Non-breeding season population density of hornbills in the core area of Khao Yai National Park, Thailand

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Abstract

*Hornbills are recognized as environmental indicators and are the focus of awareness-raising and tourism activities, but their populations are declining due to habitat degradation and poaching in Thailand. The objectives of this study were to estimate the population densities of four hornbill species found in Khao Yai National Park, Thailand, namely Oriental Pied Hornbill (*Anthracoceros albirostris*), Great Hornbill (*Buceros bicornis*), Wreathed Hornbill (*Rhyticeros undulatus*), and Austen's Brown Hornbill (*Anorrhinus austeni*). In the core area of the national park, covering 144 km^2 (12 km × 12 km), we surveyed the hornbills along 10 line transects of approximately 1.5 km length along nature trails, roads, and patrol routes in the non-breeding season from June 2022 to December 2022. Distance sampling density estimation using the DISTANCE 7.5 program showed that the population density of Oriental Pied Hornbill, Great Hornbill, and Wreathed Hornbill were 10.48 (n = 47), 2.41 (n = 26), and 2.60 (n = 29) individuals/km^2, respectively. The densities of the first two species were lower than in an earlier study conducted in Khao Yai and in Huai Kha Khaeng Wildlife Sanctuaries, possibly due to the habitat changes and seasonal movements, respectively. Austen's Brown Hornbill was not detected during the survey period. The results can serve as a baseline for long-term monitoring of hornbill populations, help evaluate the management effectiveness and guide tourism activities in Khao Yai National Park, a portion of the Dong Phayayen – Khao Yai Forest Complex Natural World Heritage Site.*

Keywords: hornbills, population, density estimation, Khao Yai National Park

Introduction

Hornbills belonging to the Family Bucerotidae are medium- to large-sized, large-billed, long-tailed birds of tropical forests, savannas, and grasslands. Sixty-three hornbill species are distributed widely through the tropical regions of Africa and Asia (IUCN, 2024). Most hornbills live in relatively intact forests, and nest in cavities in large trees, while some species, such as the Southern Ground-Hornbill (*Bucorvus leadbeateri*) in Africa, occur in grassland and open woodland (Combrink *et al*., 2020). Of the thirteen species of hornbills recorded in Thailand (Poonswad *et al*., 2013), populations of twelve species are decreasing (IUCN, 2024) chiefly due to forest fragmentation and habitat loss. Hornbills are recognized as keystone species

noted for their role as seed dispersers in tropical forests, due to which they are commonly referred to as forest farmers. Nevertheless, 50% of hornbill species are vulnerable to terrestrial hunting and trapping, followed by small-holder farming and effects of logging. Based on a review of studies, Asian hornbills are known to disperse seeds of 748 plant species in tropical forests, as recorded in data on 29 different hornbill species in 98 publications from 8 countries, particularly Thailand (Kitamura, 2011; Naniwadekar and Datta, 2013). Therefore, they are recognized as ecological indicators of the integrity of environmental changes and as species that perform crucial ecosystem functions. In addition, hornbills have distinctive features such as large bills, casque and peculiar breeding habits making them attractive and charismatic species suitable for awareness raising and tourism activities.

Thailand's forest cover in 2023 was 31.47% of the total country area, following a decrease of over 50,800 ha from the previous year (Forest Land Management Office, 2023). Besides habitat loss and fragmentation, the destruction of primary forest is also diminishing hornbill habitat and reducing availability of potential breeding sites and food resources. Moreover, nest trees losses and poor cavity condition can be a natural threat to hornbill populations and breeding. Repairing cavities before the breeding season has therefore been emphasized as a technique by the Thailand Hornbill Project team (THP team) to increase the breeding opportunities. In Khao Yai National Park, Thailand, populations of hornbills, especially Great Hornbills (*Buceros bicornis*), would have likely decreased without cavity monitoring and management (Poonswad *et al.*, 2013). Among other species, Rufous-necked Hornbill (*Aceros nipalensis*) is absent from Mae-Ping-Omkoi and Doi Phukha-Mae Yom Complexes in Thailand because of hunting and forest encroachment, while the Tickell's Brown Hornbill (*Anorrhinus tickelli*) and Great Hornbill persist at low abundance at Om Koi but have disappeared from Mar Tuen, Thailand, because of prolonged fragmentation (Pattanavibool and Dearden, 2004; Trisurat *et al.*, 2013). Globally, the IUCN has designated three species of hornbills as Critically Endangered, five as Endangered, seventeen as Vulnerable, and other species at lower risk (IUCN, 2024). In addition, most hornbill species in Thailand have been classified as endangered or critically endangered by the Thailand Red List (ONEP, 2017).

There are 18 forest complexes (Fig. 1a) and 445 units of protected area covering 108,115 km^2 or approximately 21% of the land area in Thailand (DNP, 2021, 2022). A recent study reported that hornbills are distributed in 12 forest complexes in Thailand, with the total extent of hornbill habitats spanning 9.3% of the country's land area (Fig. 1b, Trisurat *et al.*, 2013). The nationwide assessment indicated that Thailand's hornbills are mainly concentrated in 5 hornbill hotspots among the total 18 protected area complexes, namely Western Forest complex (WEFCOM), Dong Phayayen – Khao Yai, Khlong Saeng – Khao Sok, Khao Luang, and Hala Bala. These areas have high species richness, conservation status and potentially suitable habitat size criteria more than other complexes. The WEFCOM is the largest surviving forest in Thailand where five hornbill species are recognized. Despite the complex's high biodiversity, human disturbances, illegal logging, agricultural practices, and wildlife poaching occur in this area. (Emphandhu and Kalyawongsa, 2006; Trisurat *et al.*, 2013). Dong Phayayen – Khao Yai, was isolated from other complexes so it plays a role as a source of hornbills in the north-east besides being important for Austen's Brown Hornbill *Anorrhinus austeni* (Trisurat *et al.*, 2013). Six hornbill species were

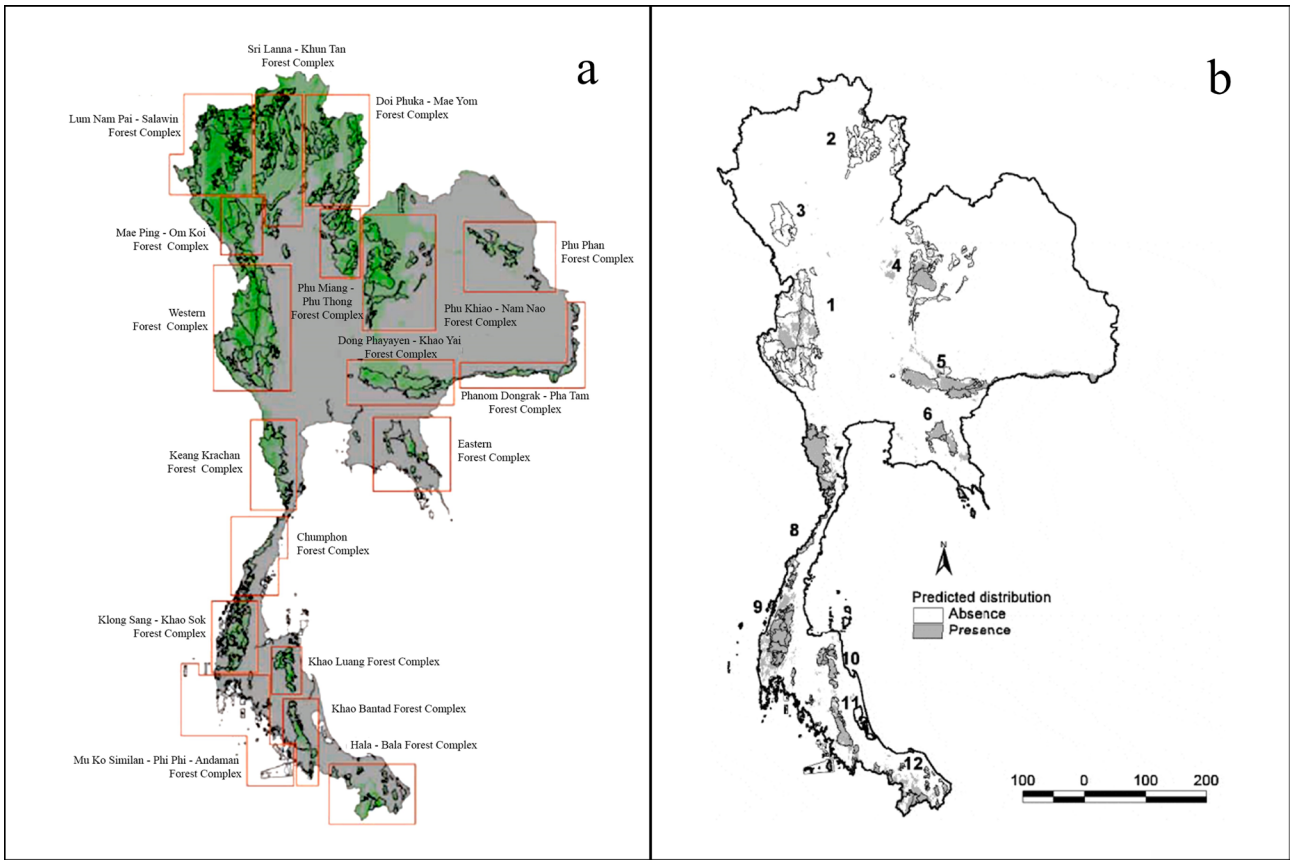

Fig. 1. Map of Forest Complexes in Thailand (a) (DNP, 2021) and (b) the predicted distribution map of hornbills (Trisurat *et al*., 2013).

found in Khlong Saeng-Khao Sok complex (Trisurat *et al*., 2013). Human disturbance and forest fragmentation affected the Khao Luang forest; however the Black Hornbill (*Anthracoceros malayanus*) occurs here (Round *et al*., 2006; Trisurat *et al*., 2013). Although Hala Bala was subject to logging during 1987 – 1992, it is home to nine of the thirteen species of hornbills, especially Rhinoceros Hornbill (*Buceros rhinoceros*) and Wrinkled Hornbill (*Rhabdotorrhinus corrugatus*) only found in this habitat (Gale and Thongaree, 2006; Trisurat *et al*., 2013).

Nevertheless, areas outside protected areas can offer potentially suitable habitats for some hornbill species. Thus, increasing connectivity of suitable habitats not only in forest complexes, but also outside, can help in maintaining hornbill populations. Furthermore, hunting is a big threat to hornbills since their large size and loud calls and sound make them easy and preferred targets of hunters (Poonswad *et al*., 2013).

Besides species distribution, species abundance or population density is an essential parameter to determine species status and response to changes in forests and other environmental factors (Balvanera *et al*., 2022; Brodie *et al*., 2013). In Thailand, some hornbill species are classified as "a protected wild animal" while others are classified as "a conserved wild animal" and studies on hornbill populations are critical for conservation management (Royal Thai Government Gazette, 2019). However, hornbill population estimations have been done unsystematically in selected protected areas in Thailand (Round *et al*., 2005;

BirdLife International, 2023a. 2023b; Gale and Thongaree, 2006; Johnburom *et al.*, 2010). As mentioned above, Khao Yai is the core area of WEFCOM and is recognized as a hotspot for biodiversity conservation. Understanding temporal variation in densities provides crucial information for formulating effective conservation strategies based on species-specific abundance patterns and population trends. To address this knowledge gap and obtain a baseline for use in future monitoring, the objective of this study was to estimate the population density of four hornbill species in the core area of Khao Yai National Park during the non-breeding season.

Methods

Study Area

The research was carried out at Khao Yai National Park in central and northern Thailand. Khao Yai National Park was established as the first national park in Thailand in 1962. Khao Yai National Park is a part of the Dong Phayayen – Khao Yai Forest Complex (DPKY), which comprises five almost contiguous Protected Areas: Khao Yai National Park, Thap Lan National Park, Pang Sida National Park, Ta Phraya National Park, and Dong Yai Wildlife Sanctuary. This protected forest complex was inscribed as a UNESCO natural world heritage site in 2005. Meanwhile, Khao Yai was designated an Asian Heritage Park, an important bird area (IBA, BirdLife International, 2023), and a key biodiversity area or KBA (Tordoff *et al.*, 2012). It was the first study site of the Thailand Hornbill Project initiated in 1978 (Poonswad *et al.*, 2013). The Park covers approximately 2,168 km^2 and encompasses a heterogeneous landscape across altitudes ranging from 101 m above sea level to 1,351 m at the Khao Lam peak. The average annual rainfall is 2,250 mm with the rainy season from May to October and highest rainfall in September. The average temperature is 22°C during the day and 9–10°C during the night. Khao Yai remains covered by evergreen forest (78% of the area) and mixed deciduous forest (10%), with much of it tall, good quality primary forest, besides remnant grassland and secondary growth (Temchai *et al.*, 2014).

Khao Yai National Park provides habitats for more than 800 faunal species, including 112 species of mammals, 400 species of birds, and 200 species of reptiles and amphibians. It is internationally important for the conservation of globally threatened and endangered species such as elephants (*Elephas maximus*), leopard cats (*Prionailurus bengalensis*), banteng (*Bos javanicus*), gibbons (*Hylobates lar* and *Hylobates pileatus*) and hornbills (UNESCO).

Based on long-term monitoring data, Khao Yai provides habitats for 4 out of 13 hornbills in Thailand including Oriental Pied Hornbill (PH) *Anthracoceros albirostris*, Great Hornbill (GH), Wreathed Hornbill (WH) *Rhyticeros undulatus* and Austen's Brown Hornbill (BH) (Poonswad *et al.*, 2013). Previous hornbill studies in Khao Yai also included home ranges of male Great, Brown and Wreathed Hornbills (Poonswad and Tsuji, 1994) and the nest site characteristics of four sympatric hornbill species (Poonswad, 2008).

The density of four hornbills including Oriental pied Hornbill (PH), Great Hornbill (GH), Wreathed Hornbill (WH), and Austen's Brown Hornbill (BH) at Mo Singto forest dynamics plot, which is dominated by evergreen forest surrounded by forest edge and secondary growth, was estimated at 0.57, 0.04, 0.13 and 0.02 individuals/ha, respectively (Round *et al.*, 2005). Since then, there has been no population estimation in Khao Yai National Park.

Khao Yai National Park is the highest visited national park in Thailand with around 1.4 million visitors per year (DNP, 2022). The main human activities in the park are hiking, wildlife watching, visiting waterfalls, and camping. Moreover, Khao Yai is the one of the best places for bird watching in Thailand (Khao Yai National Park, n.d.). Promoting ecotourism, besides economically benefiting the park, can also help in conserving and raising awareness on hornbills if proper birdwatching etiquette, observer behavior and environmental sensitivity are fostered. Ecotourism during wildlife watching can supplement patrolling of the park (Koid *et al.*, 2021). Ecotourism can potentially have positive impacts for hornbill conservation, alongside other management efforts such as cavity monitoring and repairing, and protection from human disturbance and logging in the protected area and surrounding buffer zone. Presently, Khao Yai lacks up-to-date information on hornbill population density and trends to evaluate the management effectiveness and to guide tourism activities in the park.

Survey method

The intensive study site for hornbill density estimation was located in the core area of Khao Yai, covering 144 km^2, around the park headquarters. Habitat types include moist evergreen forest (44%), dry evergreen forest (39%), mixed deciduous forest (11%), secondary growth (4%), grassland and others (3%) (Temchai *et al.*, 2014). This area has many hornbill nests (Thailand Hornbill Research Foundation, 2022) and there are many natural trails providing easy access. Elevations range from 515 m to 880 m above sea level.

Field surveys were conducted using line transect sampling between June 2022 to December 2022 mostly in the non-breeding season. Transects were surveyed from 06:00 to 11:00 h and from 14:00 to 17:00 h to record hornbills, avoiding days with heavy rain or high winds (Mynott *et al.*, 2021). The 144 km^2 (12 km x 12 km) study area was surveyed using 10 transect lines, covering natural trails, roads, and patrol routes. The transect lines were approximately 1.5 km long and spaced at least a kilometer apart to prevent duplicate counts. Each transect was walked 7 times to cover at total of 105 km (1.5 km x 10 transect x 7 revisits). There was 30 days gap between revisits to the same lines. We recorded all direct hornbill detections, both visual and aural.

For each hornbill detection, we recorded the species, number of individuals, and sex. Angles between the observation and the transect line were measured using a compass, and the distances between the observer and the bird were measured using rangefinders (Nikon Coolshot 20 GII). Besides weather conditions, we also recorded hornbill behavior such as singing, perching, and flying, as well as other activities such as eating and resting. The total survey distance was 105 km (1.5 km × 10 survey lines x 7 replications). For flying hornbills detected, we measured distance between the observer and a tree located on the same vertical plane. Locations of hornbill occurrences were recorded in UTM using AlpineQuest Off-Road Explorer 2.3.3d mobile phone application.

Data Analysis

As hornbills are large, conspicuous and mobile species, we used line transect surveys and distance sampling methods to estimate population densities (Gregory *et al.*, 2004). The data collected were analyzed using the DISTANCE 7.5 Windows computer program (Thomas *et al.*, 2010). Hornbill cluster sizes were estimated from the data on number of individuals in each detection. Density estimation was based on selection of the detection function that best fit the

data from among half-normal, hazard-rate, and uniform models with cosine adjustment terms. Model selection procedure followed Buckland *et al.*,(1993), which included: (1) selecting the model with the lowest AIC (Akaike's information criterion), as the best and parsimonious fit; (2) choosing the lowest percentage coefficient of variation (%CV) as indicative of the precision of the estimate, and (3) based on the Chi-square Goodness-of-fit test (P>0.05) indicative of model fit. Along with that we used 150 m and 160 m right truncation for estimation of densities of PH and GH, respectively. These truncation distances provided suitable visual detections of these two species and the lowest AIC. Likewise, we used 250 m right truncation for WH because we often detected it at longer distances than PH and GH. In addition, we estimated densities considering two options: (1) only visual detections, and (2) combined visual and auditory detections, then evaluated the performance of both options.

We created the distribution map of hornbills by overlaying hornbill observer positions and environmental variables. The observation positions were derived from the angles between the observation and the transect line and the distances between the observer and the bird. We used QGIS software (version 3.22.7) to derive relevant environmental data, including forest type, digital elevation model (DEM), distance to stream, distance to road, distance to building, and distance to ranger station (Temchai *et al.*, 2014) as indicative descriptors of habitat preferences of hornbills in the landscape.

Results

Hornbill detection, cluster size and encounter rate

During the 7-month survey, we encountered 538

Table 1. The number of hornbills found in the core area of Khao Yai National Park between June 2022 and December 2022.

Species	Number of detections						Total detections	Total individuals sighted
	During transect			Supplementary observations				
	Visual	Auditory	Total	Visual	Auditory	Total		
PH	54	45	99	19	8	27	126	173
GH	38	52	90	12	11	23	113	112
WH	37	13	50	26	1	27	77	253
BH	-	-	-	-	1	1	1	-
Total	129	110	239	57	21	78	317	538

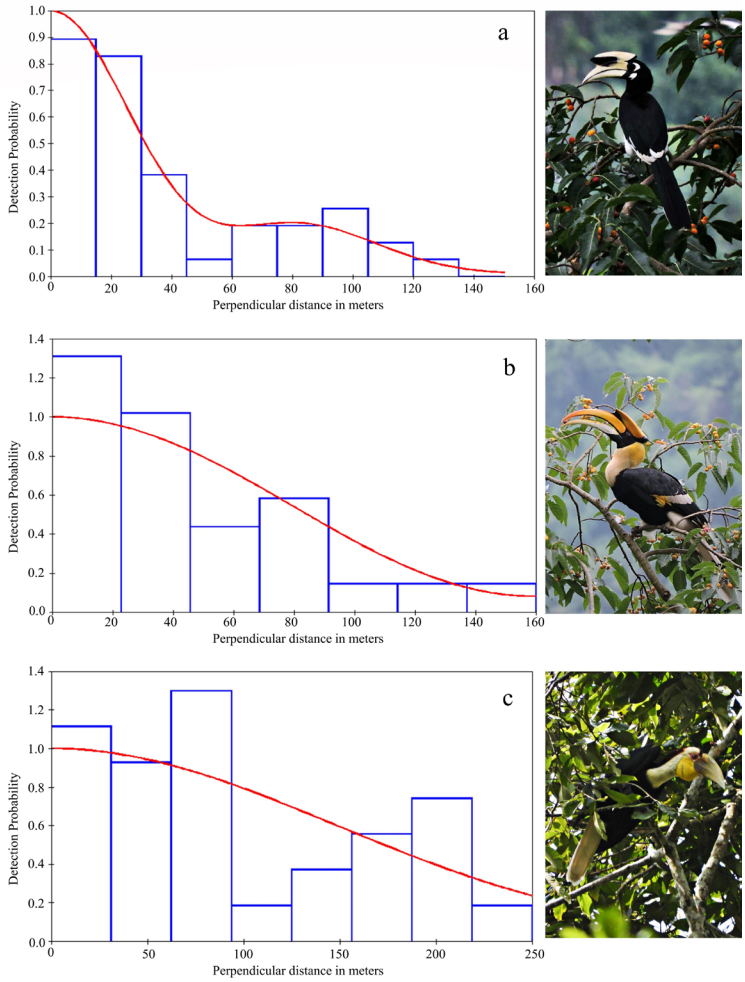

Fig. 2. Detection Probability Plots of three hornbill species in line transect surveys in the core area of Khao Yai National Park between June 2022 and December 2022: (a) Oriental Pied Hornbill; (b) Great Hornbill; (c) Wreathed Hornbill. (Photos: K. Phanakorn)

individuals of four hornbill species both along the transects and outside the transects in supplementary observations (Table 1). The numbers of WH contributed about 47% of the total individuals. During the survey period, Austen's Brown Hornbill was not detected and only one auditory detection was recorded. Therefore, it was excluded for density estimation.

Model fit (using AIC, %CV, and Chi-square Goodness of fit test) was assessed separately for: (1) only visual detections, and (2) combined visual and auditory detections. As the model results showed that visual detection data of three hornbill species provided better performance than the combined visual and auditory detections, it was used to calculate cluster sizes, encounter rates, and densities. Details of best-fit models and fitted detection functions are presented in Table 2 and Fig. 2.

Based on the visual detections of hornbills along transect lines, PH, GH and WH had mean cluster size in individuals/cluster (and encounter rates in individuals/km) of 2.33 (0.51), 2.24 (0.36), and 4.43 (0.35), respectively (Table 3).

Population density of hornbills

Based on the selected models and parameters

Table 2. Details of selected models for density estimation of hornbills in the core area of Khao Yai National Park between June 2022 and December 2022.

Species	Detection	Key function + Series expansion	Right truncation (m)	AIC	GOF χ^2 p
PH	Visual	Half-normal+cosine	150	438.87	0.56
GH	Visual	Uniform + cosine	160	253.35	0.55
WH	Visual	Half-normal + cosine	250	317.99	0.45

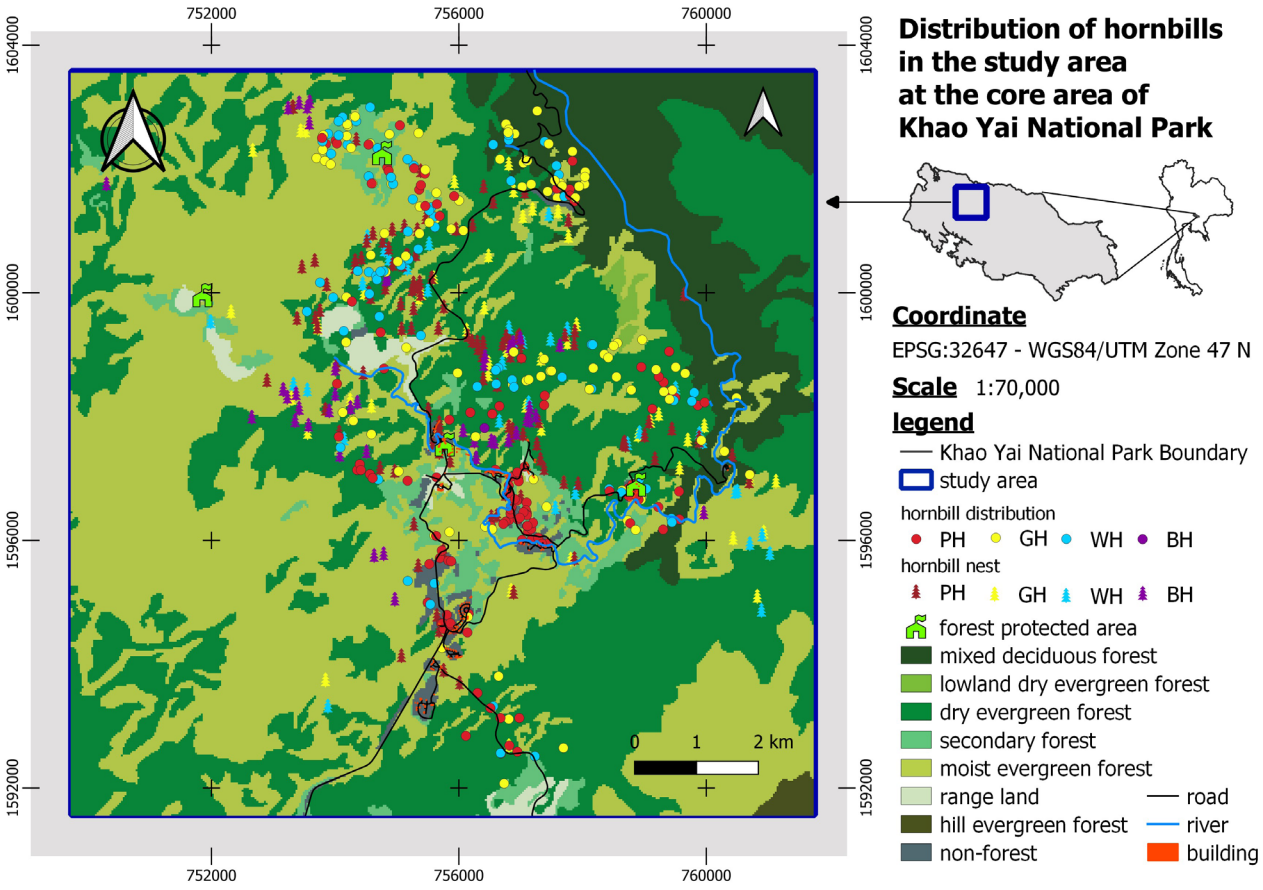

Fig. 3. Distribution map of four hornbill species with environmental layers in the core area of Khao Yai National Park.

Table 3. The mean cluster size and the encounter rate of hornbills in the core area of Khao Yai National Park between June 2022 and December 2022.

Species	Detection	Number of clusters (n)	Mean cluster size	Standard error	Encounter rate (individuals/km)
PH	Visual	54	2.33	0.17	0.51
GH	Visual	38	2.24	0.29	0.36
WH	Visual	37	4.43	0.96	0.35

Table 4. The estimated densities of hornbills in the core area of Khao Yai National Park between June 2022 and December 2022.

Species	DS	n	Density (individuals/km²)				
			D	SE±	%CV	95% CI	
						Lower	Upper
Oriental pied Hornbill (PH)	4.98	47	10.48	3.22	30.72	5.62	19.52
Great Hornbill (GH)	1.43	26	2.41	0.83	34.66	1.16	4.98
Wreathed Hornbill (WH)	0.82	29	2.60	0.87	33.31	1.33	5.12

Abbreviations: DS: density of clusters (clusters/km²); n: number of hornbill detections/clusters; D: density (individuals/km²); SE±: standard error; %CV: % coefficient of variation; 95% CI: 95% Confidence Interval

(Tables 2 and 3) we estimate PH, GH, and WH cluster densities at 4.98, 1.43, and 0.82 cluster/km², respectively (Table 4). The corresponding PH, GH, and WH densities were 10.48, 2.41, and 2.60 individuals/km², respectively. In the DISTANCE models, about 13%, 31% and 26% of visual detections for PH, GH and WH, respectively, were discarded for the analysis after right truncation.

Environmental variables in study area

The results of GIS overlay and field observations indicated that moist evergreen forest was the most frequent habitat of occurrence for all

hornbills (43.5%), followed by dry evergreen forest (39.0%), mixed deciduous forest (10.8%) and others 6.7% (Fig. 3).

Discussion

Khao Yai National Park located in the WEFCOM is recognized as a hornbill hotspot in Thailand (Trisurat *et al.*, 2013). The park provides habitats for 4 out of 13 hornbill species, namely Oriental Pied Hornbill (PH), Great Hornbill (GH), Wreathed Hornbill (WH), and Austen's Brown Hornbill (BH) (Poonswad *et al.*, 2013). In addition, Khao Yai is one of three research areas for long-term monitoring of hornbill populations and nesting (Thailand Hornbill Research Foundation, 2022). In addition, hornbills are flagship species for ecotourism in the park (Koid *et al.*, 2021). Up-to-date information on hornbill population and their distribution can therefore serve as a baseline for long-term monitoring of hornbill populations and help evaluate the management effectiveness, besides helping guide tourism activities in Khao Yai National Park.

Population density was not estimated for Austen's Brown Hornbill due to inadequate detections. The number of visual detections for PH was heighest (Table 3) likely due to PH being the most adaptable hornbill, listed as Least Concern (LC) status at global and national levels (BirdLife International, 2020a; ONEP, 2017). With their small size and broader habitat preference, they are more frequently detected (BirdLife International, 2023a). In contrast, the GH is generally found in evergreen forests and is more sensitive to human proximity (BirdLife International, 2023b). This may account for the less frequent detections of GH than PH (Hornbill Specialist Group, n.d.). The WH also normally avoids disturbed habitats and proximity to humans and despite their wide-ranging habits are more difficult to detect compared to PH and GH. Nevertheless, WH has the highest number of individuals (253 individuals; Table 1) and a higher encounter rate possibly due to larger flock sizes (maximum in a fruiting tree was up to 30).
Round *et al.*,(2005) found 57 individuals/km² of PH in a biodiversity research plot in Mo Singto at Khao Yai National Park, which is almost 5 times higher than this study (10.48 individuals/km²). Similarly, the average population density of PH in the entire Khao Yai National Park during 2004-2008 was 21 individual/km² (BirdLife International, 2023a). In addition, the density of the Oriental Pied hornbill in the Pakke Tiger Reserve in Arunachal Pradesh, India, affected by human disturbance was 19 individuals/km² (Dasgupta and Hilaluddin, 2012).

The previous studies at Khao Yai were conducted when Mo Singto covered a variety of forest types such as deciduous forest, secondary forest, grassland, and open areas. Such heterogeneous landscapes are preferred by PH (Hornbill Specialist Group, n.d.; BirdLife International, 2023a). During the last two decades, the open woodlands have been transformed to mature evergreen forests and only a few patches of secondary forest remain (Temchai *et al.*, 2014). Round *et al.*,(2005) combined line transects and circular plots to survey the birds only in morning, whereas visual detections in the morning comprised 66% of the total detections in the present survey. In addition, mist-nets and playback tapes were used to attract birds to the net in the earlier study (Round *et al.*, 2005). Therefore, the lower PH density noted during the present study may be due to both habitat changes and differences in survey times and methods.

The IUCN Red List classifies the GH as a Vulnerable species (VU) (BirdLife International, 2020b), while it is Near Threatened in Thailand

(ONEP, 2017). GH density in the present study (2.41 individuals/km²) was generally lower than other areas in Thailand and in the region, except lowland forests in Hala-Bala. The Round *et al*. (2005) estimate for GH in Mo Singto was 4 individuals/km² reflecting differences in survey methods and survey time as mentioned above. The density of the GH at Huai Kha Khaeng Wildlife Sanctuary was 5.28 individuals/km², which was higher than in this and the previous studies because Huai Kha Khaeng witnesses seasonal movements of GH and WH and has preferred feeding sites during the non-breeding season (Johnburom *et al*., 2010). Meanwhile, the density of GH in Namdapha Tiger Reserve in Arunachal Pradesh, and in Pakke Tiger Reserve in India was 3.9 individual/km² (Naniwadekar and Datta, 2013) and 3.8 individuals/km², respectively (BirdLife International, 2023b). The differences may be due to tourism activities in the Indian reserves being limited compared to Khao Yai. In addition, the GH prefers dense old growth unlogged forests. Some transects of our study cover grassland and forest edge, while the entire study in India were in large stretches of rainforests. Gale and Thongaree (2006) found 0.124 individuals/km² in Hala-Bala Wildlife Sanctuary on the Thai–Malaysia border where 9 out of Thailand's 13 hornbill species occur. Range overlap and food competition among these 9 species, especially with Rhinoceros Hornbill, may cause the lower density of GH in Hala Bala.

The WH is classified as a Vulnerable species (VU) at the global level (BirdLife International, 2018b) and as Near Threatened in Thailand (ONEP, 2017). Our study indicated the density of the WH was 2.6 individuals/km², which was slightly greater than the previous study of 2 individuals/km² (Round *et al*., 2005), but substantially greater than the Bala Forest (0.69 individuals/km²; Gale and Thongaree, 2006). This is possibly due to the Bala Forest being degraded from logging during 1987 – 1992 and becoming less suitable for WH (Trisurat *et al*., 2013). Moreover, a lower density may have been recorded as the survey was conducted in the breeding season (Naniwadekar and Datta, 2013; Poonswad and Tsuji, 1994).

In contrast, the density of the WH found in Mount Ungaran, Central Java, Malaysia (Rahayuningsih and Nugroho, 2013) and in Namdapha Tiger Reserve, Arunachal Pradesh, India were 14.60 individuals/km² (Rahayuningsih and Nugroho, 2013), and 16.1 individuals/km² (Naniwadekar and Datta, 2013), respectively. Potential reasons for differences between this and other areas include the composition of habitat types and survey methods. WH inhabits closed forest, both evergreen and deciduous, from the lowlands to the lower montane forest. About 83% of the study area are dense forests, while the reaming areas are degraded forest and grassland, while the other areas are almost entirely closed forests. This assumption is relevant to the visual detections of this study. More than 95% of total visual detections of WH and GH were found in dense moist and dry evergreen forests, but the statistical influence of these factors requires further investigation.

Evergreen forests are recognized as suitable habitats for the four hornbill species, which provide abundance of fruits and nutrient resources. There are 139 ripe fruit species, from 76 genera and 36 plant families found in the diet of hornbills (Poonswad, 2010). Additionally, the PH was detected in closed forests near road and stream because PH prefers forest edges and open woodlands whereas GH and WH were found in the core areas of primary evergreen and deciduous forests. In addition, we found that more than 90% of hornbill occurrences were at elevations above 700 m. This

is different from Namdapha Tiger Reserve, India, where low densities of Great and the Austen's Brown hornbills are noted in higher elevations (Naniwadekar and Datta, 2013). In Khao Yai, lower elevations (515 – 700 m) have been converted for cultivation before the park establishment and are now categorized as secondary growth and grassland (Temchai *et al.*, 2014).

Khao Yai National Park provides habitats for more than 400 species of birds (UNESCO) and at least 159 bird species have been recorded in the Mo Singto plot (Round *et al.*, 2005) inside the study area. In addition, birdwatching especially for hornbills is one of the main visitor activities in the park. Visitors can participate and get involved in sharing and contributing hornbill data through citizen science. The data reported by visitors can supplement long-term monitoring of hornbill populations implemented by the Thailand Hornbill Research Foundation (2022). Eventually, the combined data will increase scientific knowledge to evaluate the management effectiveness of Khao Yai National Park as a portion of the Dong Phayayen – Khao Yai Forest Complex Natural World Heritage Site. In addition, density estimation in the breeding season is highly recommended to understand spatial-temporal variation in densities and for providing crucial information for formulating effective conservation strategies.

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Competing Interests Statement

Authors have no competing interests to declare.

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