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Importance of Srepok Wildlife Sanctuary, Cambodia, for the endangered green peafowl: implications of co-occurrence near human use areas

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Abstract. The globally endangered green peafowl (*Pavo muticus*) has dramatically declined over recent decades. Deforestation, land-use modification, hunting and increasing encroachment levels continue to threaten remaining populations. Northern and eastern Cambodia represent one of the species' remaining strongholds. However, only a few robust population estimates exist across this species' range. We conducted distance-based point counts of vocalisations to estimate male green peafowl densities in the Srepok Wildlife Sanctuary, eastern Cambodia. We surveyed a total of 80 listening post stations across two different management areas during the 2016 breeding season. Results indicate that the Srepok Wildlife Sanctuary supports the largest population of green peafowl in Cambodia, with an estimated population of 1,165 calling males. Male peafowl densities were higher in the outer survey area, closer to human settlements and agricultural farms, than the core survey area, with estimated densities of 1.08 males/km² and 0.56 males/km² respectively. Distances to rivers and villages also influenced green peafowl detection rates. Overall, these results highlight the global importance of the Srepok Wildlife Sanctuary for conserving green peafowl populations. However, this species also damages agricultural crops. Thus, future conservation initiatives need to incorporate a holistic approach that integrates the needs of people and wildlife co-existing in areas of shared resources. To achieve this, future interdisciplinary strategies should focus on wildlife-friendly agricultural approaches that will benefit landowners' economic outputs whilst simultaneously promoting pro-conservation attitudes. At the same time, management approaches need to address wildlife hunting and the use of lethal mitigation measures within and around human use areas.

Key words. green peafowl, *Pavo muticus*, distance sampling, General Linear Model, Cambodia

INTRODUCTION

Biodiversity declines occurring across Southeast Asia primarily stem from human activities, such as deforestation, large scale land conversion, logging (legal and illegal) (Ghazoul & Sheil, 2010; Sodhi et al., 2010), agriculture expansion (Hosonuma et al., 2012) and exploitation (Corlett, 2007; Harrison et al., 2016; Gray et al., 2018). Green peafowl, *Pavo muticus*, a large bodied Galliformes, was historically widespread throughout dry forest habitats across Southeast Asia (McGowan et al., 1998). However, only 16% of this species' historical range remains (Sukumal et al., 2020). Deforestation, habitat conversion, range reduction, persecution, and wildlife trade are some of the key factors that have contributed to localised extinctions and dramatic population declines (McGowan et al., 1998; Brickle et al., 2008; Goes, 2009; Sukumal et al., 2015). Furthermore, the amalgamation of these anthropogenic threats continues to pose a threat to this species' existence across its extant range.

To date, only six green peafowl strongholds exist throughout their Southeast Asian mainland historical range, in south-central Myanmar, northern and western Thailand, and northern and eastern Cambodia (Sukumal et al., 2020). Its global population has declined by more than 50% and current estimates suggest fewer than 30,000 individuals remain in the wild (BirdLife International, 2018). As a result of this rapid population decline and range contraction, the IUCN status for green peafowl had been listed as globally endangered in 2009 (IUCN, 2018). If the current rate of threats continues future localised extirpations and population declines are likely.

Fortunately, there has been a growing body of research focusing on estimating green peafowl densities in different protected areas across mainland Southeast Asia (Table 1). Although differing methodologies have been implemented, results highlight the global importance of these sites for

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Table 1. Estimated green peafowl densities across the Asian mainland as reported in recent literature.

Country	Site	Estimated density	Reference
Cambodia	Keo Seima Wildlife Sanctuary	0.30 birds/km^2	Nuttall et al. (2017)
	Siem Pang Wildlife Sanctuary	0.35–1.70 males/km^2	Loveridge et al. (2017)
Myanmar	Pwe Hla agricultural landscape	1.83 birds/km^2	Shwe et al. (2021)
Thailand	Doi Phu Nang National Park	14.88 calling males/km^2	Saridnurun et al. (2021)
	Huai Kha Khaeng Wildlife Sanctuary	1.13–11.34 calling males/km^2	Sukumal et al. (2017)
	Mae Yom National park	13.55 calling males/km^2	Saridnurun et al. (2021)
	Tub Phaya Lor Non-Hunting Area	15.00 calling males/km^2	Saridnurun et al. (2021)
	Wiang Lor Wildlife Sanctuary	19.89 calling males/km^2	Saridnurun et al. (2021)
Vietnam	Cat Tien National Park	3.03 calling males/km^2	Sukumal et al. (2015)
	Yok Don National Park	0.25 calling males/km^2	Sukumal et al. (2015)

preserving the remaining green peafowl populations. However, varying levels of illegal hunting, logging, agricultural expansion, cattle grazing, collection of non-timber forest products, and forest fires still occur across the majority of these sites, and will likely continue as human populations and economic development projects grow in the region. Consequently, the long-term persistence of this globally endangered species will be dependent upon future management strategies aimed at balancing socio-ecological needs through sustainable management of multi-use landscapes.

Cambodia currently supports more than 50 protected areas, covering more than seven million hectares (UNEP-WCMC, 2020) that jointly support a number of globally important wildlife populations (Maltby & Bourchier, 2011; Gray et al., 2012; Loveridge et al., 2017; Rostro-García et al., 2018; Pin et al., 2020). A large proportion of these wildlife populations co-occur with people across a spectrum of land use types. In 2008, the Royal Government of Cambodia released the Protected Area Law, which stipulates that up to four different management zones can occur within protected areas. These include a strict protection core zone, a conservation zone, a sustainable use zone, and a community use zone, the latter predominately being comprised of human settlements and agricultural lands. The purpose of mixed zonation systems is to preserve ecological integrity of the protected area whilst simultaneously benefitting local communities living within and adjacent to these sites. However, at the time of this survey, no official government approved zones existed within our study area.

The green peafowl in Cambodia occur across a range of differing habitats (Loveridge et al., 2017; Nuttal et al., 2017) including agricultural lands within community village boundaries (Crouthers, 2021). Consequently, this species is not only threatened by snares set within and outside protected zones, but also by lethal human-wildlife conflict mitigation measures set around farmland boundaries (Crouthers, 2021). Unfortunately, robust green peafowl population estimates in Cambodia are limited to two protected areas, and no published long-term studies exist. Consequently, the extent of a range collapse or population decline remains unknown. Therefore, this study aimed to broaden our knowledge on the status of the green peafowl in one of the largest multi-use protected areas located in eastern Cambodia, the Srepok Wildlife Sanctuary, henceforth referred to as Srepok. The objectives of this study were to (1) estimate the density of the male green peafowl located throughout Srepok; (2) compare density estimates between the protected core area and outer core area that is co-utilised by local communities; and (3) highlight key factors that affect current green peafowl densities. Overall, this study provides the first robust estimates of green peafowl within Srepok, thus providing a baseline for future long-term surveys. These results can also be used to guide future evidence-based conservation strategies to conserve green peafowl and other Galliformes species that co-utilise the same habitats.

Study area. The Srepok, formerly Mondulkiri Protected Forest, covers an area of 3,730 km^2 and is located within the centre (12°40′N, 107°00′E, Fig. 1) of a transboundary socio-ecological landscape, referred to as the Eastern Plains Landscape. The wider landscape spans approximately 14,000 km^2 and consists of eight contiguous protected areas straddling Cambodia and Vietnam. At the time of this survey, in 2016, Srepok was divided into a core area (1,756 km^2) and outer core area (1,994 km^2). The core area had restricted access; only government, community law enforcement officials, and researchers were legally permitted to enter. The outer core area comprised different land use types that include areas of conservation value to areas that can be used for economic and subsistence purposes and/or support human settlements.

The predominant habitat type throughout Srepok is deciduous dipterocarp forest, dominated by two species (*Shorea obtusa* and *Dipterocarpus tuberculatus*) (Pin et al., 2013). Smaller patches of mixed deciduous forest, semi evergreen, bamboo and riverine forest are interposed throughout the area (Phan & Gray, 2010). Water systems consist of a mix of perennial rivers and seasonal waterholes, regularly used by an array of globally threatened fauna (Pin et al., 2020). This site experiences two distinct seasons, monsoon season (May to October) and dry season (November to April), with a mean annual rainfall ranging between 1,500–1,800 mm

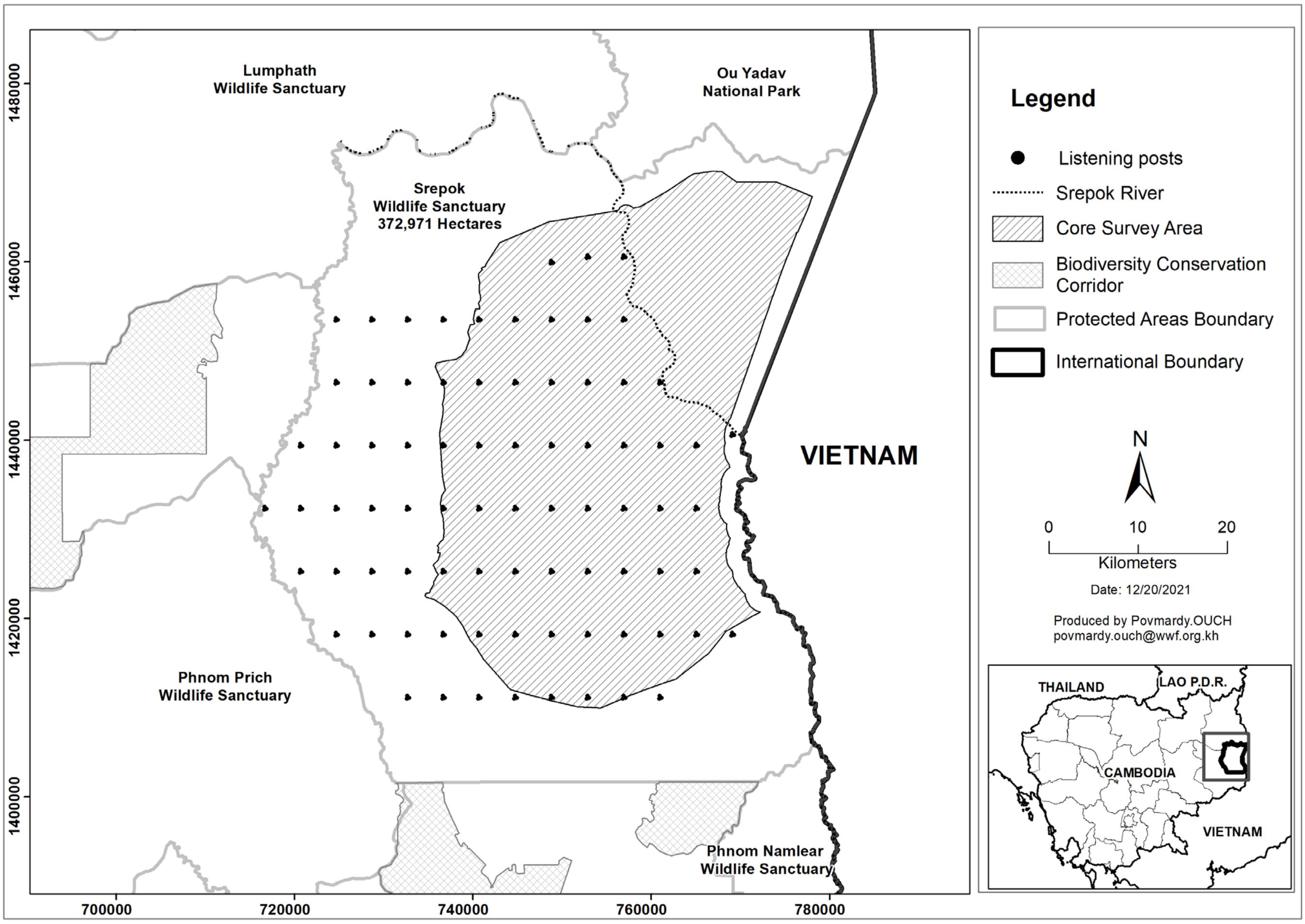

Fig. 1. The 80-point count listening post locations within the core and outer core area of Srepok Wildlife Sanctuary.

(Bruce, 2013). During the dry months this area is subject to reduced water availability and frequent forest fires (McShea et al., 2011).

MATERIAL AND METHODS

Point counts using aural detection. To estimate male green peafowl density and population size we used a systematic grid of point count listening stations across a 2,096 km^2 survey area (1,736 km^2 core area; 359 km^2 located within the outer core area) (Fig. 1). However, due to safety concerns, difficulties in accessibility, and time constraints, the area to the east of the Srepok river was removed from the survey area (Fig. 1). Consequently, the final survey area covered 1,757 km^2 (1,398 km^2 core area and 359 km^2 outer core area). The survey was undertaken during the 2016 dry season (December 2015 to May 2016), which is considered to be the green peafowl breeding season when the frequency of calls by displaying males is at its highest (Sukumal et al., 2015). It was assumed that the calling rate would remain relatively consistent throughout the survey duration.

A total of 80 sampling locations (48 in the core area and 32 in the outer core area) spatially separated by 4 km intervals along a horizontal line and 7 km along a vertical line were included in the survey design (Fig. 1). All sampling locations consisted of three listening posts in a triangular design, spatially separated by 300 m. Each of the three listening posts within a sampling location were surveyed simultaneously by two researchers totalling six researchers per sampling location. Researchers were rotated within each survey pair and between listening posts throughout the survey period. Each array of listening points was surveyed twice daily, once in the early morning (0530–0730 hours) and once in the late afternoon (1600–1845 hours). All surveyors had been trained to estimate the distance of calling males across different habitat types using recorded and actual peafowl vocalisations; the former allowed trainers to check the accuracy of distance estimates recorded. Surveys commenced once distance estimations to recorded vocalisations were consistent and standardised across all surveyors.

Only calling birds were used to estimate green peafowl densities, following similar protocols applied in other peafowl studies (Sukumal et al., 2015, 2017; Saridnurun et al., 2021; Shwe et al., 2021). Any visual sightings were recorded but were not integrated into the final dataset. Upon hearing a calling individual, the researchers recorded: time, angle and estimated distance of the calling male from the observer. Estimated distances were grouped into 100 m intervals (Sukumal et al., 2015). Any detections recorded outside the 1,000 m category were later removed.

Landscape variables. The habitat variables were derived from a 2006 Forestry Administration habitat cover dataset

Table 2. Density estimates of green peafowl in Srepok Wildlife Sanctuary with Coefficient of Variance (CV) and 95% Confidence Intervals (CI) for both survey areas and the combined survey area.

Area	Number of locations	Sampling Area (km^2)	Density Estimate	% CV	95% CI (Lower)	95% CI (Upper)	Abundance Estimate	95% CI (Lower)	95% CI (Upper)
Core	48	1,398	0.56	18.01	0.39	0.79	778	545	1,110
Outer core	32	359	1.08	16.45	0.78	1.49	387	279	535
Both areas	80	1,757	0.66	13.21	0.51	0.86	1,165	897	1,512

and habitat types were classified as: 1=DDF (Deciduous Dipterocarp Forest), 2=EF (Evergreen Forest), 3=NF (Non-Forest), 4=OF (Other Forest), 5=SEF (Semi-Evergreen Forest), 6=WSD (Wood Shrub Dry) and 7=WE (Wood Evergreen).

Peafowl were not recorded in three (EF, WE, and OF) of the seven different habitat types. Thus, in order to investigate the influence of habitat across their range, data analysis was performed using the remaining four habitat variables (DDF, SEF, NF, and WSD). Habitat type was defined as the dominant habitat coverage within a 1 km radius of the midpoint for each of the listening posts using ArcGIS 10.3. Distances to the nearest rivers, waterholes, and villages were calculated from the centre point between the three listening posts using the “near” tool on ArcGIS 10.3.

Data analysis. All audible detections across all listening posts were recorded during the sampling period. Following the same methodology as Loveridge et al. (2017), all audible detections that occurred within 300 m and/or less than 45° from the previous calling male(s) were considered duplicate counts and subsequently discarded. The northern listening post recorded the highest number of independent detections across the majority of 80 sampling locations. Consequently, density estimates were produced using detections from each of the northern listening posts per sampling location.

Data were entered and analysed using Distance software 6.2 and analytical methods followed Buckland et al. (2001). For analytical purposes, all detections were combined, and area specific detection functions and encounters were used to derive male green peafowl density estimates for (1) the whole study area (2) the core area and (3) the outer core area.

We assessed the fit of uniform, half-normal, hazard-rate, and negative-exponential models, with series adjustments of cosine, simple polynomial, and hermite polynomial. The best model and function were selected using the lowest Akaike’s Information Criterion (AIC). If similar AIC values were produced, we visually examined outputs of a quantile-quantile plot (Q-Q plot) and assessed goodness of fit tests (Buckland et al., 2001).

Generalised Linear Models were used to investigate the effects of different landscape variables (habitat, distance to waterhole, distance to river, and distance to village). Models included all recorded green peafowl detections across all sampling locations from the whole survey area (1,757 km^2). To identify the appropriate error term for the response variable (number of calling birds), we examined the distribution of observed data by calculating the variance to mean ratio, which indicated a Poisson distribution was appropriate (variance/mean = 1.357). Each continuous predictor variable (i.e., distance to waterhole, distance to river, and distance to village) was standardised by dividing the values by twice the standard deviation in order to transform data to the same scale (Gelman, 2008). Habitat type was treated as a factor with four variables including DDF, SEF, NF, and WSD. The R packages lme4 and MASS were used to fit Poisson models in a familiarised linear model (R Development Core Team, 2016).

RESULTS

Density estimates. After removing double counts, surveyors recorded a total of 438 male green peafowl calls at 167 of the 240 listening posts (62 of the 80 sampling locations) (Table 2). Of the 438 peafowl calls recorded, 193 were recorded during the morning survey and 245 during the evening survey. The uniform model with cosine adjustment was the best selected model based on lowest AIC score. Results indicate that the mean estimated density across the whole survey area (1,757 km^2) was 0.66 calling males/km^2 (between 6 and 7 calling individuals per 10 km^2; 95% Confidence Interval, CI = 0.51–0.86) with an average population estimate of 1,165 individuals (CI = 897–1,512) (Table 2). Overall mean density and abundance was higher in the outer core area, with 1.08 calling males/km^2 (10 per 10 km^2; CI = 0.66–1.49), than the core area 0.56 calling males/km^2 (5 per 10 km^2; CI = 0.39–0.79) (Table 2).

Environmental Variables. Out of the 65 independent detections in the core area, 92.3% were recorded within DDF, 4.6% in SEF, and 1.5% in both NF and WSD (Table 3). Out of the 71 detections in the outer core, 87.3% of calls were recorded in DDF, 11.3% in SEF, and 1.4% in WSD (Table 3).

The generalised linear model analysis indicated that four of the seven landscape variables had a significant influence on number of birds detected (Table 4). DDF had a significant positive effect, whilst a significant negative effect of NF

Table 3. The percentage of detections per habitat in core and outer core survey areas.

Habitat	Core area % detection	Outer core area % detection
Deciduous Dipterocarp Forest	92.30	87.32
Semi-evergreen Forest	4.61	11.26
Non-Forest	1.53	0
Wood Shrub Dry Forest	1.53	1.40

Table 4. Landscape parameter results from Generalised Linear Models. Parameters considered significant had a *p*-value < 0.05.

Parameters	β	Standard Error	Z-Value	p-value
Distance to waterhole	0.237	0.164	1.447	0.147
Distance to village	-0.872	0.203	-4.297	0.001
Distance to river	-0.663	0.200	-3.315	0.001
Deciduous Dipterocarp Forest	0.985	0.227	4.343	0.001
Non-Forest	-1.983	0.718	-2.761	0.005
Semi-evergreen Forest	-0.346	0.282	-1.229	0.218
Wood Shrub Dry Forest	-1.287	0.7237	-1.778	0.075

habitat was also evident (DDF: $\beta = 0.985$, $P < 0.001$ and NF: $\beta = -1.983$, $P < 0.005$), thus suggesting that peafowl were less likely to be detected in the 'non-forest habitat' type. The presence of waterholes did not significantly influence peafowl presence. However, distance to village ($\beta = -0.872$, $P < 0.001$) followed by distance to river ($\beta = -0.663$, $P < 0.001$) exhibited a significant negative influence on the number of detections, indicating that numbers of detections were higher in closer proximity to rivers and villages (Table 4).

DISCUSSION

Accurate population and density estimates are an essential part of monitoring endangered species. However, obtaining a sufficient number of visual detections to produce robust density estimates as recommended by Buckland et al. (2001) can prove difficult for elusive forest dwelling Galliformes. If sufficient detections cannot be obtained in one survey period, pooling data over several survey years may be necessary, which is both costly and labour-intensive. Since Galliformes can be reliably vocal, distance-based sampling using bird vocalisations is becoming increasingly used to estimate densities for an array of Galliformes including green peafowl (Sukumal et al., 2015, 2017; Loveridge et al., 2017; Saridnurun et al., 2021; Shwe et al., 2021), Great Argus *Argusianus argus* (Dawrueng et al., 2017), Germain's Peacock Pheasant *Polyplectron germaini*, and Orange-necked Partridge *Arborophila davidi* (Nguyen et al., 2018). However, obtaining precise distance estimates of vocalisations can be problematic. To ensure key distance sampling assumptions are not violated, audible detections should be grouped into appropriate distance intervals (Gale et al., 2009), and rigorous distance training is required to improve accuracy and reduce estimation error between surveyors, both of which were applied during this survey.

Using distance-based point counts of vocalisations, we estimated male green peafowl densities over a large survey area during a single season. Results produced an overall mean density estimate of 0.66 calling males/km^2 (CI = 0.51–0.86), thus highlighting the global importance of Srepok for green peafowl in Cambodia (Table 1). Our findings suggest that Srepok supports higher male green peafowl densities than the total (male and female) mean densities produced by Nuttall et al. (2017) from the nearby Keo Seima Wildlife Sanctuary (Table 1). Whereas, male green peafowl density estimates from the ecologically similar Siem Pang Wildlife Sanctuary in north-eastern Cambodia recorded by Loveridge et al. (2017) were relatively similar to the male green peafowl densities in Srepok (Table 1). Keo Seima Wildlife Sanctuary has a higher coverage of denser forest types, whereas DDF is the predominant habitat type in Srepok. The higher proportion of DDF coverage in Srepok and Siem Pang Wildlife Sanctuary could potentially explain the higher male green peafowl densities. However, to determine the influence of differing habitat types on peafowl abundance, further research utilising the same methodologies is required across these important green peafowl sites.

Unfortunately, historical scientific baseline population estimates are non-existent for green peafowl in Cambodia. Nonetheless, estimated densities produced in this study, as well as other sites in Cambodia and Vietnam (Table 1) are considerably lower than Huai Kha Khaeng Wildlife Sanctuary (Sukumal et al., 2017) and other sites in northern

Thailand (Saridnurun et al., 2021) (Table 1). Thus, it is highly likely that green peafowl populations in Cambodia have been kept low over recent decades due to a range of anthropogenic factors. Habitat modification, exploitation, human-induced fires, and overgrazing have been listed as some of the key factors contributing to the density declines (Sukumal et al., 2015). Similar threats continue to occur at differing levels throughout Srepok and Cambodia. Thus, in order to curb future declines and conserve remaining fragmented populations it is crucial that evidence-based adaptive strategies are developed.

Conservation and management implications. Hunting of peafowl is particularly acute, supplying the demand for ornamental displays, meat consumption, and the pet trade (BirdLife International, 2001). Both singular and multi-species hunting techniques are used in Cambodia to target mammals and birds, and the placement of lethal traps/snares continues to pose a significant threat to an array of globally threatened species (Gray et al., 2018; Belecky & Gray, 2020). During our study period, more than 3,000 snares were removed by patrol and research teams in 2016 (Groenenberg et al., 2020). Despite law enforcement efforts, placement of snares and targeted shooting of wildlife was still evident throughout Srepok, especially blanket snaring occurring close to seasonal water sources. Whilst results from this study indicated that presence of waterholes did not significantly influence peafowl presence, it is still likely that remaining populations will be vulnerable to intensive rates of snaring, due to their ecological traits as a ground-dwelling species that congregate in open areas (Loveridge et al., 2017; Nuttall et al., 2017; Sukumal et al., 2017; Pin et al., 2020). Therefore, urgent adaptive law enforcement strategies are required to combat different illegal hunting techniques. Otherwise population declines of green peafowl are inevitable.

Local residents from several villages in and around Srepok reported that green peafowl damage agricultural crops (Crouthers, 2021). Consequently, lethal mitigation measures, including the placement of snares and poison along farmland boundaries to protect crops and livelihoods (Crouthers, 2021), also pose a threat to green peafowl populations utilising these areas. As land conversion and habitat modification continue to shrink the remaining forested areas, negative interactions between people and peafowl are likely to intensify (Crouthers, 2021). Moreover, results from this study highlight that peafowl densities are higher in more disturbed areas, and peafowl presence was negatively associated with distance from villages. These findings were contrary to the expectation that green peafowl densities would be higher in less disturbed DDF areas.

In order to enable and maintain a positive relationship between people and green peafowl, there is an urgent need to develop and implement cross-disciplinary strategies. Furthermore, it is crucial that such approaches consider and address both the threats to the peafowl and the needs of the local communities. One potential approach could involve creating community cooperatives to grow organic or wildlife-friendly agricultural products such as a current wildlife certified project in northern Cambodia called the Ibis Rice project. Adapting and integrating such initiatives into remaining peafowl populations could prove mutually beneficial to both people and wildlife.

In addition, future protected area management strategies should incorporate a fire management component. Natural fires can assist in developing and maintaining dry forested areas (Ratnam et al., 2016) and can have low impact on seasonal tropical forests, if they remain infrequent with low burn rates (Baker & Bunyavejchewin, 2009). However, frequent burns can also negatively impact forest composition by consistently clearing large sections of understorey vegetation (McShea et al., 2011). The repeated loss of understorey vegetation due to frequent and widespread human-induced fires occurring in Srepok could prove highly detrimental for ground-dwelling species, particularly as frequent forest fires simultaneously impact food availability and reproductive success rates, given that green peafowl build shallow nests on the forest floor. Hence, it is essential that protected area management strategies incorporate measures to control the frequency and spread of both natural and human-induced fires.

Overall, our results highlight the global significance of Srepok for supporting an important population of endangered green peafowl. In addition, results from this study further emphasise the importance of producing basic population measures in conjunction with understanding habitat utilisation and current threats. Whilst the number of studies producing green peafowl density estimates across Southeast Asia has increased over the last decade, it is still difficult to accurately compare densities across sites due to different methodological techniques used and analytical tools applied. To monitor range-wide population trends and assess the effectiveness of conservation strategies, there is a pressing need to develop a cost-effective standardised method across the remaining green peafowl range.

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