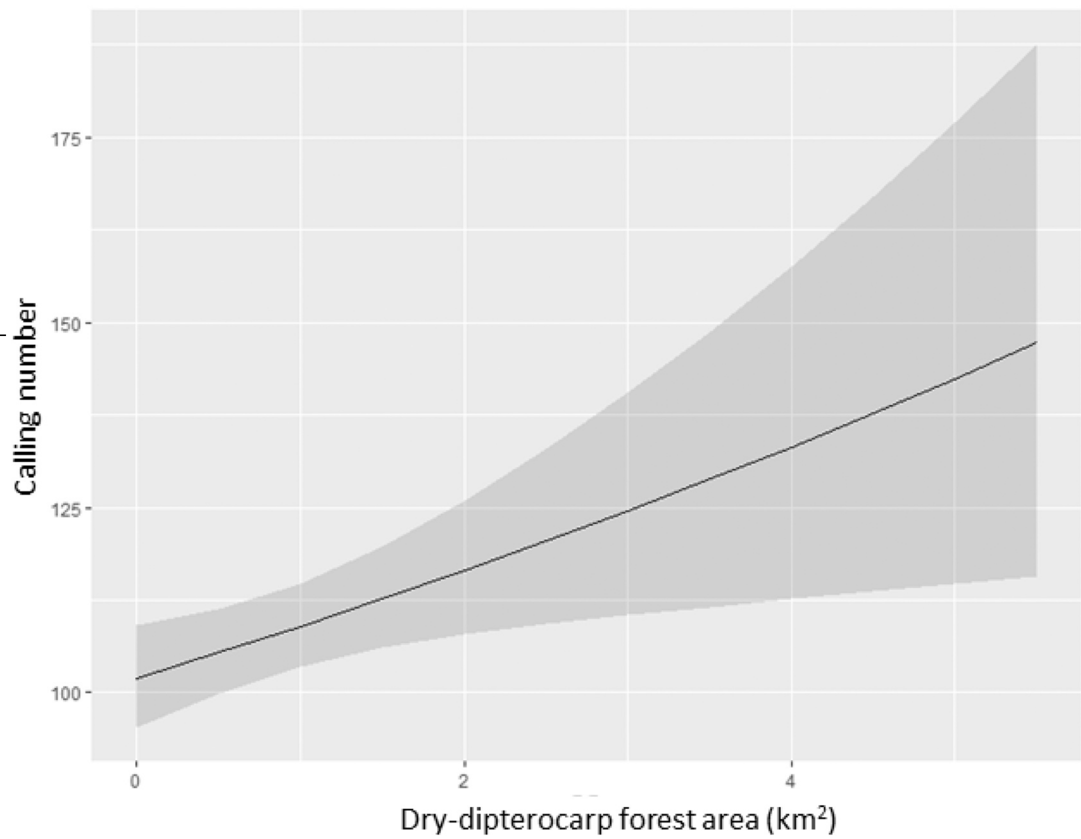


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Fig. 4. The predicted calling count responded to 2 variables from selected Landscape-scale model including Distance to the nearest human settlement and dry-dipterocarp forest area respectively.

Table 3
Parameters of the distribution model from line transect surveys.

Parameters	β	SE	85%LCI	85%UCI
Landscape variables				
Dry-dipterocarp forest	0.06685	0.02604	0.02899118	0.1039600
Distance to village[a]	0.30263	0.02611	0.26501225	0.3401899
Micro-habitat and threat variables				
Ground cover	0.14080	0.05546	0.06062181	0.2203340
Cattle presence[a]	-0.35155	0.06234	-0.44140100	-0.2618992
Domestic dog presence[a]	-0.41774	0.08757	-0.54230780	-0.2900927
Human activities presence	-0.33214	0.10611	-0.48531344	-0.1796829
Fire presence[a]	0.42919	0.05758	0.34606927	0.5118635

[a] Indicates significant influence on density.

5.3. Edge effect on density estimates

As found elsewhere (Shwe et al., 2021), the highest density (18.13 calling males/km^2) was found in the interior of protected areas, up to 1 km away from intensive human activities. The high density could also be related to the generally high protection level, with minor disturbance from villagers, who use the area mainly for non-timber forest product collection, which should not affect a relatively tolerant species such as Green Peafowl. The results confirm that large, continuous primary forest patches are important for long-term population conservation as they provide the various needs of the species throughout its life cycle, including shelter and food sources (Gutierrez et al. 2019), as recorded for other large umbrella species such as Asiatic Elephant *Elephas maximus*, Tiger *Panthera tigris*, and Leopard *Panthera pardus* (Huang et al., 2019; Tempa et al., 2019; Jhala et al., 2020; Noor et al., 2020 respectively).

Edges, between 0 and 1 km, showed the second highest density with 17.43 calling males/km^2. This zone connecting the surrounding agricultural landscape with the forest interior was illegally encroached, cleared and converted to agricultural fields, but Forestry Department intervened, and secondary forests have taken over. The encroached habitat provided structural variability in resources available to the species. Plantations, especially teak, longan, rubber and mango, along the boundary are regularly used by Green Peafowl as they share similar characteristics as the preferred open forest (Sukumal et al., 2017). Moreover, the encroached habitat can also be seen as connecting the forest interior to agricultural resources by forming corridors, as observed in endangered species adapted to fragmented landscapes (Sodhi et al., 2009). Corridors are important for long-term conservation as they provide connectivity between separated populations living in fragmented habitats (Miller et al., 2018).

Crop-raiding by Green Peafowl in border areas between forest edge and agriculture fields is not uncommon due to the proximity to the forest boundary. To protect their means of livelihood, farmers often scare the birds off using firework or domestic dogs, which can result in fatalities.

The lowest estimated density (16.15 calling males/km^2) was recorded in the agricultural landscape adjacent to the protected areas. Birds were found in agricultural areas mostly during the breeding season (November – March), which coincided with the cropping period for rice, corn and beans. During the breeding season, Green Peafowl gathered in large flocks (up to 60 birds or more) in fields where there were high-quality food sources and waterholes in the dry season. Males use the open space for their mating display. The end of the dry season, characterized by a limited supply of food in the agricultural landscape following crop harvesting, coincided with the nesting season (Sukumal et al., 2017). This adaptation to anthropogenic habitat was also recorded in Vietnam (Sukumal et al., 2015), Cambodia (Chandara, 2017) and in forest fragments in Myanmar (Shwe et al., 2021).

Regarding micro-habitat use and threats along the line transects, the birds were mostly detected in areas with high ground vegetation coverage, as observed in Huai Kha Kahaeng Wildlife Sanctuary in western Thailand (Sukumal et al., 2017) and Yok Don National Park in southcentral Vietnam (Sukumal et al., 2015). High ground vegetation coverage might provide a variety of food for the birds. The birds were detected in low numbers in areas with a high presence of humans, cattle and domestic dogs. Large numbers of cattle can cause overgrazing and habitat deterioration, while domestic dogs hunt and disturb the birds, especially during the mating season when they gather in large flocks. We found evidence of fire incidence mostly in areas with a high number of peafowl, which might be because our study areas, especially the entire mixed deciduous and dry dipterocarp forests, were burned during the survey. Forest fire occurs every year in northern Thailand during the dry season (DNP, 2020) and threatens wildlife populations in the area, including Green Peafowl.

5.4. Management

There was a 72% overlap between predicted areas of high species occurrence and areas of high density (Fig. 3C). High-level key

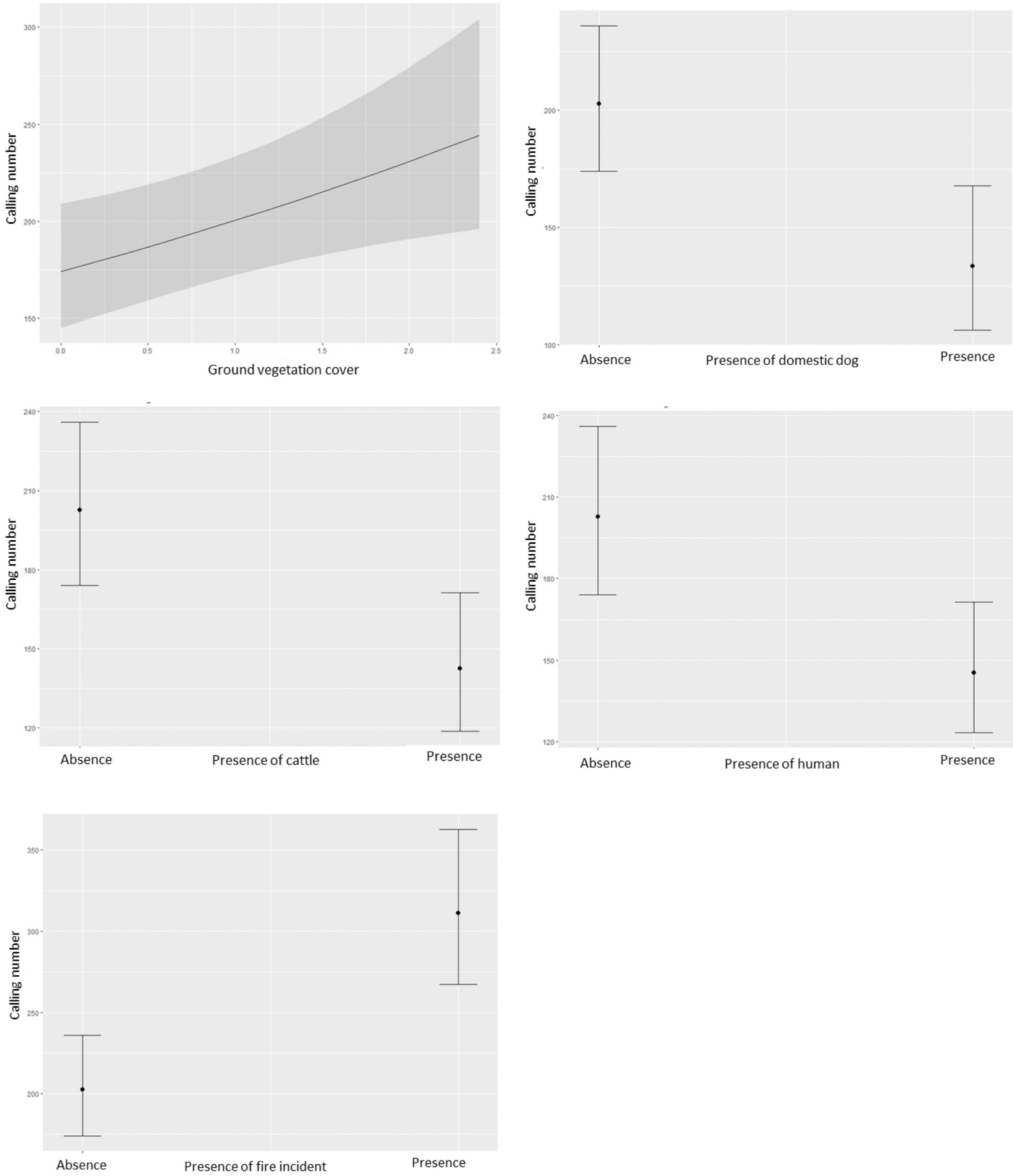

Fig. 5. The predicted calling count responded to 5 variables from selected Micro-scale model including ground vegetation cover, presence of cattle, presence of domestic dog, presence of human and presence of fire incident respectively.

distribution areas only appeared within the center of Doi Phu Nang National Park (Fig. 3C), where threats and landscape fragmentation are low. As tourism in this protected area mainly occurs at the edge, the interior is spared of its negative impacts on wildlife (Tablado and D'Amico, 2017). Some patches of high-level key distribution areas were, however, found outside this protected area, within legally unprotected large forest patches or within the adjacent Mae Yom National Park, which also has large continuous forest patches but was excluded from this landscape analysis due to the different survey design (see method section). Medium key distribution areas were primarily observed in the center of Wiang Lor Wildlife Sanctuary. Despite being of large size and relatively free from tourism, this protected area has a narrow shape with most of it relatively close to edges, mostly showing low-level key distribution areas where external threats are higher. However, despite this, the area showed the highest density, among the four protected areas, mostly due to the tight protection priority as a wildlife sanctuary and also a consequence of indirect protection linked to local beliefs, especially Buddhism, which forbid harming of Green Peafowl, as observed in other parts of the species range (Shwe et al., 2021). Religious /cultural beliefs might also explain the high species population relative to other wildlife like leopards (*Panthera pardu*), sun bear (*Helarctos malayanus*), Eld's Deer (*Rucervus eldii*) and hog deer (*Axis porcinus*), which are extinct primarily due to hunting. A recent attempt at reintroducing the two deer species failed due to hunting pressure (pers. comm. Wiang Lor Wildlife Sanctuary). Low-key distribution areas were mostly found in the small Tub Phaya Lor Non-hunting Area, unsurprisingly. This protected area shows the lowest protection and is surrounded by agricultural landscapes, human settlements and roads. The resulting narrow suitable area and low predicted density highlight the importance of large contiguous forest patches for peafowl conservation. The species faces a long-term risk of extinction in highly fragmented landscapes due to the forced proximity to edges where direct and indirect threats from human activities are much greater.

In general, our results point out that peafowl distribution is negatively affected by surrounding agricultural landscapes and human settlements. The use of chemical fertilizers, herbicides and pesticides in cropping fields and the presence of domestic and feral dogs are increasingly a major threat to Green Peafowl (Shwe et al., 2021). The raiding of crops, particularly rice and corn, by Green Peafowl is also an important trigger of conflict with farmers, who respond using guard dogs, poisoned seeds, fireworks or stone-throwing to keep them away, which often results in fatalities. Human-wildlife conflict, arising when wildlife move out of their natural habitat interacting negatively with local communities, has been extensively researched for large mammals such as elephants (Shaffer et al., 2019), tigers (*Panthera tigris*) and leopards (*Panthera pardus*) (Dhungana et al., 2018; Dhungana et al., 2019). Our results show that peafowl regularly move in the farmland surrounding protected areas increasing the risk of arising conflict with farmers. Recently, road kill have been also recorded.

A long-term conservation project has been initiated by local conservation groups, park rangers and university researchers to adapt the surrounding agricultural landscapes close to forest patches for ecotourism. The project aim is to use Green Peafowl as iconic animal for the area and develop around it ecotourism to provide basic biological knowledge of the species and its habitat, especially protected forest (Chen, 2020; Wang, 2020). As a consequence, the reputation to the species towards local communities has improved. However, despite this, the cost linked to human-wildlife conflict still outweighs the local ecotourism benefit. Our results could be used to monitor the success of such activities in the long term. In the end, our result also points out areas of different levels of importance for Green Peafowl within the protected areas, and the data could help park rangers strategize as efficiently as possible for more effective outcomes.

Our survey results confirm what suggested by Sukumal et al. (2020a) about the possibility of this area representing an important stronghold for green peafowl. The area has a high species density making it an important population source. Investigating therefore the species' movement, and providing it with well-designed corridors could enable its dispersal to surrounding forested areas outside the study site. The detailed spatial distribution over the four protected areas should be used to implement long term species monitoring as part of the regular ranger patrol protocol currently undertaken in each protected areas in the country. This should be combined with a regular re-survey for the species, for example every five years, to monitor its possible status change and defining spatial variation in its long-term viability, following what done in Cat Tien National Park, southcentral Vietnam, where also ecotourism has been suggested as the cause for predicted population increase over time (Sukumal et al., 2020b). On the other hand, a decline in population size over time should trigger an increase in threat control (i.e. human disturbance, hunting or feral dogs attack). In the end, animals found in the agriculture landscape should be monitored for the appearance of human-wildlife conflict. If this become more severe, specific outreach activities should be suggested and carried on by the local management group, bearing in mind that conservation management and ecotourism project could be more effective when combined with socio-economic research and development. While the developing conservation management and ecotourism were initiated also forming the community network and benefit management for appreciate the local who benefit from wildlife leading to human-wildlife co-existence (Zanamwe et al., 2018; Stronza et al., 2019).

Ethical standards

The submitted research comply with the journal's Code of Conduct for authors contributing articles. This research did not involve human subjects, experimentation with animals and/or collection of specimens.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ghan Saridnirun reports article publishing charges was provided by The National Science and Technology Development Agency ID P-19-50806.

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Author contributions

All authors designed the project and wrote the manuscript, GS collected and analyzed the data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2021.e01674.

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