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Article

# Habitat Preference of Key Wildlife Species in One of the Largest Lowland Evergreen Forests in Southeast Asia

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## Abstract

Wildlife plays a vital role in maintaining ecological balance and biodiversity, relying on habitats that provide shelter, food, and essential resources. This study investigated wildlife distribution and diversity across the REDD+ program area in Cambodia's Prey Lang Wildlife Sanctuary, a lowland evergreen forest ecosystem, and assessed the effects of forest habitats and anthropogenic pressure on their distribution. We used square transects for sampling and ArcGIS to calculate forest cover and distance to the nearest village as a proxy for human impact. Overall, we recorded seven mammals and two birds, with the great hornbill most frequently detected, followed by pileated gibbon, wild pig, long-tailed macaque, green peafowl, northern red muntjac, and Indochinese silvered langur; gaur and sambar deer were least detected. Wildlife richness and abundance were higher in evergreen-dominated habitats than in mixed deciduous-evergreen forests. Certain K-selected species, including pileated gibbon, Indochinese silvered langur, and great hornbill, were highly specialized and preferred intact forests, whereas generalist species such as northern red muntjac, long-tailed macaque, and wild pig showed ecological flexibility in habitat use. These findings emphasize tailored conservation strategies: protecting intact evergreen forests via REDD+ supports specialized species, while adaptive management in mosaic landscapes benefits generalists, enhancing wildlife conservation and sustainable management of Prey Lang Wildlife Sanctuary.

**Keywords:** distance sampling; transect survey; K-selected species; generalist species; mammals; birds; great hornbill

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## 1. Introduction

Wildlife is an important component in natural ecosystems by contributing to ecological balance and biodiversity [1]. Their survival, reproduction and daily activities in the ecosystem require a suitable habitat that provides essential resources such as food, water, shelter, and space [2]. The required amount of these resources is varied from one to another taxonomic group and habitat types. For instance, some K-selected species such as the Asian elephant and gaur in lowland evergreen forest are more associated with dense forest cover and perennial water sources [3,4]. Bird species such as the great hornbill are influenced by the availability of large fruiting trees and nesting cavities [5], and others such as the giant ibis, lesser adjutant, and Asian woolly-necked stork have been mainly recorded from protected areas where deeper waterholes and wetlands are present [6].

Lowland evergreen forests are globally recognized for their exceptional biodiversity and complex ecological interactions, particularly species habitat relationships [7]. In mainland Southeast Asia, Cambodia's Prey Lang Wildlife Sanctuary (PLWS) represents one of the largest remaining tracts

of lowland evergreen forest, comprising a mosaic of evergreen and deciduous forest types [7]. PLWS supports a remarkable diversity of wildlife, including iconic species such as the Asian elephant, Malayan sun bear, pileated gibbon, long-tailed macaque, great hornbill, and green peafowl [8,9]. Notably, species richness recorded from this sanctuary are highest in the dense forest areas concentrated near the core zone, whereas wildlife abundance appears more randomly distributed across the broader landscape; for example, wild pig, Malayan sun bear, northern red muntjac, and long-tailed macaque [9,10].

In Cambodia, diverse forest ecosystems across protected areas continue to support rich wildlife biodiversity, yet research on species' habitat preferences remains limited. Some exceptions include the study of Gray et al. [11] investigating the habitat requirements of Bengal florican and found that the species depends on grassland habitats maintained by traditional agricultural practices. Gray et al. [10] assessed the status and habitat preferences of wild cattle and large carnivores in eastern Cambodia, indicating that these species rely on mosaics of deciduous dipterocarp and mixed deciduous/semi-evergreen forest. Similarly, Gray and Phan [12] reported that large mammals in Phnom Prich Wildlife Sanctuary prefer mixed-deciduous and semi-evergreen forest. While these contributions provide valuable insights, the habitat preferences of other wildlife species in different protected areas, including the PLWS, remain poorly understood. Moreover, the influence of different forest cover classes (e.g., evergreen forest, semi-evergreen forest, dry dipterocarp forest) and anthropogenic pressures on wildlife distribution is scarcely documented, despite increasing threats from logging, land encroachment, and hunting.

To address this need and contribute to biodiversity research on habitat preferences of key species in PLWS, we (1) investigate the distribution patterns, species diversity, richness and abundance of ecologically important mammal and bird species across the sanctuary, and (2) assess the levels of impact of evergreen forest proportion and anthropogenic pressure on the faunal distribution. The results of this study also serve as a baseline survey using the transect sampling for long-term biodiversity monitoring in the area, and a preliminary assessment of the REDD+ project implementation. Previous records of the target species are also discussed and compared with their present records in this study to confirm their existence in the PLWS.

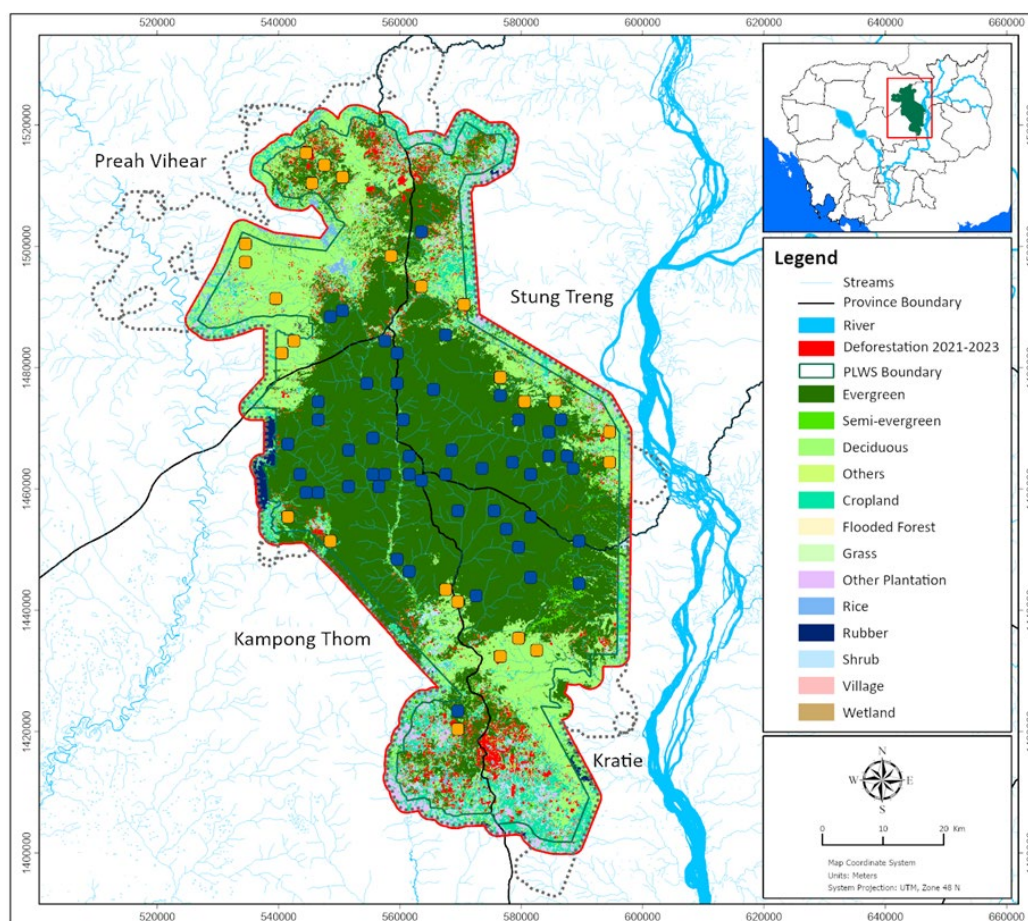
## 2. Methodology

### 2.1. Study Site

The study was conducted at PLWS, located in the central plains of Cambodia which comprises areas from four provinces, including Stung Treng, Kampong Thom, Preah Vihear, and Kratie. The total area of the PLWS is 4316.83 km<sup>2</sup>, mainly attributed to evergreen forest (57%) and de-ciduous forest (26%). PLWS experiences a tropical climate with distinct wet and dry seasons. The wet season typically spans from May to October, with the southwest monsoon bringing substantial rainfall, while the dry season lasts from November to April. During this period, the region receives approximately 1,300 to 1,800 mm of precipitation annually.

PLWS is essential to the well-being of over 250,000 indigenous and local people. The majority of local communities live in the western and northern parts of Prey Lang (particularly in Kampong Thom and Preah Vihear provinces) (Figure 1). The forest is deeply woven into their cultural and spiritual lives, and they rely heavily on the rich ecosystem services from the forest to meet their social and economic needs. Local villagers engage in fisheries and agriculture, and gather resin, building materials, medicine, and local food from the forest, with many depending on these resources for their livelihoods [13].

Our study site is located in the REDD+ project area (3752 km<sup>2</sup>) of the PLWS. As of the 2023, this REDD+ project area is mainly characterized by evergreen forests (69%), deciduous forests (24.35%), semi-evergreen forests (0.14%), cropland (0.33%), grassland (1.94%), and other plantations (0.043%). Forest clearance for agriculture is also occurring within the sanctuary, with an estimated rate of approximately 0.81% [14].



**Figure 1.** Map of Prey Lang Wildlife Sanctuary and the selected quadrat-transect lines (squares) inside the REDD+ area, with high-intact forest indicated in blue and moderate-intact forest in yellow.

## 2.2. Target Species

Fifteen species of mammals and birds were targeted for the survey (Table 1). The selection of these is based on the fact that their occurrences are crucial for informing conservation strategies and facilitating the development of targeted management plans, particularly for species experiencing population declines. The fifteen species are also of high conservation value (i.e., Threatened category in the IUCN Red List) and their ecological and biological significance in the ecosystem. For instance, gibbons are critical for seed dispersal, while dholes serve as top predators, regulating prey population in the landscape [15,16]. These species play pivotal roles in maintaining ecological balance and are therefore essential components of conservation monitoring efforts [17]. For additional information on each species, we refer to Table 1 below.

**Table 1.** Selected species for key biodiversity monitoring at PLWS, their IUCN status, ecological roles, and previous record in PLWS.

Common name	Scientific name	IUCN Status	Ecological roles	Previous records
Asian elephant	<i>Elephas maximus</i>	EN	Seed dispersal, habitat creation, and vegetation modification [18]	[8,9,19]
Banteng	<i>Bos javanicus</i>	EN	Seed dispersal [20]	[8,9,19]
Gaur	<i>Bos gaurus</i>	VU	Plant population control and main prey for large carnivores [21]	[9,19]
Dhole	<i>Cuon alpinus</i>	EN	Prey regulation [16]	[9,19]

Sambar deer	<i>Rusa unicolor</i>	VU	Seed dispersal and keystone herbivore (Quin, Morgan, & Murphy, 2023)	[8,9,19]
Northern pig-tailed macaque	<i>Macaca leonina</i>	VU	Seed dispersal and forest regeneration [22]	[9,19]
Pileated gibbon	<i>Hylobates pileatus</i>	EN	Seed dispersal [23]	[9,19]
Indochinese silvered langur	<i>Trachypithecus germaini</i>	EN	Regulate vegetation growth and forest structure [24]	[9,19]
Long-tailed macaque	<i>Macaca fascicularis</i>	VU	Seed dispersal and insect control through predation [25]	[8,9,19]
Northern red muntjac	<i>Muntiacus vaginalis</i>	LC	Herbivory, seed dispersal, and serving as prey species [50]	[8,9,19]
Wild pig	<i>Sus scrofa</i>	LC	Soil disturbance, seed dispersal, and maintaining ecological balance [26]	[8,9,19]
Great hornbill	<i>Buceros bicornis</i>	VU	Seed dispersal, forest regeneration, and ecological balance [27]	[9,19]
Green peafowl	<i>Pavo muticus</i>	EN	Feeding on plants and dispersing seeds [28]	[8,9,19]
Malayan sun bear	<i>Helarctos malayanus</i>	VU	Seed dispersal and maintenance of forest understory structure [29]	[8,9,19]
Asiatic black bear	<i>Ursus thibetanus</i>	VU	Seed dispersal and insect control [30]	[8,9,19]

### 2.3. Transect Designs and Development

In this study, we used a 1-km side square transect (i.e., 1-km<sup>2</sup> grid) as the distance sampling method. This approach is an effective method to estimate key species density and population size and is a standard monitoring approach in two other protected landscapes in Cambodia [31].

A total of 74 1-km side squares were randomly selected across the REDD+ project area in PLWS (Figure 2) using Global Information System ArcMap 10.81. We initially randomly selected 400 grids 1 km<sup>2</sup> grid. We removed grids that were adjacent or connected to each other to allow for independence and areas that had been previously deforested. This resulted in a reduced set of 149 grids. Due to time, resources, and logistic constraints, we randomly selected 74 grids from the 149 grids. The number of grids selected eventually corresponds to ~2.4% of the total area. This approach of using a subset of grids is commonly practiced in ecological studies, where sampling a smaller representative area is both efficient and effective for data collection and analysis [32].

Comprehensive training sessions of the field teams were conducted from July 26–28, 2022, to ensure that sampling and methodological protocols were highly adhered (Figure 2a). Transects were established and marked using a compass and paints to direct and mark the transect trails and corners. The transect trails along the four sides of each square were cleared using machetes, creating a trail width of ~1 m to minimize the impact on vegetation covers.

For each square transect, a trail of 4-km cumulative length (4 sides \* 1-km length) required a collaborative effort of 8 individuals, with an average of 6- to 8-hour work. We spent approximately 4 months to complete the 74 square transects development at the study site, commencing on September 13, 2022, and concluding on December 29, 2022. The total length of all transect trails is 296 km.

### 2.4. Data Collection, Processing, and Preparation

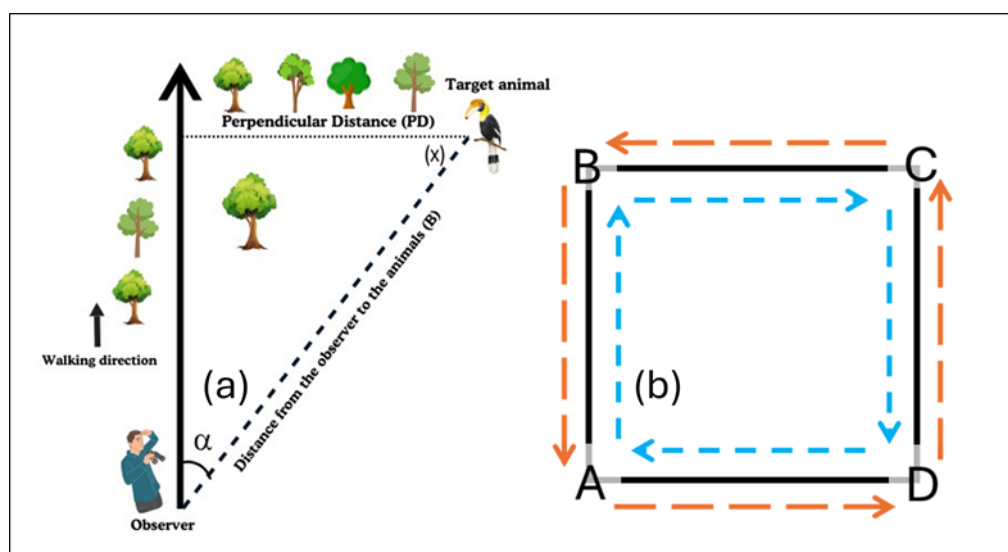
The data collection period was from January 13 to May 21, 2023, corresponding to the second half of the dry season (which runs from around December through May). The order of square transects establishment was arranged for the data collection, meaning that the square transect that was first developed was chosen for the first data collection, and so forth. In this way, each square

transect had about four months without any human presence. We adopted this process to minimize the effect of human-made trails on animal behaviors (e.g., foraging, courting, etc.).

Each square transect was walked twice per day, once in the morning from 06:00 – 11:30 and once from 13:00– 16:30. The morning team began their walk from right to left (4 km) at a starting point and ended their walk when arriving at the starting point. The afternoon team reversed their walk direction from left to right (4 km), beginning and ending also at the same starting point (Figure 2b). Each team consisted of two trained observers who walked along the transect line. One observer focused on the area directly along or near the transect, while the other observer focused on the areas to the left and right of the transect [31]. Only animals detected through direct visual sightings were recorded; other evidence such as calling or signs was not included in this study. During the survey, team members remained silent to avoid disturbing wildlife. They walked slowly along the transects, stopping whenever animals were observed. If no animals were detected, they paused every 50 meters to conduct a careful search.

A Global Positioning System (GPS) unit was used to record the relative location of detected animals. Some other field equipment was also used: a timer to record the time during the survey, a compass to measure the bearing from the observer to the detected animals, and a laser rangefinder to measure the distance from the observer to the detected animals. A measuring tape was used instead in case the laser rangefinder was not applicable, e.g., in a densely forested area.

The perpendicular distance (PD) from the transect line to the detected animals was computed using the formula:  $D = B * \sin\alpha$ , where  $B$  is the distance from the observer to the detected animals and  $\alpha$  is the bearing angle between the walking direction along the transect and the detected animals (Figure 2a). The perpendicular distance was also calculated for further analysis to estimate the density of target species.



**Figure 2.** The distance sampling design. (a) The observers walk along the transect line following the walking direction, and (b) the opposite walking direction between the morning (blue short-dashed line) and the afternoon (orange long-dashed line) that begins and ends at the starting point [33].

### 2.5. Forest Cover Proportion Calculation and Anthropogenic Pressure

The estimation of forest cover proportion and anthropogenic pressure is used to assess the levels of their impact on the faunal distribution. The percentage of forest cover classes (e.g., evergreen forest, cropland, dry dipterocarp forest, semi-evergreen forest, shrub, other plantations, rice field, and grass) representing the forest habitat for each transect was calculated from an area of 9 km<sup>2</sup>, combining each surveyed transect located in the center and surrounding eight 1-km side squares. The process of combining the surrounding 8 km<sup>2</sup> was the same across the 74 square transects. An area of 9 km<sup>2</sup> is indicative of habitat preference for animals' daily activities, especially foraging [34]. Based on the

2023 forest cover, deforestation and administrative data [14], we used ArcGIS version 3.4.0 to calculate the percentage of each forest cover class characterizing each surveyed transect, and the distances from each transect to the nearest village center and the nearest deforested areas. These distances are considered proxies for anthropogenic pressure on wildlife distribution.

From the calculated percentage of forest cover classes characterizing each transect, we further categorized them into two main habitat types: the forest habitat dominated by evergreen forest or the highly intact forest (hereafter refers as high-intact) habitat, which comprises  $\geq 80\%$  of evergreen forest, and the forest habitat dominated by deciduous and evergreen forest or the moderately intact forest (hereafter refers as moderate-intact) habitat, which comprises  $< 80\%$  of evergreen forest. We used these thresholds because most of the global intact forest habitats comprise an approximately 75% of evergreen forest [35]. This selecting criterion (80% thresholds) is important to indicate landscape biodiversity hotspots or climate-sensitive regions for ensuring long-term sustainability of the study landscape, PLWS. The two categories of forest habitats were classified to analyze their association with wildlife diversity, species composition, and occurrences.

## 2.6. Data Analysis

### 2.6.1. Species Distribution, Detection, and Diversity

For each transect, the total number of species (richness), individuals (abundance), and the diversity index (Shannon index, the higher value indicates the higher diversity) were computed. We also calculated the encounter rate (per km) for every sighted animal in each square transect by taking the total number of sightings of each species divided by the length of the transect walked, as described by Pramod et al. [36]. ArcMap 10.81 was then used to project the number of species and their abundance recorded onto a map to illustrate their distribution patterns. To detect differences, species diversity metrics, such as richness, abundance, and Shannon diversity index (diversity H), were compared between the high- and moderate-intact forest habitats using an unpaired t-test, given that the two datasets had a normal distribution and homogeneity of variance; otherwise, the alternative Mann-Whitney U test was used.

### 2.6.2. Influences of Habitat Characteristics and Anthropogenic Pressure

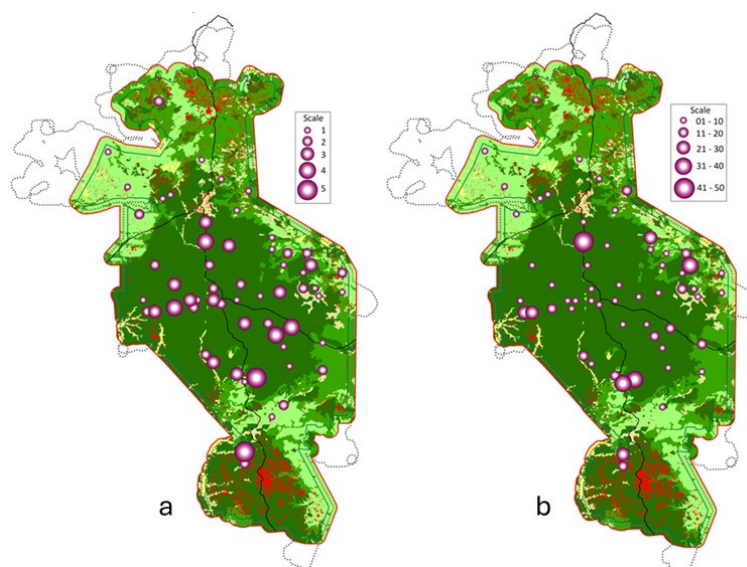
Logistic regression analysis was employed to evaluate the influence of habitat characteristics (evergreen forest, cropland, dry dipterocarp forest, semi-evergreen forest, shrub, rice, other plantation, rice and grass) and anthropogenic pressure (distances from each transect to the nearest village center and the nearest deforested areas) on the presence or absence of detected wildlife species. The logistic regression model was used because it can estimate the probability of species occurrence at each site, revealing how different habitat characteristics and proximity to human activities and settlements influence habitat suitability of wildlife species [37,38]. In this model, the presence/absence of wildlife species was fitted using the standardized predictor variables, which were measured on different scales (e.g., kilometers and hectares) [39]. To identify which predictors mainly influence wildlife occurrence distribution, we performed a forward stepwise selection starting from a null model (no predictor included) to the final model that selected the most important predictors from the full model (all predictors included). This process resulted in a parsimonious logistic regression model, based on the lowest value of the Akaike's Information Criterion (AIC), that included only the predictors that significantly contributed to explaining the variation in the presence/absence of the wildlife species. Moreover, to analyze whether any of the key species has a forest habitat preference, we used a chi-square test to identify a significant association between the presence-absence of each species and the two categorized forest habitat types (high- and moderate-intact habitats). For the analysis that yielded significant association results ( $p < 0.05$ ), we sorted the frequencies of only the presence data of the species and then compared their frequency between the two forest habitat types using also the Chi-Square test. This two-step chi-square analysis provides a sound and reliable result indicating which condition of the forest is the preferred habitat of sighted

animals and thus informing conservation strategies in human-impacted landscapes. All statistical analysis was performed using the R statistical program, and the p-value  $<0.05$  was considered significant for all analysis.

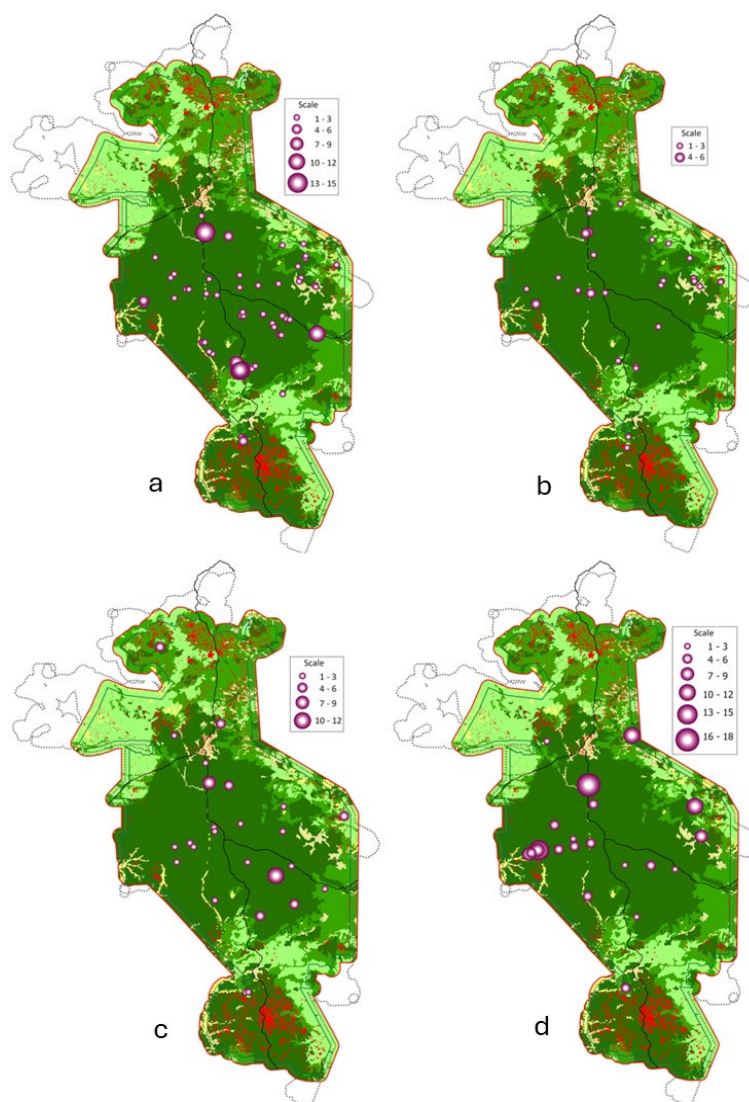
### 3. Results

#### 3.1. Distribution Patterns and Diversity

Out of the fifteen species targeted, we detected only nine during the entire course of the survey. Seven species were mammals, and the remaining two species were birds. The most detected animal were great hornbills (*B. bicornis*, 76 sightings), followed by pileated gibbons (*H. pileatus*, 31), wild pigs (*S. scrofa*, 25), and long-tailed macaques (*M. fascicularis*, 23); whereas the least detected species, with only one sighting, were gaur (*B. gaurus*) and sambar deer (*R. unicolor*) (Table 2). We found no distinct spatial pattern emerged from the observational data across the sanctuary, but species counts were notably lowest in the northern sections of the park (Figure 3a) and abundance were highest around the central area of the park (Figures 3b). This pattern was similarly observed for the four most detected species (Figure 4a-d). For the least detected species, however, the small number of detections prevented a clear spatial inference (Figure A1).



**Figure 3.** The distribution pattern of species richness (a) and abundance (b) of the target species recorded from the transect survey.



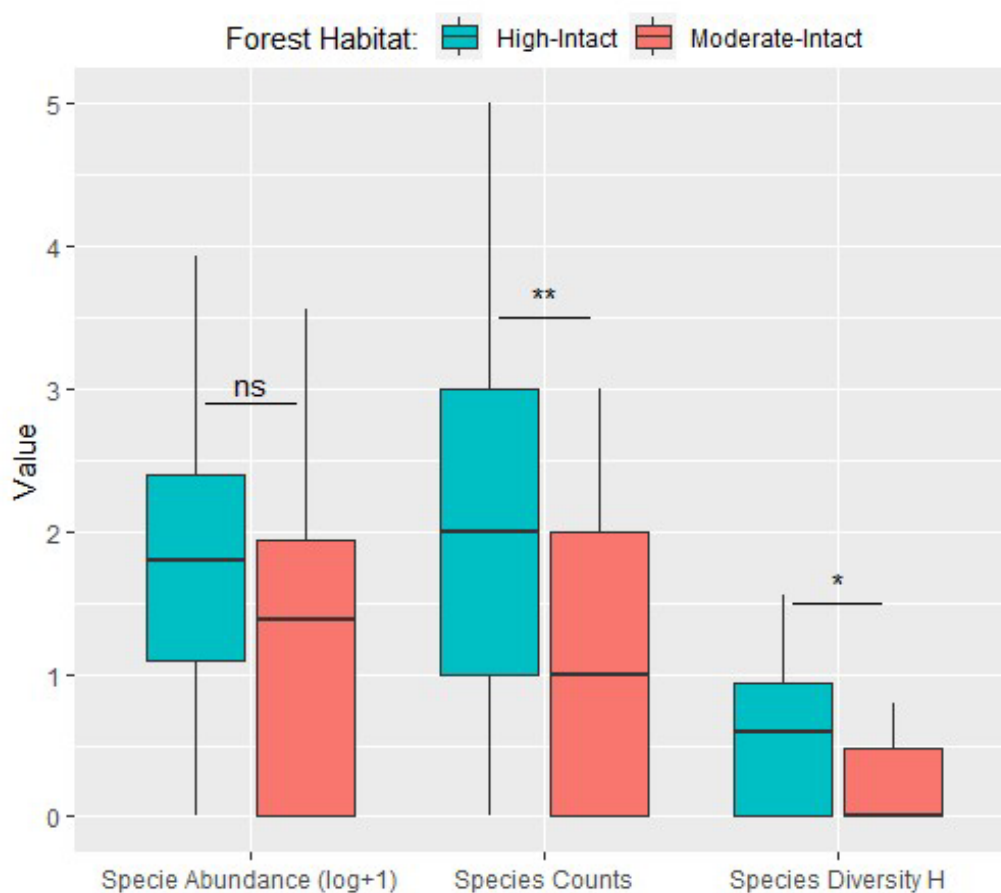
**Figure 4.** Abundance distribution pattern of the four most detected species: (a) great hornbill, (b) pileated gibbon, (c) wild pig, and (d) long-tailed macaque.

**Table 2.** The detected species and their numbers of sighting, average cluster size, and encounter rate. .

No	Common name	Scientific name	# Detections/ sightings	Cluster Size (average)	Encounter rate
1	Great hornbill	<i>B. bicornis</i>	76	2.34	0.826
2	Pileated gibbon	<i>H. pileatus</i>	31	2.23	0.337
3	Wild pig	<i>S. scrofa</i>	25	2.88	0.272
4	Long tailed macaque	<i>M. fascicularis</i>	23	5.96	0.250
5	Green peafowl	<i>P. muticus</i>	13	1.62	0.141
6	Northern red muntjac	<i>M. vaginalis</i>	10	1	0.109
7	Indochinese silvered langur	<i>T. germaini</i>	8	8.13	0.087
8	Gaur	<i>B. gaurus</i>	1	1	0.011
9	Sambar deer	<i>R. unicolor</i>	1	1	0.011

Overall, we detected an average of  $1.6 \pm 1.27$  species,  $7.6 \pm 9.75$  individuals, and  $0.4 \pm 0.46$  of diversity H per transect. When computed based on each forest habitat type, the high-intact habitat supported an average of  $1.9 \pm 1.4$  species,  $8.5 \pm 10.4$  individuals, and  $0.49 \pm 0.49$  of diversity H; while the moderate-intact habitat supported an average of  $1.0 \pm 0.89$  species,  $5.8 \pm 8.3$  individuals, and  $0.21 \pm 0.29$  of diversity H per transect. Based on the Mann-Whitney U test, species richness ( $p = 0.008$ ) and species

diversity H ( $p = 0.015$ ) were found to be significantly higher in the high-intact habitat compared to the moderate-intact habitat (Figure 5).



**Figure 5.** Box plots of species richness (counts), abundance, and diversity H between the high- and moderate-intact forest habitats.

### 3.2. Habitat Preference and Anthropogenic Pressure

Based on the logistic regression model, evergreen forest was selected as the most important variable, appearing in the final models for three species – great hornbill, pileated gibbon, and northern red muntjac. It had a positive association with the occurrence of great hornbill (coefficient = 1.54) and pileated gibbon (0.69), but a negative association with northern red muntjac (−2.67). Dry dipterocarp forest was selected as the key variable negatively influencing the occurrence of green peafowl (−798.56) and long-tailed macaque (−1.01), while other plantations positively associated with the occurrence of the northern red muntjac (5.23) and long-tailed macaque (0.46). Cropland, rice field, and the distance to nearest village, were important variables for only one species; cropland exhibited a positive association (30.22) with green peafowl, rice field and distance to nearest village showed negative associations with Indochinese silvered langur (−506.7) and northern red muntjac (−3.6), respectively. No predictors were retained as the key predictors in the final model for wild pig (Table 3).

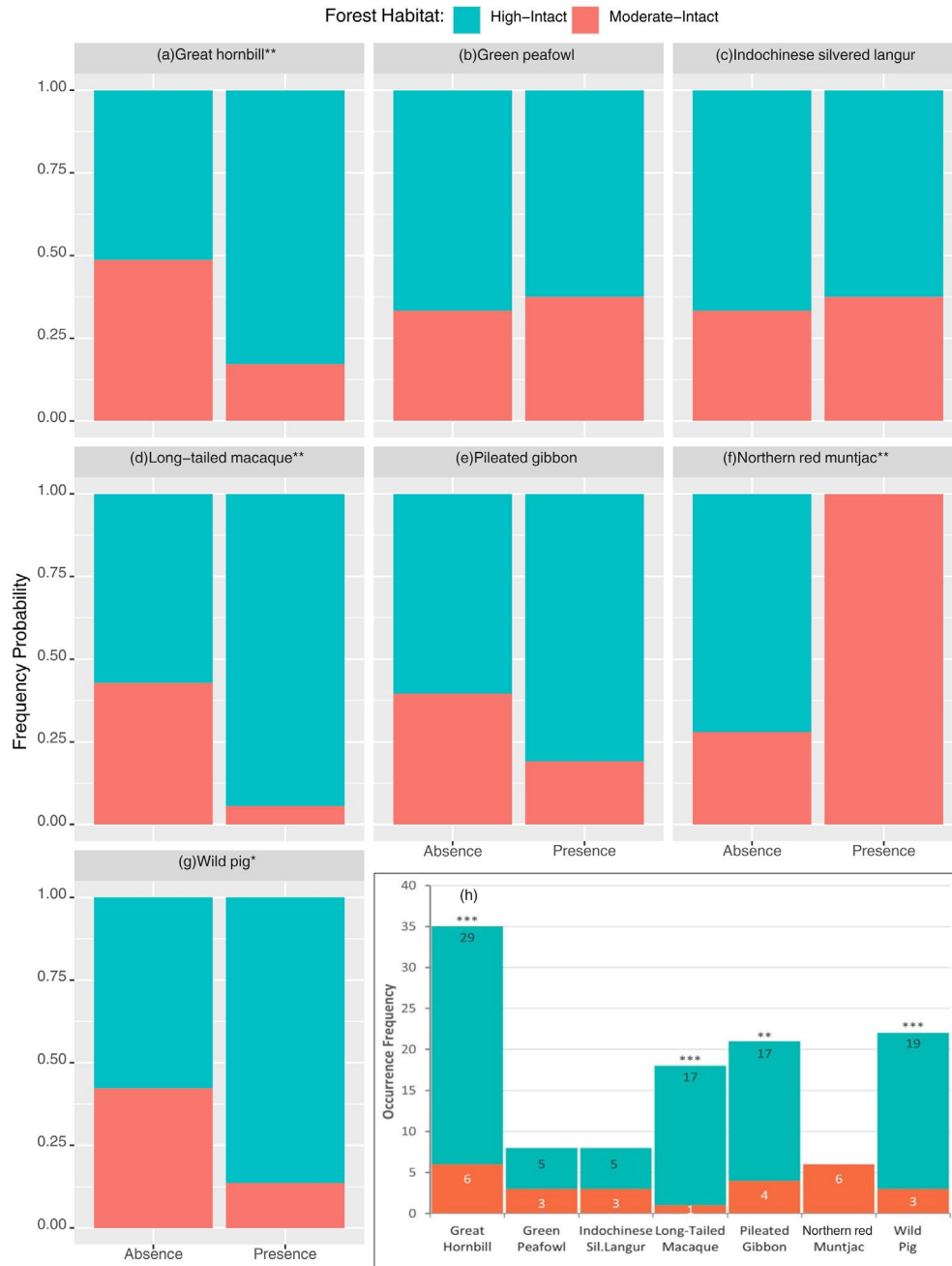
**Table 3.** The variables influencing the presence/absence of wildlife species based on results of multiple logistic regression analysis indicate selected variables (from most to least important) retained in two models based on the minimum AIC value.

<u>Wildlife Species</u>	<u>Important variables selected for the final model</u>						<u>AIC</u>	
	<u>EVE</u>	<u>DDF</u>	<u>OTP</u>	<u>CRL</u>	<u>RIF</u>	<u>DNV</u>	<u>Full model</u>	<u>Final model</u>
Great hornbill	1.54	-	-	-	-	-	92.98	85.89
Pileated gibbon	0.69	-	-	-	-	-	96.74	87.64
Indochinese silvered langur	-	-	-	-	-506.7	-	1103.3	49.62
Northern red muntjac	-2.67	-	5.23	-	-	-3.6	22	20.94
Green peafowl	-	-798.56	-	30.22	-	-	48.41	34.66
Long-tailed macaque	-	-1.01	0.46	-	-	-	91.42	80.32
Wild pig	-	-	-	-	-	-	107.7	-

**Note:** EVE = Evergreen Forest; DDF = Dry Dipterocarp Forest; OTP = Other Plantations; CRL = Cropland, RIF = Rice Field, DNV = Distance to Nearest Village; (+) indicates a positive association; and (-) indicates a negative association.

From the comparative analysis of species-habitat preference, we found that the presence-absence of great hornbill (Chi-squared = 6.87,  $p = 0.009$ ), long-tailed macaque (Chi-squared = 6.89,  $p = 0.009$ ), northern red muntjac (Chi-squared = 9.78,  $p = 0.002$ ), and wild pig (Chi-squared = 4.47,  $p = 0.034$ ), were significantly dependent on the conditions of the forest habitats (high- vs. moderate-intact habitats). The presence probability of great hornbill, long-tailed macaque, and wild pig is strongly dependent on the high-intact forest habitat, whereas that of northern red muntjac was entirely dependent on the moderate-intact habitat (Figure 6a-g).

Further analysis of the comparison of species presence data revealed a significantly high occurrence frequency of great hornbill, long-tailed macaques, pileated gibbon, and wild pig in the high-intact forest habitats (Figure 6h).



**Figure 6.** Results of habitat preference analysis. The significant association between the species presence-absence and the two types of forest habitats: high-intact and moderate-intact (a-g), and the significant differences in the proportion of occurrence frequency of the species between the two types of forest habitats (h).

#### 4. Discussion

We detected nine species out of the 15 targeted species that are important for ecosystem functions, e.g. Indochinese silvered langur regulates forest growth and structures, pileated gibbon distributes plant seeds across their habitat, while others play different important roles in their ecosystems such as seed dispersal, plant and insect population control, vegetation modification, and forest regeneration (see Table 1).

Average species richness and abundance were significantly higher in high-intact forest habitats, suggesting these areas are preferred by forest-dependent wildlife. This observation is consistent with Gibson et al. [40] who emphasized the critical and irreplaceable role of high-intact forests in sustaining tropical biodiversity. Compared to moderate-intact forests, high-intact forests generally

support greater biodiversity due to increased food availability, numerous microhabitats, and diverse tree compositions [41]. These forests also provide essential cover from predators and protection from environmental and anthropogenic disturbances [42]. Furthermore, they demonstrate greater resistance to short-term climatic anomalies such as droughts and wildfires, and support high intraspecific genetic diversity, which enhances species' adaptability to changing environmental conditions [43].

The analysis of habitat preference and anthropogenic pressure reveal a clear ecological gradient among the detected species in relation to forest integrity. Highly specialized species like great hornbill and pileated gibbon are strongly associated with high-intact forests, underscoring the need for strict protection of evergreen forest ecosystems to ensure their survival [44,45]. The Indochinese silvered langur, also a specialized species, showed a negative association with rice fields, indicating its sensitivity to human-modified landscapes and highlighting the detrimental impacts of agricultural expansion. These findings align with global studies demonstrating the vulnerability of K-selected species such as gibbons and langurs, and forest-dependent species (hornbills) to habitat loss and fragmentation [46,47].

On the other hand, species such as the northern red muntjac, long-tailed macaque, and wild pig exhibited greater adaptability. These species were found either in the high- or moderate-intact forests or human-modified landscapes including plantations, croplands, and areas near villages (Figure 6, Table 3). Their presence in these environments suggests either a lower sensitivity to disturbance or an ability to exploit available resources. While this adaptability may indicate resilience, it could also reflect shifts in ecological roles or increased reliance on human-provided resources, potentially leading to human-wildlife conflicts. For instance, the northern red muntjac is capable of inhabiting a wide range of habitats, including various forest types and dense vegetation [48]. Long-tailed macaques selectively use human-modified habitats when food and cover are sufficient [49]. Wild pigs in croplands can cause significant agricultural damage, a common issue across Southeast Asia [50]. The green peafowl showed a strong negative association with dry dipterocarp forest (DFF) and a positive association with cropland (CRL), suggesting a more nuanced habitat use. While pheasant species are typically associated with forests, this finding may indicate a preference for transitional zones, forest edges, or mosaic landscapes that include agricultural elements [51,52].

Despite previous documentation (Table 1), several targeted species including the Asian elephant, dhole, northern pig-tailed macaque, banteng, Malayan sun bear, and Asiatic black bear were not detected during this survey. However, signs such as footprints, scratches, and dung confirmed their presence. Their absence from direct sightings may be attributed to behavioral factors (e.g., nocturnal vs. diurnal activity), habitat types, and sensitivity to human disturbance. These species are often elusive and difficult to detect through line transect sampling, especially in dense vegetation. Elephants, for example, are known to be elusive and sensitive to human presence, particularly in areas with hunting pressure [53]. The dhole is considered one of the most obscure apex carnivores in Asia's tropical forests [54]. Similarly, Malayan sun bears and Asiatic black bears exhibit elusive behaviors and are rarely observed directly, though they leave clear signs such as claw marks on trees [55].

This study, which employed transect surveys as a distance sampling method, represents the second biodiversity monitoring campaign in PLWS following the systematic camera trap survey conducted in 2021, which reported the presence of 54 species [8]. In our study, we selected 15 key fauna species to monitor wildlife biodiversity distribution and assess the impact of the REDD+ program in the sanctuary. Most species occurrences and individual detections were mainly found in high-intact forests. However, we were unable to estimate species density and population across the entire sanctuary. Future research should aim to address this gap, particularly for species detected above the threshold ( $\geq 60$ –80 detections), such as the great hornbill, to better assess the impact of forest conversion under the REDD+ project [56].

## 5. Implication and Conclusions

As the PLWS has been considered as one of the last and largest areas of lowland tropical forests left in mainland Southeast Asia, protecting the forest as the habitat for wildlife biodiversity is crucial. There have been conservation efforts operated in this area, such as law enforcement, community engagement, livelihood improvement, environmental safeguards, and biodiversity monitoring. Despite these significant protection efforts, ongoing threats continue to cause wildlife biodiversity loss due to wildlife trade, agricultural expansion, and especially habitat loss [57]. In our survey, we encountered hunting, habitat fragmentation, agricultural land clearance, and illegal logging, in particular along the edges in the northern and southern parts of the PLWS. These threats inevitably affect the distribution and population of the key wildlife biodiversity. Implementing REDD+ program is one of the crucial approaches in protecting habitats and wildlife biodiversity because it reduces deforestation and forest degradation. Protecting intact forests via REDD+ implementation means providing homes to a significant portion of the world's terrestrial biodiversity and protecting key wildlife species in particular ecosystems. One notable example of REDD+ conserving wildlife species is the Orangutan Conservation Project in Indonesia, which focuses on protecting the habitat of the critically endangered orangutans in the forests of Borneo and Sumatra by preventing deforestation and promoting sustainable forest management [58].

The findings of our study support the previous positive impact of REDD+ on wildlife conservation. We found a higher number of species and their abundance in the high-intact forest habitats of the REDD+ project in PLWS. This strategy serves as one of the sustainable conservation approaches for Cambodian wildlife biodiversity. Without significant enhancements in conservation management, key species in PLWS, like the endangered pileated gibbon, Indochinese silvered langur, banteng, etc., may follow the fate of kouprey, tiger, and wild water buffalo, leading to their complete absence from the sanctuary. The ecological ramifications of such a loss are profound because their absence not only disrupts the ecological equilibrium but also adversely affects the indigenous communities whose subsistence and genetic resources are inextricably linked to these forest resources. Therefore, effective and adaptive management of the sanctuary should be in place by incorporating wildlife monitoring, conservation planning, and sustainable carbon financing (e.g., via REDD+). The suggestion from our study is that conservation efforts need prioritize strict protection and restoration of core forest areas for species highly dependent on intact forests (e.g. great hornbill, pileated gibbon and silver langur). For more adaptable species, management strategies might focus on mitigating human-wildlife conflict and promoting coexistence in mosaic landscapes, while still ensuring the ecological integrity of their habitats. Effective conservation efforts and adaptive management of the sanctuary (both the high- and moderate-intact forest, and the edge/mosaic areas) will enhance biodiversity and maintain the system integrity, functions, and services (e.g., climate regulation, water and air purification, nutrient cycling, carbon sequestration, and erosion and flood control) [59] and consequently contribute to human-nature harmonization, employment, and socioeconomics of the people sharing this important protected area, the Prey Lang Wildlife Sanctuary.

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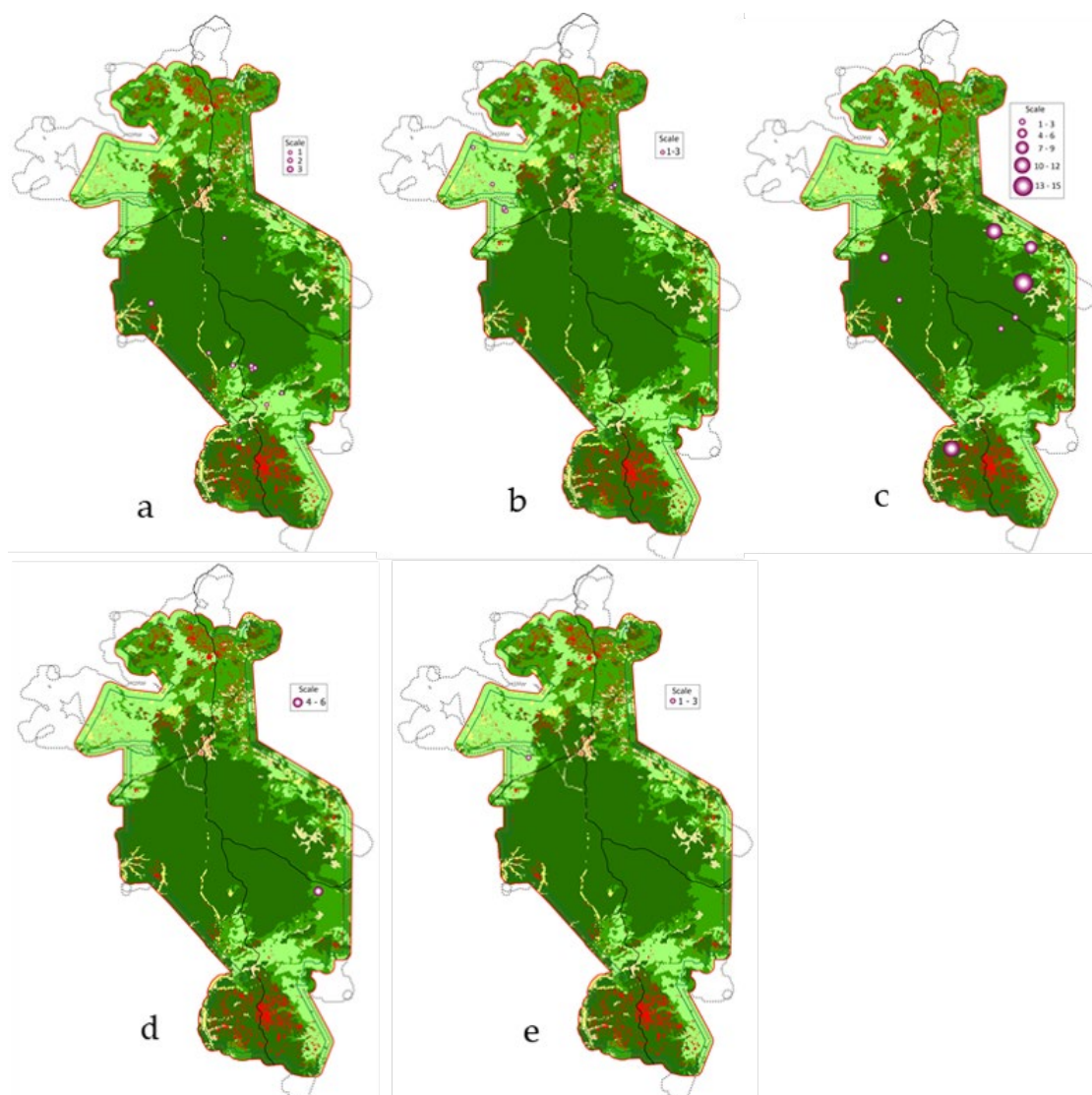
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## Abbreviations

The following abbreviations are used in this manuscript:

AIC – Akaike's Information Criterion  
CI – Conservation International  
CRL – Cropland  
DDF – Dry dipterocarp forest  
DNV – Distance to Nearest Village  
EVE – Evergreen Forest  
GPS – Global Positioning System  
MoE – Ministry of Environment  
OTP – Other Plantations  
PD – Perpendicular distance  
PLWS – Prey Lang Wildlife Sanctuary  
PDoE – Provincial Ministries of Environment  
RIF – Rice Field  
USAID – United States Agency for International Development

## Appendix A



**Figure A1.** Distribution pattern of the four least detected species (less than 20% of total transects): (a) green peafowl, (b) northern red muntjac, (c) Indochinese silvered langur, (d) guar, and (e) sambar deer.

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