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Population Density Estimation of Hornbills in the Eastern Part of Huai Kha Khaeng Wildlife Sanctuary, Thailand

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ABSTRACT

Hornbills belong to the Bucerotidae Family, and almost all species within this family are vulnerable to extinction. This study examined the population density of four hornbill species in the eastern part of the rainforest of the Huai Kha Khaeng Wildlife Sanctuary. The species studied were the Great Hornbill (*Buceros bicornis* Linnaeus 1758), Rufous-necked Hornbill (*Aceros nipalensis* Hodgson 1829), Wreathed Hornbill (*Rhyticeros undulates* Shaw 1811), and Tickell's Brown Hornbill (*Anorrhinus tickelli* Blyth 1855). Moreover, the study investigated factors influencing hornbill density using distance sampling with point transect methods, as well as the unmarked package in R. The survey was conducted along four 9-km survey lines, covering a total of 36 km, using 45 survey points with 200-m spacing between points. In total, 180 points were surveyed, with each point observed for 10 min. The study was replicated twice, covering an area of approximately 600 km^2, with surveys conducted from November 2023 to January 2024, and again from March 2024 to October 2024. The results showed the following hornbill population densities (individuals/km^2): Great Hornbill 10.16±0.07 (n=108), Rufous-necked Hornbill 5.95±0.07 (n=74), Tickell's Brown Hornbill 4.42±0.03 (n=61), and Wreathed Hornbill 1.52±0.01 (n=22). Factors that significantly influenced hornbill density included elevation, slope, average precipitation, average temperature, and montane forest. These findings contribute to the understanding of hornbill ecology and population dynamics. The results can guide management strategies and promote public awareness of habitat conservation.

HIGHLIGHTS

This study examined the density of four hornbill species: Great Hornbill, Rufous-necked Hornbill, Wreathed Hornbill, and Tickell's Brown Hornbill in the Huai Kha Khaeng Wildlife Sanctuary. The results revealed that the Great Hornbill, Rufous-necked Hornbill, and Tickell's Brown Hornbill had higher densities, whereas the Wreathed Hornbill had a lower density than in previous studies. Factors affecting hornbill densities included elevation, slope, stream, dry evergreen, mixed deciduous, and montane forests, which were critical habitats supporting different hornbill species according to their ecological requirements. In particular, the preservation of large trees is fundamental to sustaining hornbill populations, as nest cavities, food sources, and communal roosting sites represent key limiting resources.

1. INTRODUCTION

Hornbills (Family Bucerotidae) are the largest avian frugivores in Southeast Asia, playing a crucial role in forest ecology through seed dispersal (Jinamoy et al., 2013; Jinamoy et al., 2014). Globally, there are 62 hornbill species, with 32 found in Asia and 30 in Africa (IUCN Hornbill Specialist Group, 2025). Currently, 26 species are classified as Globally Threatened or Near Threatened with extinction, while the remaining species are listed as Least Concern (IUCN, 2025). In Thailand, 13 hornbill species are present (Trisurat et al., 2013; Thailand Hornbill Research Foundation, 2024a), representing approximately 1 in 5 of all hornbill species worldwide.

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Six hornbill species are found in the Huai Kha Khaeng Wildlife Sanctuary (HKKWS) (Poonswad and Kemp, 1993). There are four Vulnerable species according to the IUCN (2025): Great Hornbill (GH) (*Buceros bicornis*); Rufous-necked Hornbill (RNH) (*Aceros nipalensis*); Wreathed Hornbill (WH) (*Rhyticeros undulatus*), and Plain-pouched Hornbill (*Rhyticeros subruficollis*) IUCN, 2025); also 1 Near Threatened species, Tickell's Brown Hornbill (TBH) (*Anorrhinus tickelli*) (IUCN, 2025); and 1 Least Concern species, the Oriental Pied Hornbill (*Anthracoceros albirostris*). Only four species were found in the survey: the GH, the RNH, the TBH, and the WH. The Plain-pouched Hornbill is found in the southern part of HKKWS, while the Oriental Pied Hornbill is mostly found in the forest edges (IUCN Hornbill Specialist Group, 2025). Neither species was found in the study area. However, hornbill populations have declined significantly in recent years (Annorbah et al., 2016; Wijerathne and Wickramasinghe, 2018; Chaitanya et al., 2024; Monchaithanaphat et al., 2024; Thailand Hornbill Research Foundation, 2024b). As an important part of the ecosystem, hornbills are considered an appropriate proxy for monitoring forest health (Ardiantiono et al., 2020). Hornbills, valued for their conservation importance and key role in forest restoration, rely on natural tree cavities for nesting; therefore, the presence of suitable cavities is vital for their breeding success. (Datta and Rawat, 2004; Jinamoy et al., 2014). Habitat loss and the scarcity of tree cavities are major factors contributing to population declines (Jinamoy et al., 2014). Therefore, population density data provide important insights into the conservation status of a species or target population (Marthy et al., 2016). Establishing density baselines is crucial for wildlife monitoring, enabling researchers to track population trends and evaluate the effectiveness of conservation efforts (Ardiantiono et al., 2020). In addition to species distribution, population abundance and density are important parameters for assessing species status and their responses to forest change and other environmental factors (Callaghan et al., 2024), which vary depending on the natural history and ecological needs of each species. The occurrence of these species in the same area confirms the habitat characteristics and evolutionary relationships that should be studied for a better understanding. Knowledge about population density and environmental relationships for each hornbill species in the area is needed. This study was conducted on four hornbill species found in the high mountain range to the east of the area, where these species have been previously recorded. It also serves as a continuation of hornbill population monitoring in the region, following the work of Jornburom et al. (2010), who reported four hornbill species, namely, GH, RNH, TBH, and WH, using the point transect method. To date, no studies have investigated how these hornbill species respond to environmental variables in this area. This study aimed to address two main hypotheses: (1) changes exist in hornbill population during the non-breeding season, so we need a comparison of hornbill densities between the study area and other regions and (2) there are relationships between the occurrence of each hornbill species and 11 environmental factors, elevation, slope, forest types, normalized difference vegetation index (NDVI), canopy height, precipitation, stream, threat and temperature.

The specific objectives of this study were to estimate hornbill population densities using distance sampling, particularly the point transect method (Tiwari et al., 2021), which can clearly estimate the density, and to identify key environmental variables hypothesized to influence hornbill occurrence using zonal statistics derived from raster analysis in QGIS and the unmarked package (Kellner et al., 2023) within RStudio software. The expected findings will contribute to a deeper understanding of Hornbill ecology and inform future conservation and habitat management strategies.

2. METHODOLOGY

2.1 Ethics statement

This study was conducted with permission from the Department of National Parks, Wildlife and Plant Conservation (DNP) (License No. 0907.404/890, dated Jan 15, 2024).

2.2 Study site

The study area focused on was the eastern part of HKKWS, covering approximately 600 km² of its total area of 2,780 km². HKKWS, a UNESCO World Natural Heritage Site (15°28′16.4″N, 99°13′54.2″E) (Figure 1), is part of the Western Forest Complex (WEFCOM). The sanctuary preserves a pristine forest ecosystem and abundant wildlife, providing habitat for a wide variety of species and essential water and food sources for wildlife, including *Panthera tigris* Linnaeus 1758, *Panthera pardus* Linnaeus 1758, *Elephas maximus* Linnaeus 1758, *Bos javanicus* D'Alton 1823, *Bos gaurus* Smith 1827, *Bubalus arnee* Kerr 1792, *Tapirus indicus* Desmarest 1819, and

Aceros nipalensis Hodgson 1829 (Saisamorn et al., 2024). Forest types include montane, dry evergreen, mixed deciduous, and dry deciduous dipterocarp forests (Trisurat, 2004). Ouithavon et al. (2005) found that the fruits eaten by hornbills belong to the families Moraceae, Myristicaceae, Annonaceae, Meliaceae, and Luaraceae and that the most common trees used for nesting by hornbills in this area are *Dipterocarpus* and *Eugenia* (Poonswad, 1995).

2.3 Data collection

Four 9-km-long survey lines were established in the study area (Figure 1), located in the following areas: (1) Khao Nang Ram Wildlife Research Station, (2) Huai Isa Ranger Station, (3) Wang Pai Ranger Station, and (4) Saiboe Ranger Station. The topography of Khao Nang Ram is primarily covered with mixed deciduous forest, dry evergreen forest, and mountain forest. The Huai Isa and Saiboe areas are covered with dry evergreen forest and hill evergreen forest or mountain forest, respectively. In Wang Phai, the dominant vegetation types are dry evergreen forest and mountain forest. Generally, mountain forest prevails in areas above 1,000 meters above sea level. Lower elevations are dominated by dry evergreen forest, while vegetation in moist areas along streams and valleys may be dominated by moist evergreen forest. Mixed deciduous forests also dominate in the lower elevations. Forty-five survey points were positioned along each line at 200-m intervals (Pawar et al., 2018) to monitor the population of all hornbill species. The locations of the points were recorded using GPS with the UTM coordinate system (Map Datum WGS 84). In total, the survey covered 72 kilometers (four 9-km lines, each with two replications) and included 360 survey points (45 points per line, with two replications) (see Figure 1).

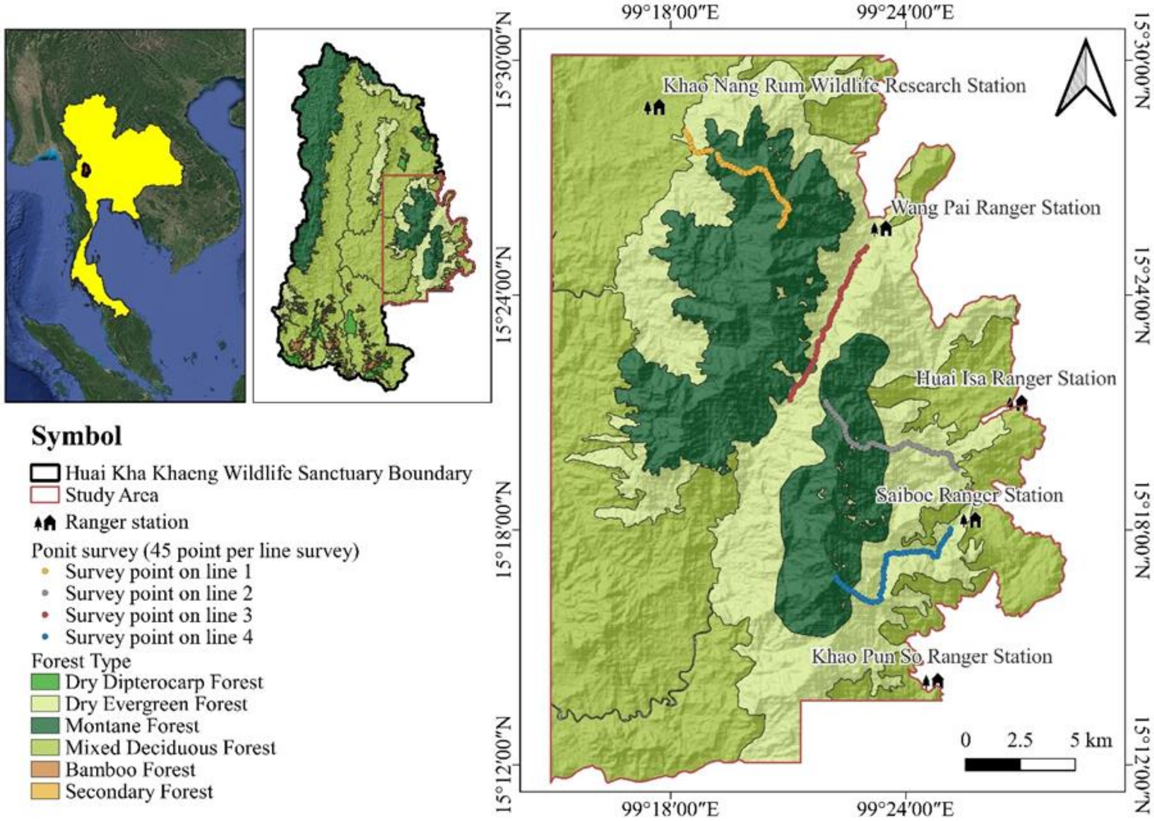

Figure 1. Study area locations in the Eastern part of the Huai Kha Khaeng Wildlife Sanctuary, Thailand

2.4 Population survey

The first survey was conducted primarily during the non-breeding season, from November 2023 to January 2024, and the second from June 2024 to October 2024 (Monchaithanaphat et al., 2024), resulting in two complete replications. The study period was divided into two periods due to the conditions of permission to study in the first period and the exception during the breeding season that occurred in late January to May (Jinamoy et al., 2013).

Surveys were conducted in the morning from 7:00 a.m. to 11:00 a.m. and in the afternoon from 2:00 p.m. to 5:00 p.m. Each survey point was observed for 10 minutes to minimize the risk of double-counting. Since using a survey time of 10 minutes is an appropriate time for population studies and is consistent with the research of Jornburom et al. (2010) used in their research, using too little time may result in an underestimation of the survey population, while using too much time may result in an overestimation of the survey population (Jornburom et al., 2010; Jinamoy et al., 2013; Pawar et al., 2021; Monchaithanaphat et al., 2024).

During data collection, the following information was recorded: (1) hornbill species, (2) detection type (visual or vocal), and (3) estimated distance between the survey point and the hornbill. Since some areas have dense tree canopies, it is not possible to measure distances with a laser rangefinder. Therefore, it is necessary to estimate the hornbill's position from the nearest tree and measure the distance from that tree instead. Sometimes, when moving the survey point, when hornbills are found, even though the data is recorded, it is not included in the density calculation, measured using a laser rangefinder, (4) angle between the survey point and the hornbill, and (5) number of individuals detected. Both visual and vocal detections were used to estimate density, as visibility is often limited in dense canopy forests (Marthy et al., 2016; Ardiantiono et al., 2020). Data were not collected on days with heavy rain, strong winds, or dense fog (Mynott et al., 2021). Hornbills flying over the survey point were recorded but excluded from the density analysis, as accurate distance measurements could not be obtained.

2.5 Data analysis

2.5.1 Population density

Hornbill population density was estimated using the distance sampling method (Chandler, 2020; Monchaithanaphat et al., 2024; Sriprasertsil et al., 2024). The analysis was conducted using a distance sampling model implemented in the unmarked package (version 1.4.3) (Kellner et al., 2023) within RStudio software (version 2024.09.1+394) (RStudio Builds, 2024). Zonal statistics derived from raster analysis in QGIS (version 3.28.13) (QGIS Project, 2024) were used to calculate hornbill density across different forest types: dry evergreen forest, mixed deciduous forest, and montane forest. To estimate the population density of hornbills in this study area, the analysis was performed using R Studio with the unmarked package. After the results were obtained, the density values of each forest type were read using the Zonal statistics tool in QGIS. To identify the most suitable model for the dataset, key detection functions, including half-normal, hazard-rate, and uniform, were evaluated based on the lowest Akaike Information Criterion (AIC) value (Paguntalan et al., 2021; Monchaithanaphat et al., 2024). The detection function curve was truncated at the right tail. Since estimating the distance of a sound is difficult, it relies on measuring the distance from the sound location with a laser rangefinder. To better fit the detection function curve to the survey data, a right truncation of no more than 10% was performed to mitigate bias from imprecise long-distance observations. Environmental factors were removed in a stepwise fashion to determine the best-fitting model for hornbill density estimation.

2.5.2 Environmental factors

Hornbill population density was analyzed in relation to various environmental and climatic factors that influence their distribution and habitat suitability. Key climate variables, such as temperature and precipitation, are critical in determining species distribution, as they directly impact resource availability and biological processes, including reproduction and feeding (Naniwadekar et al., 2020; Monchaithanaphat et al., 2024; Wijerathne et al., 2024). Temperature and precipitation data were obtained from Google Earth Engine for the period January 2023 to October 2024. Average temperature was estimated in relation to land surface conditions derived from the Normalized Difference Vegetation Index (NDVI), following the methodology of Ridho (2023). Average precipitation data were sourced from the Climate Hazards Center InfraRed Precipitation with Station Data (CHIRPS, version 2.0 Final) (USGS, 2024).

Forest type was also considered a key variable, as it directly influences the availability of food and nesting sites, which are factors that significantly affect hornbill populations. Different hornbill species exhibit varying forest type preferences (Patel et al., 2022; Mohd-Azlan et al., 2023). This study employed forest classification data from the Royal Forest Department (2018), which includes montane forest data from 2000 and dry evergreen and mixed deciduous forest data from 2018. In addition, elevation and slope were incorporated as topographic variables influencing habitat suitability and accessibility. These features also affect water distribution within the habitat, thereby shaping forest structure and wildlife movement patterns (Valderrama-Zafra, 2024). Elevation and slope data were derived from NASA's SRTM Digital Elevation Model at 30 m resolution [Earth Resources Observation and Science (EROS) Center, 2018].

NDVI was used to assess vegetation density, a key indicator of habitat quality. High NDVI values correspond to areas with dense vegetation, which typically offer greater food availability and more suitable nesting sites for hornbills (Setiawana et al., 2023). As hornbills rely heavily on fruiting trees and dense forest canopies, areas with high NDVI values are expected to support larger populations. This highlights the significance of vegetation density in influencing the spatial distribution of hornbills within the study area. Canopy height, representing forest vertical structure, was also included, as it is essential for species that nest in tall, large trees (Chaitanya et al., 2024). NDVI data were sourced from USGS Landsat 9 Level 2, Collection 2, Tier 1 for the period from January 2023 to October 2024 (USGS, 2025).

Streams are vital for the survival of wildlife, significantly influencing the distribution and behavior of species. In HKKWS, streams and other water bodies serve as key foraging habitats for hornbills such as the RNH. At this site, the RNH's diet contains roughly 22% animal matter, including freshwater crabs and frogs (Nepal, 2020; Thailand Hornbill Research Foundation, 2024a). Notably, RNH are often observed feeding on freshwater crabs along stream margins (Nepal, 2020; Saputra, 2024; Thailand Hornbill Research Foundation, 2024a). Data on proximity to human threats, collected by the DNP (2024), offer insights into anthropogenic impacts, such as poaching, habitat degradation, and conservation efforts (Monchaithanaphat et al., 2024; Sriprasertsil et al., 2024). Streams and threat location data were obtained from the DWR (2024) and the DNP (2024), respectively. These datasets were used to calculate distances using QGIS version 3.28.13 (RStudio Builds, 2024) with the r.grow.distance function (GRASS Development Team, 2024). The threat point uses data from January 2023 to October 2024 from the SMART patrol database of the DNP (2024). Together, these factors provide a comprehensive understanding of variables influencing hornbill population density. The contributions of the various data sources are summarized in Table 1 and Figure 2.

3. RESULTS

3.1 Hornbill detection

The results showed that the total number of detections for GH, RNH, TBH, and WH were 191, 74, 61, and 22, respectively. These detections were further categorized into visual detections (108, 18, 54, and 19, respectively) and vocal detections (83, 56, 7, and 3, respectively) (Table 2).

Table 1. Environmental factors used for modelling

Type	Factor name	Code	Data source	Reference from
Climate	Average temperature	TEM	USGS Landsat 9 Level 2, Collection 2, Tier 1	USGS (2025)
	Average precipitation	ARF	Climate Hazards Center InfraRed Precipitation with Station Data (version 2.0 Final)	Funk et al. (2015)
Forest type	Montane Forest	MF	Royal Forest Department (RFD)	RFD (2018)
	Dry Evergreen Forest	DEF		
	Mixed Deciduous Forest	MDF		
Environmental	Elevation	ELV	NASA SRTM Digital Elevation 30 m	Farr et al. (2007)
	Slope	SLP		
	Streams (Distance from nearest stream)	STR	Department of Water Resources (DWR)	DWR (2024)
	Normalized Difference Vegetation Index	NDVI	USGS Landsat 9 Level 2, Collection 2, Tier 1	Cook et al. (2014) USGS (2025)
	Canopy Height	CNP	Global Canopy Height	Tolan et al. (2023)
	Threat (Location of the nearest threat factor)	THR	Department of National Parks, Wildlife and Plant Conservation (DNP)	DNP (2024)

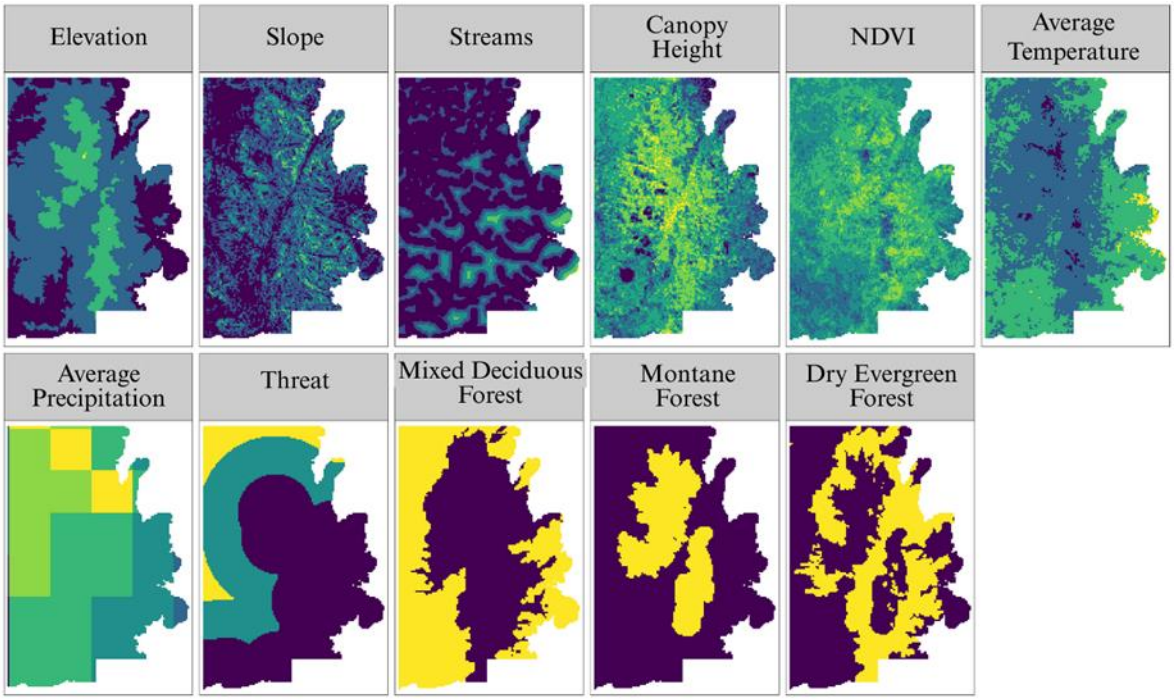

Figure 2. Climate, forest type, and environmental factors in the eastern part of the Huai Kha Khaeng Wildlife Sanctuary, Thailand

Table 2. Observations of hornbills in the eastern part of the Huai Kha Khaeng Wildlife Sanctuary, Thailand, were recorded during the nonbreeding season, spanning from November 2023 to January 2024 and from June 2024 to October 2024.

Hornbill species	Number of detections (Individuals)			%Detection	
	Visual	Vocal	Total	%Visual	%Vocal
Great Hornbill	108	83	191	56.54	43.46
Rufous-necked Hornbill	18	56	74	24.32	75.68
Tickell's Brown Hornbill	54	7	61	88.52	11.48
Wreathed Hornbill	19	3	22	86.36	13.64
Four Hornbill species	199	149	348	57.18	42.82

3.2 Population density

The densities of GH, RNH, TBH, and WH were 10.16, 5.95, 4.42, and 1.52 individuals/km², respectively (Table 3). The study also analyzed hornbill densities across various forest types, including dry evergreen, mixed deciduous, and montane forests. The densities of GH in these forest types were 14.35, 8.85, and 4.07 individuals/km², respectively. RNH densities were 5.94, 6.23, and 5.44 individuals/km², whereas TBH densities were 4.69, 3.73, and 4.75 individuals/km², and WH densities were 1.62, 1.13, and 1.90 individuals/km² (Table 4). In this study, the detection of GH was based on visual observation, while for the other hornbill species, both visual and acoustic observations were used (Ardiantiono et al., 2020). This difference reflects species-specific detection capabilities and methodological limitations during fieldwork.

3.3 Environmental factors affecting the density of hornbill species

The results of the study revealed that the factors that significantly negatively affected the density of GH were Montane Forest (P=0.0003), Average Temperature (P=0.0080), and Average Precipitation (P=0.0115), while the factors that significantly affected negatively the density of RNH were Elevation (P=0.0232), Average Temperature (0.0284), and only a marginal effect for Distance to the Nearest Stream (P=0.0606). In the case of the WH, the factor that significantly affected the density was slope (P=0.0433) (Figure 3 and Table 5).

Table 3. Details of the selected model for hornbill density estimation in the eastern part of the Huai Kha Khaeng Wildlife Sanctuary, Thailand, recorded during the non-breeding season, spanning from November 2023 to January 2024 and from June 2024 to October 2024

Species	Detection	Number of detections (Individuals)	Key function	Right truncation (m)	AIC
Great Hornbill	Visual	108	Half-normal	170	382.83
Rufous-necked Hornbill	Visual and Vocal	74	Hazard	200	471.69
Tickell's Brown Hornbill	Visual and Vocal	61	Half-normal	150	136.17
Wreathed Hornbill	Visual and Vocal	22	Half-normal	100	123.30

Table 4. Population density estimation of four hornbill species in the eastern part of the Huai Kha Khaeng Wildlife Sanctuary, Thailand, during the non-breeding season, from November 2023 to January 2024, and from June 2024 to October 2024

Hornbill species	Density estimation in each area	Density (individuals/km²)	Standard error	95% CI	
				Lower	Upper
Great Hornbill	Study area	10.16	0.07	10.02	10.29
	Dry Evergreen Forest	14.35	0.13	14.10	14.60
	Mixed Deciduous Forest	8.85	0.06	8.74	8.97
	Montane Forest	4.07	0.04	3.98	4.15
Rufous-necked Hornbill	Study area	5.95	0.02	5.91	5.98
	Dry Evergreen Forest	5.94	0.03	5.87	6.00
	Mixed Deciduous Forest	6.23	0.03	6.18	6.28
	Montane Forest	5.44	0.04	5.37	5.52
Tickell's Brown Hornbill	Study area	4.42	0.03	4.35	4.48
	Dry Evergreen Forest	4.69	0.05	4.60	4.78
	Mixed Deciduous Forest	3.73	0.04	3.66	3.81
	Montane Forest	4.75	0.10	4.56	4.94
Wreathed Hornbill	Study area	1.52	0.01	1.50	1.53
	Dry Evergreen Forest	1.62	0.01	1.60	1.64
	Mixed Deciduous Forest	1.13	0.01	1.12	1.15
	Montane Forest	1.90	0.02	1.87	1.93

Table 5. Environmental factors affecting the density of four hornbill species in the eastern part of the Huai Kha Khaeng Wildlife Sanctuary, Thailand, during the non-breeding season, from November 2023 to January 2024, and from June 2024 to October 2024

Hornbill species	Environmental factors affecting the density				
	Environmental factors	AIC	Coefficient	Standard error	p-value
Great Hornbill	Slope (SLP)	382.83	0.228	0.156	0.1450
	Montane Forest (MF)		-0.680**	0.189	0.0003
	Average temperature (TEM)		-0.635**	0.240	0.0080
	Average precipitation (ARF)		-0.539*	0.213	0.0115
Rufous-necked Hornbill	Elevation (ELV)	471.69	-0.572*	0.252	0.0232
	Distance to the Nearest Stream (STR)		0.265	0.141	0.0606
	Average temperature (TEM)		-0.450**	0.205	0.0284
Tickell's Brown Hornbill	Normalized Difference Vegetation Index (NDVI)	136.17	0.609	0.382	0.1108
	Canopy height (CNP)		-0.853	0.583	0.1435
Wreathed Hornbill	Slope (SLP)	123.30	0.514*	0.255	0.0433

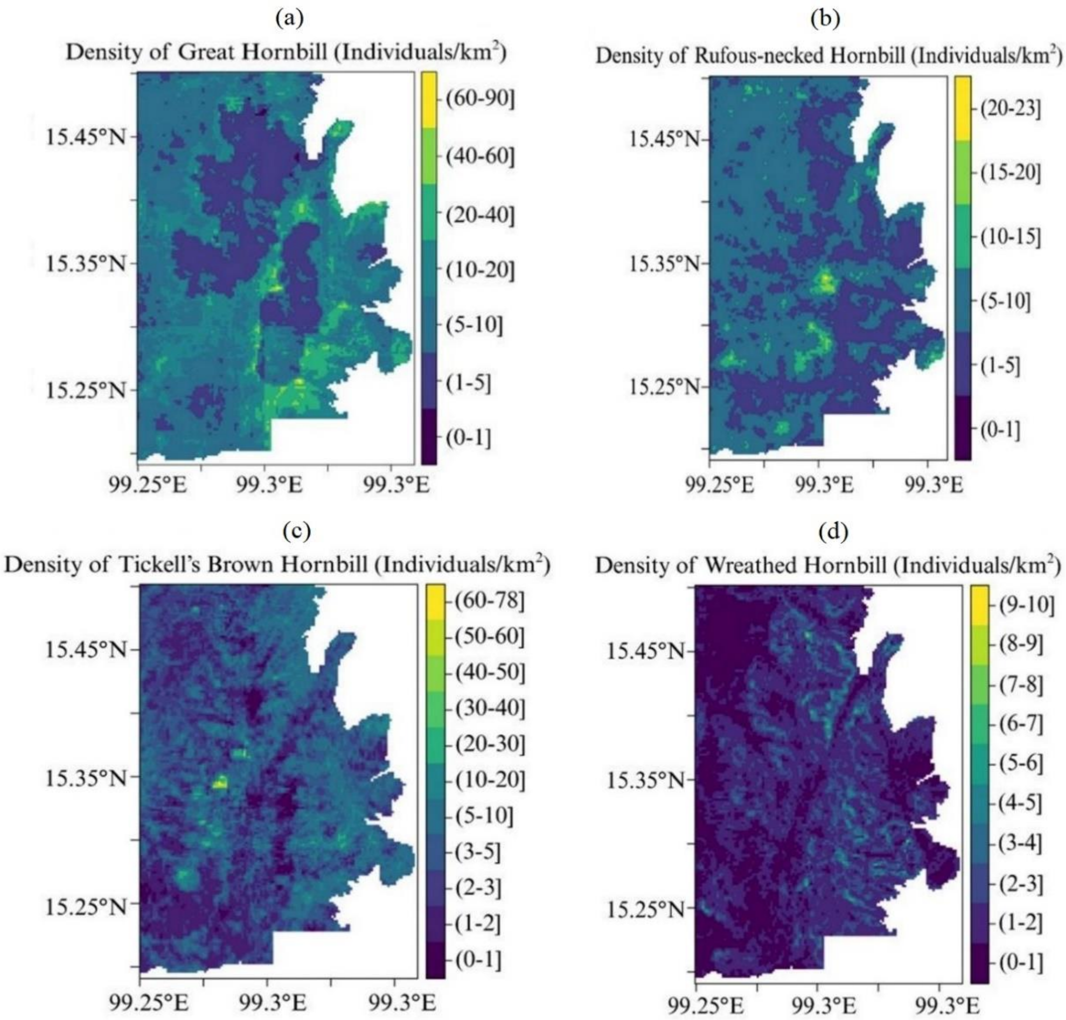

Figure 3. Predicted density (individuals/km^2) of Great Hornbill (a), the Rufous-necked Hornbill (b), the Tickell's Brown Hornbill (c), and the Wreathed Hornbill (d), being density in relation to environmental factors, with 95% confidence interval

4. DISCUSSION

When comparing the results of this study with those of Jornburom et al. (2010), who used the point transect method in the same area, the densities of GH, RNH, and TBH were found to be approximately twice as high as those reported previously. In contrast, the density of WH was more than tenfold lower than reported by both Jornburom et al. (2010) and Naniwadekar and Datta (2013), who recorded 11.47 and 16.1 individuals/km^2 of WH during the non-breeding season in the study area and the North-East India. However, the WH density in this study was still higher than that reported by Monchaithanaphat et al. (2024), who recorded 2.60 individuals/km^2 in Khao Yai National Park during the non-breeding season. These findings indicate a significant population increase of GH, RNH, and TBH over the past 15 years, while the sharp decline of WH may suggest population movement or habitat-related factors requiring further investigation. However, WH is a migratory species and not a permanent resident of the HKKWS (Anggraini et al., 2000). It is most abundant in montane evergreen and dry evergreen forests during the non-breeding season, moving to higher elevations to forage in the canopy of large trees (IUCN, 2025). Thus, the population level of the WH in this area remains uncertain because no nesting records or hornbill carcasses have been documented. The absence of such evidence not only limits reliable population estimates but also hinders the evaluation of post-breeding survival and flocking behavior, which are crucial for understanding population dynamics.

RNH is generally sedentary and territorial (Tifong et al., 2007), though seasonal movements to locate patchily distributed fruit resources have been documented. In this study, RNH was observed above 500 mean sea level, consistent with reports that streams in mixed deciduous forests significantly influence its density (Nepal, 2020; Thailand Hornbill Research Foundation, 2024a). This study showed that

RNH densities were highest in mixed deciduous forests, followed by dry evergreen and montane forests. This pattern suggests that a mosaic of forest types provides complementary resources necessary to sustain the species (IUCN, 2025).

A comparison with Jinamoy et al. (2013), who reported 5.55 individuals/km² for RNH in Thung Yai Naresuan (East) Wildlife Sanctuary, indicates that their recorded density was lower than in the present study. This difference is likely due to detectability bias during the breeding season, when females remain sealed inside nest cavities. However, the RNH density reported here was still slightly lower than that documented by Naniwadekar and Datta (2013) in India (6.9 individuals/km²) using the line transect method.

TBH densities were greatest in montane forests, aligning with IUCN (2025), which reports the species as most abundant in dense evergreen and deciduous forests up to 1,500 m, particularly in montane evergreen habitats.

In the case of GH, the largest-bodied hornbill species in Thailand, the highest density was observed in dry evergreen forests. These forests provide moderate moisture, diverse food resources, and large *Dipterocarpus* trees suitable for nesting cavities (Sibarani et al., 2020). Conservation of this forest type is therefore critical to sustain GH populations. Compared with Pawar et al. (2018), who recorded 31 individuals/km² in India, densities in this study were considerably lower. The elevated numbers in India may reflect differences in habitat characteristics, as GH populations there occurred in landscapes adjacent to coffee plantations that are privately managed and protected from major threats such as poaching and large-scale habitat degradation.

The present findings confirm the strong preference of GH for dry evergreen forests, emphasizing the importance of prioritizing their conservation and management, particularly around the three forest protection units. These areas, being adjacent to local communities, are at higher risk of disturbance. In addition to anthropogenic pressures, climate variability poses emerging threats. Excessive rainfall may alter forest structure, reduce fruit availability, or cause nest tree collapse, while rising temperatures could affect foraging and nesting behavior. Similar climate-related influences on hornbill density have been reported in Khao Yai National Park (Naniwadekar et al., 2020; Monchaithanaphat et al., 2024; Wijerathne et al., 2024).

In this study, GH densities were the highest in the dry evergreen forests around Khao Nam Yen, suggesting that food availability and stable climatic conditions in this habitat are critical for sustaining GH populations. Protecting and managing this forest type is thus essential, not only to safeguard key ecological resources but also to enhance the resilience of hornbill populations to the impacts of climate change, thereby ensuring their long-term persistence in the region. Hornbill densities are strongly influenced by food availability, anthropogenic disturbance, and breeding site conditions (Pradhan et al., 2024). Monitoring populations over the long term is therefore essential for detecting changes driven by these factors and for guiding effective conservation strategies (Pawar et al., 2021).

In the case of environmental factors, the distance to streams showed a positive but non-significant effect on RNH density. Streams remain crucial habitats because they provide both foraging opportunities and water for hydration (Saputra, 2024). The proximity of RNH to streams enhances their access to food and other essential resources (Nepal, 2020; Thailand Hornbill Research Foundation, 2024a). Reflecting these ecological benefits, the highest RNH density was recorded in the Khao Nam Yen region, which offers abundant food, a favorable climate, and suitable elevation, creating optimal conditions for the species. The RNH is also found in Mae Wong National Park, Umphang Wildlife Sanctuary (BirdLife International, 2020), and Thung Yai Naresuan Wildlife Sanctuary (Jinamoy et al., 2014). Therefore, it is a species that is specific to high mountain areas covered with mountain forests, as well as countries in the Himalayan Mountain range, such as Nepal, Bhutan, southern China, and northern Burma (Kemp and Kirwan, 2020).

Elevation negatively impacts RNH density, likely average temperatures. Thus, elevation affects RNH density, particularly in challenging regions, as Dahal et al. (2023) reported that the annual mean temperature has a significant influence on the model, followed by elevation, and the least by slope RNH in Bhutan. This suggests that high temperatures may affect foraging and nesting behaviors critical for population sustainability (Monchaithanaphat et al., 2024; Wijerathne et al., 2024).

The analysis included variables such as elevation, slope, distance to streams, canopy height, NDVI, and forest types. The lack of significant relationships suggests that these general habitat variables may not sufficiently represent the ecological requirements critical to hornbill occurrence. Hornbills depend on specialized resources, particularly suitable nesting cavities and fruiting trees such as those of the *Ficus* genus (Pawar et al., 2021), which were not directly captured by the variables used in this study. This highlights the need for future analyses to incorporate more species-specific ecological factors.

For WH, higher densities were associated with steeper slopes, which can be attributed to several ecological and anthropogenic factors. Steep slopes generally experience reduced human disturbance, provide tall and mature trees for roosting, and support a greater abundance of fruiting trees, thereby offering diverse food sources (Hadiprakarsa and Kinnaird, 2004; Kitamura, 2011; Cheng et al., 2022). This finding is consistent with those from Khao Yai National Park, where hornbills prefer habitats characterized by minimal human activity and abundant food resources (Monchaithanaphat et al., 2024). Additionally, steep slopes often act as natural barriers that protect habitats from anthropogenic threats such as logging and hunting (Cheng et al., 2022). BirdLife International (2018) further noted that during the nonbreeding season, WH tend to move uphill to forage in tree canopies, reinforcing the ecological importance of sloped habitats.

This study has certain limitations, particularly the potential bias introduced by relying on acoustic detections for estimating hornbill densities. Although call-based identification may reduce accuracy, it provides a practical means of achieving the recommended minimum of 40 detections necessary for reliable point transect analysis. To address this issue, if possible, future research should compare density estimates derived from visual encounters with those obtained from acoustic detections to evaluate possible discrepancies. Continued long-term monitoring will also be essential to improve accuracy, enhance ecological understanding, and guide effective conservation planning for hornbills in this landscape. At the habitat level, the study highlights that dry evergreen, montane evergreen, and mixed deciduous forests, when spatially connected across the landscape, serve as critical habitats supporting different hornbill species according to their ecological requirements. Effective management to minimize disturbance in these forests is therefore crucial. In particular, the preservation of large trees is fundamental, as they provide nesting cavities, food sources, and communal roosting sites, which represent key limiting resources for hornbill populations. Most hornbill nesting cavities are found in large Dipterocarpus trees (Poonswad, 1995; Poonswad et al., 2013), underscoring the need to maintain these keystone structures to secure the long-term viability of hornbill populations.

5. CONCLUSION

This study found higher densities of GH, RNH, and TBH but lower densities of WH than those reported in the literature. Factors affecting the hornbill density include (1) elevation and slope, (2) stream, (3) montane forest, (4) precipitation, (5) Normalized Difference Vegetation Index, (6) temperature, and (7) canopy height, though these vary by species. For GH, montane forest, temperature, and precipitation are important, while elevation and temperature impact RNH, and slope significantly affects WH. Based on the analyzed hornbill densities across various forest types, the report emphasizes the preservation of large, continuous forest environments, particularly in these high mountain ranges, which are crucial for maintaining the diversity of hornbill species. Controlling human disturbances over the long term is essential for ongoing conservation efforts.

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AUTHOR CONTRIBUTIONS

Experimental run and Data Collection: Fueakong T; Pattanavibool A; Jornburom P; Waitanyakarn K; Saisamorn A, Neepai P; Methodology: Suksavate W; Jornburom P; Fueakong T; Validation: Jornburom P; Pattanavibool A, Sukmasuang R; Supervision and Writing Original Draft Preparation: Sukmasuang R; Formal Analysis: Suksavate W; Jornburom P, Fueakong T; Data Curation: Fueakong T, Visualization: Sukmasuang R, Writing-Review and Editing: Sukmasuang R.

DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

REFERENCES

Anggraini K, Kinnaird M, O'Brien T. The effects of fruit availability and habitat disturbance on an assemblage of

Sumatran hornbills. Bird Conservation International 2000; 10(3):189-202.

Annorbah NND, Collar NJ, Marsden SJ. Trade and habitat change virtually eliminate the Grey Parrot *Psittacus erithacus* from Ghana. International Journal of Avian Science 2016; 158(1):82-91.

Ardiantiono A, Karyadi, Isa M, Hasibuan AK, Kusara I, Arwin, et al. Hornbill density estimates and fruit availability in a lowland tropical rainforest site of Leuser Landscape, Indonesia: preliminary data towards long-term monitoring. Hornbill Natural History and Conservation 2020;1(1):2-11.

BirdLife International. *Aceros nipalensis*. The IUCN Red List of Threatened Species 2020: e.T22682510A176267243 [Internet]. 2020 [cited 2025 Sep 22]. Available from: https://www.iucnredlist.org/species/22682510/176267243.

BirdLife International. *Rhyticeros undulatus*. The IUCN Red List of Threatened Species 2018: e.T22682528A132400385 [Internet]. 2018 [cited 2025 Sep 22]. Available from: https://www.iucnredlist.org/species/22682528/132400385.

Callaghan CT, Santini L, Spake R, Bowler DE. Population abundance estimates in conservation and biodiversity research. Trends in Ecology and Evolution 2024;39(6):515-23.

Chaitanya R, Naniwadekar R, Meiri S. Why did the hornbill not cross the river? Upland habitats rather than a physical barrier limit the distribution of the Brown Hornbill. Journal of Biogeography 2024;51(11):2156-69.

Chandler R. Distance Sampling Analysis in Unmarked [Internet]. 2020 [cited 2025 Jan 5]. Available from: https://cran.r-project.org/web/packages/unmarked/vignettes/distsamp.html.

Cheng Y, Wen Z, He X, Dong Z, Zhangshang M, Li D, et al. Ecological traits affect the seasonal migration patterns of breeding birds along a subtropical altitudinal gradient. Avian Research 2022;13:Article No. 100066.

Cook M, Schott JR, Mandel J, Raqueno N. Development of an operational calibration methodology for the land sat thermal data archive and initial testing of the atmospheric compensation component of a land surface temperature (LST) product from the archive. Remote Sensing 2014;6(11):11244-66.

Dahal D, Nepal A, Rai CM, Sapkota S. Understanding the impact of climate change on the habitat of the rufous-necked hornbill (*Aceros nipalensis*) (Hodgson, 1829) using MaxEnt modeling in Bhutan. Ornithology Research 2023;31:182-92.

Datta A, Rawat GS. Nest-site selection and nesting success of three hornbill species in Arunachal Pradesh, north-east India: Great Hornbill *Buceros bicornis*, Wreathed Hornbill *Aceros undulatus*, and Oriental Pied Hornbill *Anthracoceros albirostris*. Bird Conservation International 2004;14:35-92.

Department of National Parks, Wildlife and Plant Conservation (DNP). Huai Kha Khaeng Wildlife Sanctuary [Internet]. 2024 [cited 2024 Dec 6]. Available from: www.dnp.go.th.

Department of Water Resources (DWR). National maps [Internet]. 2024 [cited 2024 Nov 8]. Available from: www.opendata.onde.go.th/en/dataset/9-national-maps.

Earth Resources Observation and Science (EROS) Center. USGS EROS Archive - Digital Elevation - Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global [Internet]. 2018 [cited 2024 Nov 10]. Available from: https://usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1.

Farr TG, Rosen PA, Caro E, Crippen R, Duren R, Hensley S, et al. The Shuttle radar topography mission. Reviews of Geophysics 2007;45(2):Article No. 2005RG00018.

Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, et al. The climate hazards infrared precipitation with stations: A new environmental record for monitoring extremes. Scientific Data 2015;2:Article No. 150066.

GRASS Development Team. r.grow - Generates a raster map layer with contiguous areas grown by one cell [Internet]. 2024 [cited 2024 Oct 20]. Available from: https://grass.osgeo.org/grass-stable/manuals/r.grow.html.

Hadiprakarsa YY, Kinnaird MF. Foraging characteristics of an assemblage of four Sumatran hornbill species. Bird Conservation International 2004;14(1):53-62.

International Union for Conservation of Nature (IUCN). The IUCN Red List of threatened species. Version 2025-1 [Internet]. 2025 [cited 2025 Jan 20]. Available from: https://iucnredlist.org.

International Union for Conservation of Nature (IUCN) Hornbill Specialist Group. Hornbills of the world [Internet]. 2025 [cited 2025 Sep 22]. Available from: https://iucnhornbills.org/hornbills-of-the-world/.

Jinamoy S, Poonswad P, Pattanavibool A, Chimchome V, Thongsikem S. Estimating density of rufous-necked hornbill (*Aceros nipalensis*) using distance sampling in Thung Yai Naresuan (East) Wildlife Sanctuary. Journal of Wildlife in Thailand 2013;20(1):1-14 (in Thai).

Jinamoy S, Trisurat Y, Pattanavibool A, Pisdamkham C, Thongsikem S, Veerasamphan V, et al. Predictive distribution modelling for rufous-necked hornbill *Aceros nipalensis* (Hodgson, 1829) in the core area of the Western Forest Complex, Thailand. Raffles Bulletin of Zoology 2014;62:12-20.

Jornburom P, Chimchome V, Pattnavibool A, Poonswad P. Density estimation of hornbills in Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province. Thai Journal of Forestry 2010;29(1):1-11 (in Thai).

Kellner KF, Smith AD, Royle JA, Kéry M, Belant JL, Chandler RB. The unmarked R package: Twelve years of advances in occurrence and abundance modelling in ecology. Methods in Ecology and Evolution 2023;14(6):1408-15.

Kemp AC, Kirwan GM. Rufous-necked Hornbill (*Aceros nipalensis*), version 1.0. In birds of the world, Cornell Lab of Ornithology, Ithaca, NY, USA [Internet]. 2020 [cited 2025 Sep 25]. Available from: https://birdsoftheworld.org/bow/species/runhor1/1.0/introduction.

Kitamura S. Frugivory and seed dispersal by hornbills (Bucerotidae) in tropical forests. Acta Oecologica 2011; 37(6):531-41.

Marthy W, Clough Y, Tscharntke T. Assessing the biodiversity value of degraded lowland forest in Sumatra, Indonesia. Kukila 2016;19:1-20.

Mohd-Azlan J, Pengiran P, Maiwald MJ, Chas NBJ, Robert LA, Noske RA. Diversity and relative abundance of hornbills in selectively-logged production forests in Central Sarawak, Malaysian Borneo. Kukila 2023;24(1):1-10.

Monchaithanaphat N, Trisurat Y, Chimchome V. Non-breeding season population density of hornbills in the core area of Khao Yai National Park, Thailand. Hornbill Natural History and Conservation 2024;5:1-14.

Mynott HI, Lee DC, Santillan RA, Schwarz CJ, Tacud B, Fernandez AD, et al. Population assessment and habitat associations of the Visayan Hornbill (*Penelopides panini*) in

Northwest Panay, Philippines. Avian Research 2021; 12:Article No. 67.

Naniwadekar R, Datta A. Spatial and temporal variation in hornbill densities in Namdapha Tiger Reserve, Arunachal Pradesh, North-East India. Tropical Conservation Science 2013;6(6):734-48.

Naniwadekar R, Ghuman S, Gopal A, Page N, Ramachandran V. Characteristics of Narcondam Hornbill *Rhyticeros narcondami* nest trees. Hornbill Natural History and Conservation 2020;1(2):1-9.

Nepal TK. Distribution and threats of Rufous-necked Hornbill (*Aceros nipalensis*) in Bhutan. International Journal of Science and Research 2020;9(11):797-800.

Ouithavon K, Poonswad P, Bhumbhakpan N, Laohajinda V. A comparative study of the feeding ecology of two sympatric hornbill species (Aves: Bucerotidae) during their breeding season in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Proceedings of the Third Hornbill Workshop, The Ecology of Hornbills: Reproduction and Populations; 2005; Mahidol University, Bangkok: Thailand; 2005.

Paguntalan LJ, Reintar ART, Jakosalem PGC. Population density of Visayan Tarictic hornbill *Penelopides panini* on Negros Island, Philippines. Journal of Asian Ornithology 2021; 37:93-8.

Patel B, Sivaraman S, Balakrishnan P. Nesting ecology of Malabar Grey Hornbill *Ocyceros griseus* in a mosaic landscape in the Southern Western Ghats, India. Proceedings of the Zoological Society 2022;75:337-48.

Pawar P, Naniwadekar R, Raman T, Mudappa D. Seasonal variation in hornbill densities in coffee plantations in the Anaimalai Hills, Western Ghats, India. Sarawak Museum [Internet]. 2018 [cited 2024 Oct 12]. Available from: https://museum.sarawak.gov.my/web/subpage/webpage_view/314.

Pawar PY, Mudappa D, Raman TRS. Hornbill abundance and breeding incidence in relation to habitat modification and fig fruit availability. IBIS-International Journal of Avian Science 2021;163(2):473-85.

Poonswad P. Nest site characteristics of four sympatric species of hornbills in Khao Yai National Park, Thailand. IBIS-International Journal of Avian Science 1995;137(2):183-91.

Poonswad P, Chimchome V, Mahannop N, Mudsri S. Conservation of hornbills in Thailand. In: Sodhi NS, Gibson L, Raven PH, editors. Conservation Biology: Voices from the Tropics. 1st ed. John Wiley and Sons, Ltd.; 2013. p. 157-66.

Poonswad P, Kemp AC. Manual to the Conservation of Asian Hornbills. Bangkok, Thailand: Sirvatana Interprint; 1993.

Pradhan K, Datta A, Ganguly D, Naniwadekar R, Mahato S, Dukpa K, et al. Hornbill abundance and habitat relationships in a human-impacted protected area in the Indian Eastern Himalaya. Global Ecology and Conservation 2024;5:e02868.

QGIS Project. QGIS Desktop 3.28 User guide [Internet]. 2024 [cited 2024 Jun 20]. Available from: https://docs.qgis.org/3.28/pdf/en/QGIS-3.28-DesktopUserGuide-en.pdf.

Ridho M. Analyzing land surface temperature (LST) with Landsat 8 data in Google Earth Engine [Internet]. 2023 [cited 2025 Jan 5]. Available from: https://medium.com/@ridhomuh002/analyzing-land-surface-temperature-lst-with-landsat-8-data-in-google-earth-engine-f4dd7ca28e70.

Royal Forest Department (RFD). Forest type database [Internet]. 2018 [cited 2024 Feb 17]. Available from: https://data.forest.go.th/.

RStudio Builds. RStudio desktop [Internet]. 2024 [cited 2024 Dec 15]. Available from: http://dailies.rstudio.com/version/2024.09.1+394/.

Saisamorn A, Duangchantrasiri S, Sornsa M, Suksavate W, Pattanavibool A, Duengkae P. Recovery of globally threatened ungulate species in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Global Ecology and Conservation 2024;53:e03012.

Saputra RA. Prediction of bird habitat suitability: Determination and use of environmental parameters. Journal of Geographical Sciences and Education 2024;2(1):1-8.

Sibarani MC, Utoyo L, Pratama RD, Danus MA, Sudrajat R, Surahmat F, et al. Long-term monitoring of nesting behavior and nesting habitat of four sympatric hornbill species in a Sumatran lowland tropical rainforest of Bukit Barisan Selatan National Park. Hornbill Natural History and Conservation 2020;1(1):17-29.

Setiawana T, Prasetyob LB, Mulyanib YA, Jarulisc. The habitat suitability modelling of Rhinoceros Hornbills (*Buceros rhinoceros*) in Java Island, Indonesia. Journal of Natural Resources and Environmental Management 2023;14(2): Article No. 253.

Sriprasertsil V, Da-ouli N, Chootongkhum C, Strange BC, Khamcha D, Jinamoy S, et al. Changes in endangered hornbill populations over space and time and potential ecological impacts in peninsular Thailand. Global Ecology and Conservation 2024;53:e03006.

Thailand Hornbill Research Foundation. Hornbill species: Rufous-necked Hornbill [Internet]. 2024a [cited 2024 Feb 17]. Available from: www.hornbill.or.th/about-hornbills/hornbill-species/rufous-necked-hornbill.

Thailand Hornbill Research Foundation. Hornbill species [Internet]. 2024b [cited 2024 Oct 10]. Available from: http://hornbill.or.th.

Tifong J, Chimchome V, Poonswad P, Pattnavibool A. Home range and habitat use of rufous-necked hornbill (*Aceros nipalensis*) by radio tracking in Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province. Thailand Journal of Forestry 2007;26:28-39 (in Thai).

Tiwari G, Pandey P, Kaul R, Lee H, Singh R. Comparison of point and roadside transect methods to evaluate the abundance and richness of diurnal raptors in the arid region of Rajasthan. Public Library of Science ONE 2021;16(12):e0259805.

Tolan J, Yang H-I, Nosarzewski B, Couairon G, Vo H, Brandt J, et al. Sub-meter resolution canopy height maps using self-supervised learning and a vision transformer trained on Aerial and GEDI Lidar [Internet]. 2023 [cited 2024 Feb 9]. Available from: http://arxiv.org/pdf/2304.07213.

Trisurat Y. GIS Database and Its Applications for Ecosystem Management. Bangkok, Thailand: Western Forest Complex, Ecosystem Management Project (WEFCOM), Kasetsart University; 2004.

Trisurat Y, Chimchome V, Pattanavibool A, Jinamoy S, Thongaree S, Kanchanasakha B, et al. An assessment of the distribution and conservation status of hornbill species in Thailand. Oryx 2013;47(3):441-50.

US Geological Survey (USGS). CHIRPS, version 2.0 Final [Internet]. 2024 [cited 2024 Feb 9]. Available from: https://www.chc.ucsb.edu/data/chirps.

US Geological Survey (USGS). USGS Landsat 9 level 2, collection 2, tier 1 [Internet]. 2025 [cited 2025 Feb 20]. Available from: https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC09_C02_T1_L2.

Valderrama-Zafra JM, Rubio-Paramio MA, Garcia-Molina DF, Mercado-Colmenero JM, Oya A, Carrasco R, et al. Impact of topographic factors on animal field pathings: Analysis and prediction of deer movement patterns. Ecological Informatics 2024;80:Article No. 102487.

Wijerathne I, Wickramasinghe S. Behavioral pattern of endemic Sri Lanka Grey Hornbill (*Ocyceros gingalensis*) within the breeding and nonbreeding seasons. International Journal of Biodiversity 2018;2018:Article No. 509785.

Wijerathne IL, Vidanapathirana DR, Panduwawala PP, Nirath T, Kirambakanda K, Sarathchandra C, et al. Distribution status and influence of climate change on patterns of distribution of hornbills in Sri Lanka. Global Ecology and Conservation 2024;51:e02903.