Role of vegetation characteristics on the distribution of three hornbill species in and around Pakke Tiger Reserve, Arunachal Pradesh, India

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The change in physiognomic and floristic characteristics of vegetation composition affects the bird community assemblage and the relative abundance of different species within the community. Hornbills are mutualistic to the forest with their dependency on roosting, nesting and feeding, and helping in the regeneration of different plant species by dispersing the seeds. The relationship between various vegetation characteristics and the relative abundance of three hornbill species (Great Pied Hornbill (GPH, *Buceros bicornis*), Wreathed Hornbill (*Rhyticeros undulatus*) and Oriental Pied Hornbill (OPH, *Anthracoceros albirostris*)) was studied in and around Pakke Tiger Reserve, Arunachal Pradesh, India. We walked transects (n = 11; 22 walks) in three study sites to detect hornbills. Vegetation sampling was done using circular plots (n = 33; 10 m radius) at every 400 m interval along each transect. Encounter rate (1.5 ± 0.188/km) of GPH was highest in the protected and undisturbed forest area, where food and roosting tree density were also high (114/ha). OPH was common in both the sites in the Reserve, near riverine forests (0.75 ± 0.25/km) and the dense undisturbed forest (0.875 ± 0.226/km). Multivariate analysis revealed that tree density, presence of fruiting trees (utilized by hornbills), canopy cover and tree diversity in a particular area are the major factors responsible for the assemblage of more than one hornbill species. The study shows that protection of forest patches to keep the diversity and density of the tree species intact is crucial for the survival and distribution of hornbills in the landscape.

Keywords: Forest structure, hornbill abundance, mutualism, tiger reserve, vegetation characteristics.

VEGETATION is a major determining factor of species assemblages in a bird community and the abundance of certain bird species depends on the vegetation composition of the habitat[1–5]. Both physiognomic and floristic characteristics of vegetation affect the bird species abundance[5,6]. Change in vegetation along the complex environmental and disturbance gradient can change the abundance and distribution of a particular species or species guild[7]. The interplay between vegetation and bird species assemblage is well documented[8–12]. Bird species richness and diversity are directly correlated with physiognomic characteristics such as foliage height, foliage volume, percentage vegetation cover, etc.[10,13–15]. The abundance of some tree species or a group of species can influence the distribution of certain bird species or bird guilds[16,17]. Some species do not have a specialized niche and can thrive under varied environmental conditions; they are named generalists. Whereas, most of the species are specialists, having some definite environmental set-up to survive in[18–20]. Large-bodied bird species such as hornbills are mutualistic in the forest[19]. The Great Pied Hornbill (GPH) found in South and Southeast Asia is predominantly frugivorous[19,20]. The Wreathed Hornbill (WH) is distributed throughout North East India as well as Bhutan, Bangladesh to Southeast Asia. It is largely frugivorous and lives in flocks[19,21]. Oriental Pied Hornbill (OPH) is considered to be the most common hornbill species found in the Indian subcontinent and Southeast Asia. Although frugivorous, it feeds on insects, small birds, reptiles and bats[19,20]. In the tropical rainforest, plant–frugivore interaction is important for the sustenance of the diversity of the plant species. Most tropical species depend on vertebrate frugivores for the dispersal of their seeds[22–24]. Regeneration of forest vegetation depends on the presence of seed dispersers (such as hornbills) in the forest[25]. Seed dispersal in a tropical forest is one of the vital ecosystem services[26–28] and in the absence of dispersers, loss of diversity is well observed throughout the world[29].

Seed dispersers are particularly sensitive to both habitat destruction and hunting[30–32]. A considerable amount of habitat alteration and loss has intensified in the tropical forest of North East India in the Eastern Himalayan region[33,34]. Hunting, loss of habitat due to jhum (shifting cultivation) and developmental activities are severe in the easily accessible foothill forests near the dense human habitation[32]. The remaining forest patches are also under

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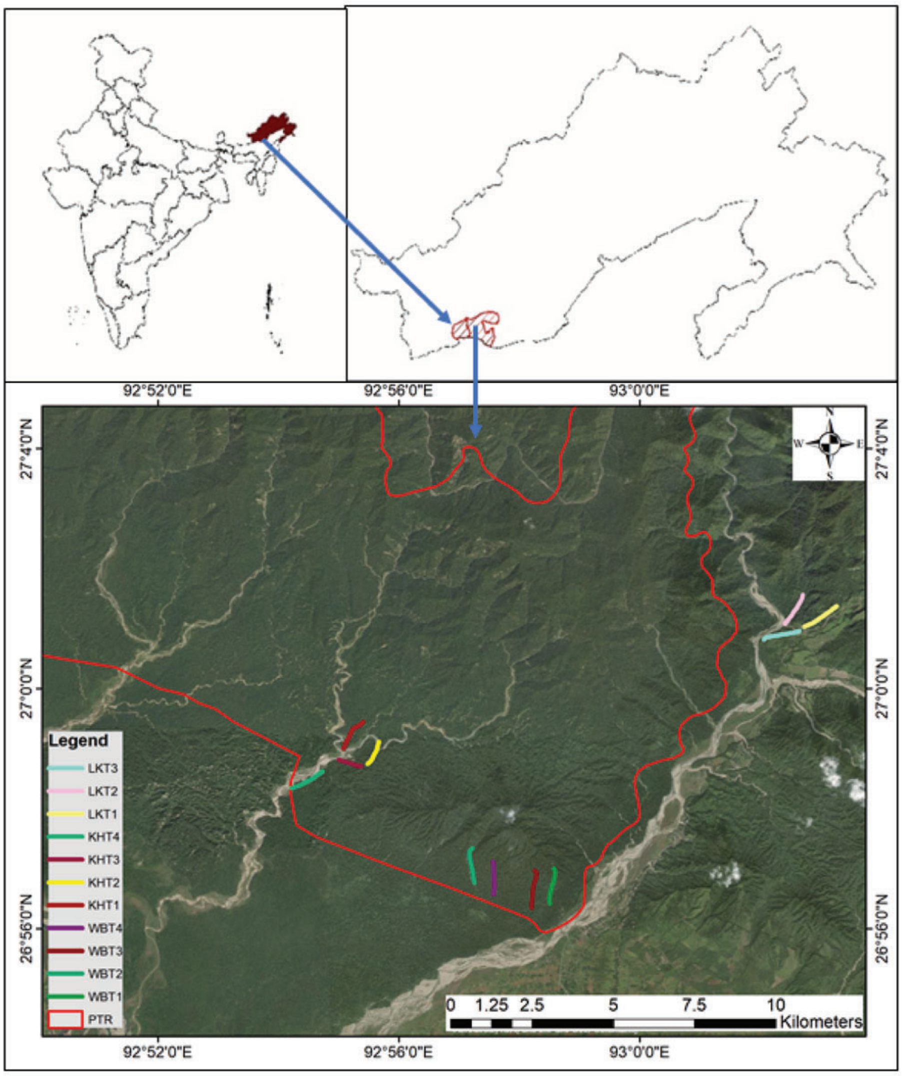

Figure 1. Map of the study area in Pakke Tiger Reserve, Arunachal Pradesh, India. Legends show the transects in Lanka (LK), Khari (KH) and the West Bank (WB), and the boundary of the Reserve.

threat due to rampant hunting and extraction of forest products[35–37]. The Pakke Tiger Reserve in Arunachal Pradesh, NE India, is an apt example of such habitat alterations. Baseline information on hornbill abundance and its role in seed dispersal is available from different forests of Arunachal Pradesh, including the Pakke Tiger Reserve[12,30,32,38]. Datta and Rawat[39] reported that tree species of Lauraceae, Meliaceae, Myristicaceae, Anacardiaceae, Clusiaceae, Burseraceae, Moraceae and Euphorbiaceae are used for their fruits in this Reserve. Seed dispersal by vertebrates and ornithochory were the most abundant dispersal modes of tree species in the Pakke Tiger Reserve[31,39].

However, information on the relationship between hornbill species occurrence and vegetation/stand characteristics in this landscape is limited[24,30,31]. The present study was carried out with two primary objectives. First, to assess the occurrence and relative abundance of different hornbill species in and around the Eastern boundary of the Pakke Tiger Reserve. Second, to observe how both physiognomic and floristic characteristics of vegetation determine the relative abundance of different hornbill species.

Methods

Study area

The study was conducted in the lowland tropical forest of the Pakke Tiger Reserve. We selected three study sites, two within the Reserve (West Bank 26°56′N, 92°58′E and Khari 26°59′N, 92°54′E) and one its Park boundary (Lanka 27°01′N, 93°02′E) (Figure 1). The major vegetation type of the study area has been classified as Assam Valley tropical semi-evergreen forest (2B/C1) by Champion and Seth[40]. Details of different habitat types and levels of disturbance can be found in Datta[30]. All three sites were selected based on the forest structure and degree of disturbance. West Bank forest (12 sq. km) is situated near Seijusa on the southern boundary of the Reserve adjacent to the Pakke River and has been free of large-scale anthropic interventions or habitat alterations recently. The area is dominated by lowland forests with an altitudinal range 150–600 m. Khari is located almost 12 km west of the West Bank and is characterized by steep terrain dominated by palm (*Livistona*), cane (*Calamus*) and bamboo (*Bambusa* and *Dendrocalamus*) species, intersected by several perennial streams. Human settlements practising log and cane extraction existed here in the past (2–3 decades ago)[30]. Lanka, on the other hand, is outside the boundary of the Pakke Tiger Reserve and therefore is heavily disturbed due to the sustained prevalence of selective logging and hunting. Local people also heavily depend on the forests of Lanka for firewood and other non-timber forest products.

Field methods

We walked transects ($n = 11$; 22 walks) of 1 km each in the three study sites to detect hornbill species from 5.00 to 7.00 h. As hornbill activity is high during this period, the chance of an encounter is also very high. Four transects each in West Bank and Khari, and three in Lanka were walked twice. Thus the total distance walked was 22 km, 8 km each in West Bank and Khari, and 6 m in Lanka. The relative abundance of hornbill species was determined using the encounter rate per kilometre walked. Vegetation sampling was carried out using circular plots ($n = 33$; 10 m radius) at every 400 m interval along each transect (i.e. three vegetation plots in each transect). In each plot, the presence of tree (≥20 cm girth), presence of climber, trail, and number of fruiting, nesting and roosting trees were recorded. Girth at breast height (gbh) for each tree inside the plot was measured using standard methodology[41]. The number of trees with more than or equal to 20 cm gbh was identified and their height was measured. Canopy cover in each plot was measured using the line intercept method[42,43]. Twenty points were taken on a single line with 1 m interval and presence–absence of the canopy above these points was recorded to calculate the percentage of canopy cover.

Analysis

As the number of encounters was not enough to obtain statistically reliable results using the DISTANCE software[44], for calculation of encounter rates we used the following formula (modified from Buckland *et al.*[45])

$$\mathrm{EN}_S = \left(\sum_{t}^{r} D_S\right) / d_t,$$

where S is a particular hornbill species, D the detection of the particular species S, d denotes the total distance of a particular transect t in region r and EN is the encounter rate. Encounter rates across individual transects were then averaged for all replications, for each study area and individual hornbill species, to arrive at relative abundance estimates per site. The standard error of means was calculated to determine the variation across averaged encounter rates for each transect.

Identification of trees, shrubs and herbs were carried out following Datta (unpublished thesis) and a species inventory was prepared for the three study sites. Tree density, diversity, dominance, average height and average gbh were calculated for each vegetation plot. Relative density, relative frequency and relative dominance of important fruiting and roosting trees for hornbills were summed to calculate the importance value index (IVI) values in three different sites. Important fruiting and roosting trees of the area are already mentioned by Datta (unpublished thesis).

The PERMANOVA test was done to assess the difference in plant community composition between the three study sites[46]. SIMPER analysis was done to identify the species influencing the differences in community structure of the three study areas with different disturbance histories[47]. The change in abundance of different hornbill species along with the difference in floristic characters was assessed through non-metric multidimensional scaling (NMDS) with Bray–Curtis distance measures[48]. The abundance of different plant species with IVI values of more than five was used for ordination along with the presence data of the hornbills. The importance of physiognomic variables was assessed through binomial regression. Using physiognomic characteristics as explanatory variables, generalized linear modelling was carried out to identify the factors governing the occurrence of different hornbill species using binomial family in R software[49]. The information generated from 33 vegetation plots was used along with the presence–absence information of the hornbill species within a 300 m stretch of the transect on both sides of the vegetation plot (Table 1). We used corrected Akaike information criterion (AIC) values to rank the models[50] and considered all the models with $\Delta\mathrm{AIC} < 2$ as equivalent. The summed model weight of each explanatory variable in these models was used to determine the most influential variables for each species. The value and sign of the logistic coefficient of each variable (positive or negative) and the associated error were used to determine the direction of influence of the variable.

Results

During transect walks, we detected the presence of three hornbill species, viz. GPH (*Buceros bicornis*), WH (*Rhyticeros undulatus*) and OPH (*Anthracoceros albirostris*) (Table 1). Encounter rate (1.5 ± 0.188/km) of GPB was highest in the protected and undisturbed forest area of the West Bank (Table 2). The encounter rates of the other two species were also higher in undisturbed protected forests than in the other two sites.

Table 1. List of variables, their abbreviations and range as used to determine the influential vegetation characteristics and their role in hornbill distribution using nonmetric multidimensional scaling followed by generalized linear modelling

Abbreviation	Full form	Description
GPH	Great Pied Hornbill	0–1
WH	Wreathed Hornbill	0–1
OPH	Oriental Pied Hornbill	0–1
diversity	Diversity of tree species	Diversity of tree species in the vegetation plot along the transect (2–19)
avght	Average height of tree species	Average height of the tree species in the vegetation plot along the transect (9.58–17.67 m)
avggbh	Average gbh of the tree species	Average gbh of tree species in the vegetation plot along the transect (41.7–149.8 cm)
density	Density of tree species	Density of tree species in the vegetation plot along the transect (5–27 trees/plot)
ftree	Presence of fruiting trees	Presence of fruiting trees of hornbill food preference in the vegetation plot along the transect (0–4)
rntree	Presence of roosting and nesting trees	Presence of roosting and nesting trees of hornbills in the vegetation plot along the transect (0–2)
canopy	Canopy cover	Percentage canopy cover in the vegetation plot along the transect (60–90%)
trail	Presence of trail	Presence of trail in the vegetation plot along the transect (0–3)
climber	Presence of climbers and epiphytes	Presence of climbers and epiphytes in the vegetation plot along the transect (7–45)

Table 2. Average values of different physiognomic variables and presence of different hornbill species in different sites as well as transects. Hornbill presence is shown as three if it was encountered in all the three segments of the transect and decreased as the encounters decreased along the transect

Site/transect	Average gbh	Average tree height	Average tree density	Canopy cover	GPH	WH	OPH
West Bank T1	57.17 ± 49.65	12.47 ± 6.66	21.6	81.66	3	1	2
West Bank T2	52.15 ± 37.63	14.46 ± 5.82	22	85	2	2	1
West Bank T3	66.6 ± 38.78	15.15 ± 4.54	21.6	81.66	1	1	2
West Bank T4	58.73 ± 36.32	14.66 ± 6.03	18.6	85	3	2	1
Khari T1	67.84 ± 44.20	12.23 ± 4.81	21.3	83.33	0	1	0
Khari T2	67.43 ± 46.73	11 ± 4.67	18.3	81.66	1	0	2
Khari T3	57.2 ± 31.96	11.95 ± 4.25	16	81.66	1	1	2
Khari T4	51.03 ± 25.98	11.61 ± 3.31	18	80	2	0	1
Lanka T1	69.67 ± 38.68	11.05 ± 3.99	13	80	1	1	1
Lanka T2	83.35 ± 40.23	14.36 ± 5.40	15	78.33	1	0	2
Lanka T3	108.2 ± 81.03	12.56 ± 4.96	8	63.33	1	2	0

From the vegetation plots of the three study sites, a total of 62 tree species were recorded among which 56 were identified up to the species level. When tree diversity and richness were measured, the Shannon index gave high measures in Lanka (3.32) among the three sites, followed by the West Bank (3.08) and Khari (2.69). On the other hand, the dominance index was much higher in Khari (0.15) than in the West Bank (0.06) and Lanka (0.04). The average gbh was higher in Lanka compared to those in the West Bank and Khari (Table 2), whereas the opposite trend was found in the case of tree density in the vegetation plots. Average tree height and canopy cover ranged from 11 to 15.153 m and 63.33% in one transect of Lanka to 85% in two transects of the West Bank. The details of the measurements are given in Table 2.

The presence–absence of three hornbill species within 300 m (150 m before and after) of the vegetation plots was assessed during data analysis. GPH was found near all three vegetation plots of two transects of the West Bank, whereas it was not encountered during the transect walk in one of the transects in Khari. WH and OPH were not encountered in one transect of Khari and Lanka, and none of the two species was encountered throughout the transects in all three sites (Table 2). The results of NMDS reveal that the presence of WH and GPH is determined by similar factors like high diversity of trees, trees with larger gbh and height, and association with tree species like *Polyalthia simiarum*, *Chisocheton* sp., *Pterospermum* sp., *Dysoxylum* sp., etc. whereas the presence of OPH is associated with canopy cover and tree density (Figure 2). The IVI values of *Polyalthia simiarum* and *Chisocheton* sp. were higher among all the 13 important fruiting and roosting trees in both the undisturbed sites (Figure 3) of the West bank and forests of Khari, where human intervention

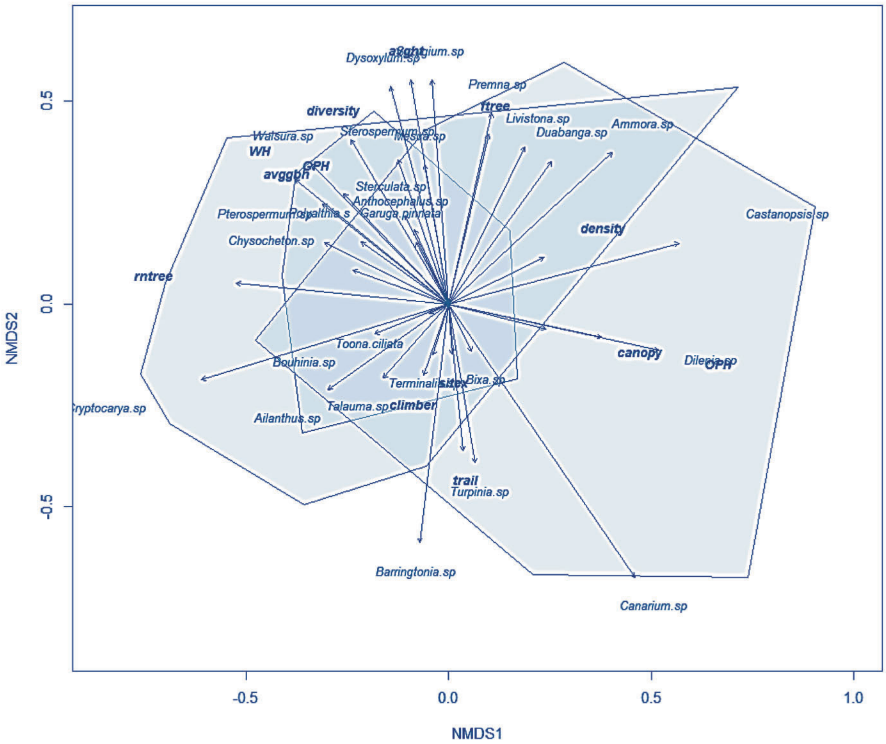

Figure 2. Results of the nonmetric multidimensional scaling showing the interaction of physiognomic and floristic characteristics with hornbill presence.

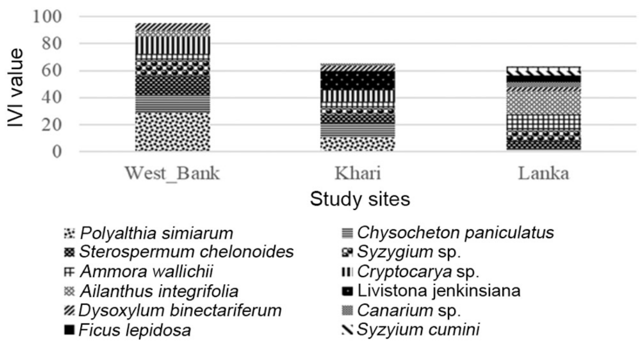

Figure 3. Importance value index (IVI) values of different fruiting and nesting trees depicted in a stacked column chart.

has occurred in the past. However, their IVI values were zero or minimal in the disturbed sites of Lanka.

The NMDS results (stress value 0.12) also show some differential association of species in the three different study sites. Species like *Terminalia*, *Garuga pinnata* and *Anthocephalus* sp. were only found in the West Bank and formed a distinct association. *Pterospermum* sp., *Polyalthia* sp. and *Chisocheton* sp. showed distinct distribution, although the abundance of these species also contributed to the dissimilarity between the tree communities in the study area. The results of PERMANOVA show significant differences ($P = 0.001$, $F = 4.32$) in the species assemblage in the tree communities in the three studied sites. SIMPER analysis shows that the species assemblage of vegetation plots in Khari and Lanka differ much more (percentage dissimilarity 93.49) than that between the West Bank and Khari (percentage dissimilarity 89.97), and the West Bank and Lanka (percentage dissimilarity 85.81). The overall dissimilarity of the tree composition was 89.78% between the tree communities, and the abundance of trees of *Canarium* sp., *Polyalthia* sp., *Cryptocarya* sp., *Pterospermum* sp. and *Bauhinia* sp. contributed to more than 50% of the dissimilarities (Table 3).

Table 4 shows the selected models for the presence of three hornbill species according to the lowest corrected AIC value. The results of generalized linear modelling show that the presence of GPH is positively associated with the presence of fruit trees as well as roosting and nesting trees, and negatively with tree density and the presence of trail. WH is associated positively with tree diversity and average gbh, whereas negatively with tree density and the presence of climbers. The presence of OPH is positively associated with the presence of fruiting trees, trail and high canopy cover (Figure 4).

Discussion

Previous studies in different landscapes of Arunachal Pradesh have shown that the habitat preferences of these three hornbill species differ[30,32] (Datta, A., unpublished thesis).

Table 3. Species responsible for average dissimilarity between the sites and their contribution according to SIMPER analysis

Taxon	Average dissimilarity	Contribution (%)	Cumulative (%)	Mean abundance In the West Bank	In Khari	In Lanka
Canarium sp.	18.6	20.72	20.72	0	6.42	0.111
Polyalthia sp.	8.624	9.605	30.32	2.25	0.75	0
Cryptocarya sp.	7.175	7.991	38.31	1.33	0.583	1
Pterospermum sp.	6.06	6.749	45.06	0.833	1.25	0.333
Bouhinia sp.	5.472	6.094	51.16	1.25	0	0.667
Castanopsis sp.	4.712	5.248	56.4	0.167	1.08	0.222
Chisocheton sp.	4.711	5.247	61.65	1.08	0.583	0.111
Syzygium sp.	3.544	3.948	65.6	0.833	0.25	0.333
Sterculata sp.	3.203	3.567	69.17	1	0	0
Sterospermum sp.	2.952	3.289	72.46	0.667	0.25	0.222
Livistona sp.	2.839	3.162	75.62	0	0.75	0
Premna sp.	2.686	2.992	78.61	0.417	0.25	0.333
Ailanthus sp.	2.463	2.744	81.35	0.167	0	0.667
Talauma sp.	1.968	2.192	83.54	0.167	0	0.556
Amoora sp.	1.727	1.924	85.47	0.0833	0.167	0.333
Dysoxylum sp.	1.674	1.864	87.33	0.333	0.167	0.111
Barringtonia sp.	1.595	1.777	89.11	0.25	0.0833	0.222
Toona ciliata	1.4	1.56	90.67	0.417	0	0
Dilenia sp.	1.384	1.541	92.21	0	0.417	0
Walsura sp.	1.377	1.534	93.74	0.0833	0	0.333
Mesua sp.	1.33	1.482	96.72	0.417	0.0833	0
Turpinia sp.	1.033	1.151	97.87	0	0.333	0
Duabanga sp.	0.9187	1.023	98.9	0	0	0.222
Garuga pinnata	0.4896	0.5454	99.44	0.167	0	0
Terminalia sp.	0.2562	0.2853	99.73	0.0833	0	0
Anthocephalus sp.	0.2448	0.2727	100	0.0833	0	0

Table 4. Top generalized linear models explaining the role of different vegetation characteristics on the distributions of GPH, WH and OPH in and around Pakke Tiger Reserve, Arunachal Pradesh

Hornbill species	Model	Log likelihood	AIC	ΔAIC	Weight
GPH	Fruiting tree	–21.053	46.5	0.00	0.362
	Fruiting tree + roosting and nesting tree + tree density	–18.679	46.8	0.28	0.314
	Fruiting tree + roosting and nesting tree	–20.372	47.6	1.07	0.212
	Fruiting tree + trail	–21.015	48.9	2.35	0.112
WH	Climber	–18.987	42.4	0.00	0.377
	Climber + average gbh	–18.285	43.4	1.01	0.226
	Climber + average gbh + tree diversity	–17.479	44.4	2.01	0.148
	Average gbh + tree density	–20.327	45.1	2.68	0.104
OPH	Canopy cover	–19.654	43.7	0.00	0.494
	Canopy cover + fruiting tree	–19.218	45.3	1.56	0.227
	Canopy cover + fruiting tree + tree diversity + presence of trail	–16.959	46.1	2.43	0.146
	Fruiting tree	–20.961	46.3	2.61	0.134

AIC, Akaika information criterion.

GPH prefers undisturbed habitats, OPH prefers riverine forest patches with secondary growth and WH shows no specific habitat preferences[39]. Our observations are comparable with these findings. GPH and WH encounter rates depend on tree density, fruiting tree density, and density of roosting and nesting trees. As communal roosting is common in GPH and WH[39] (Datta, A., unpublished thesis) nesting and roosting trees plays a significant role in their abundance. The abundance of OPH is also dependent on a high percentage canopy cover as well as the presence of fruit trees, roosting and nesting trees[30].

Though inside the protected area, low species diversity and high dominance value of the sampled plant communities in Khari might have resulted from past disturbances such as extraction of cane (*Calamus*) and bamboo (*Bambusa* and *Dendro calamus*). Lanka is outside of the protected area and selective logging has been continuous practice; however, the tree species diversity was comparable with the other two sites, while the tree species composition differed. In Lanka, the occurrence and IVI values of trees important for hornbills differed from those of the other two sites inside the protected area. The change in species

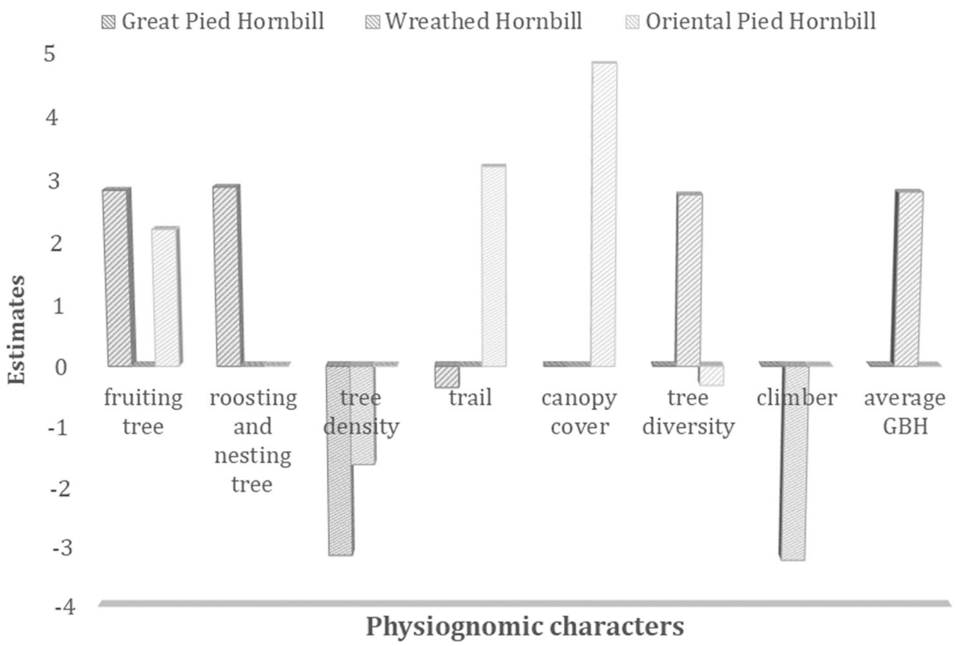

Figure 4. Average estimates of different physiognomic variables determining hornbill presence according to generalized linear modelling.

composition was well observed in the analysis of tree species assemblage in the three study sites. There were differences in overall species presence in the West bank, Khari and Lanka. These changes in structure and composition of the tree communities can explain the different species assemblage patterns of the three hornbill species as observed in this study.

Encounter rates of all hornbill species were highest in the West Bank site, probably due to higher protection. Among the three recorded hornbill species, the encounter rate of GPH was high in the West Bank, which is a more undisturbed habitat than the other two sites. Encounter rates of OPH were higher in the West Bank and Khari, having riverine habitat with secondary forest patches. Encounter rates of WH were almost similar in all three sites. This is probably because of their high selection range of habitat for food and roosting trees. The encounter rate estimated from the data was much higher than that reported by Datta[30], i.e. 1.16 ± 0.41/km in unlogged forest and 0.17 ± 0.12, 0.15 ± 0.08 and 0.10 ± 0.04 in semi-disturbed, old logged and logged forests of Pakke Tiger Reserve for GPH and zero encounter of OPH in unlogged forest, old logged and logged forest. Since the study was for a short period and sampling effort was less, it might have resulted in this variation in the encounter rate. It might also be due to some biological variation that was not assessed during the study. Encounter rate of WH did not vary between the study sites, except in the West Bank region[30]. Previous studies have shown that the density of GPH in the Reserve varied from 3 to 12 individuals per sq. km (ref. 32), comparable with 3–10 individuals per sq. km in the Western Ghats[51]. WH density was estimated to be 5–15 per sq. km in 2008 in the Pakke Tiger Reserve[32], which was comparable with studies from Sabah (7.5 individuals per square km)[52] and East Kalimantan (10–46 individuals per sq. km)[53]. A study by Naniwadekar *et al.*[38] in Namdhapa National Park, Arunachal Pradesh also revealed that the hornbill encounter rate varies between less disturbed and heavily disturbed sites.

Seed dispersers like hornbills are mutualistic to tree species assemblages in a larger landscape, as they can travel a long distance tracking food sources[38]. However, large-scale degradation of the connectivity of protected forest areas will directly affect the hornbill population, as they need undisturbed and diverse forest patches for communal roosting and nesting success[8,38]. The dispersal limitation of large-seeded tree species also affects the diversity of the tree communities and will disturb the regeneration and dynamics of the forest ecosystem. Comparative low abundance of hornbill-dispersed tree species in Lanka has been well evidenced from the present study, and low the abundance of hornbill-dispersed species and fruiting and nesting trees denotes the change in vegetation composition in Khari and Lanka from that of the West Bank site. Long-term monitoring of the vegetation dynamics is also important for generating information on the change in vegetation dynamics without limited ornithochory. The general awareness of the importance of hornbills was good and supportive in and around the Pakke Tiger Reserve (pers. obs.). As a result, the hunting pressure was not so severe in Lanka, which is outside the Protected Area. Hornbills are known to move long distances in search of fruits; they frequently move from undisturbed and dense forests to disturbed and logged forests[39,54]. Protection of vast forest patches to keep the diversity and density of the tree species intact is crucial for the survival and distribution of hornbills, and vice versa in the landscape.

Limitations of this study

Less effort (11 transects and two replicates) for detecting hornbill species during this study might be a limitation for estimating the density or encounter rate of different species. However, the major focus of the study was to assess how the structural and species composition of the vegetation affects the hornbill species abundance. Although large-bodied species like hornbills can fly long distances, their microhabitat selection for feeding, roosting and nesting is site-specific. Further, hornbill presence–absence data were used along with habitat characteristics to assess species–habitat relationship. Assessment with a small number of detections might be a limitation for long-ranging birds such as hornbills. From the present study, it is not possible to remark on the difference in hornbill abundance in the three study sites; only the species–habitat association has been established in this study.

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ACKNOWLEDGEMENTS. We thank Mr Tana Tapi (DFO, Pakke Tiger Reserve, Arunachal Pradesh) and Mr P. B. Rana (Range Officer, Seijosa Range, Pakke Tiger Reserve) for logistic support during the study period. Mr Arun Saikia and Mr Deba Mushahari for help during the field work and Mr Vivek Menon (Executive Director, Wildlife Trust of India) for the EDDG grant from the Wildlife Trust of India. We also thank the members of Ghora Abe Society and field staff of Pakke Tiger Reserve for help during the survey period, and the two anonymous reviewers for useful comments that helped improve the manuscript.

Received 5 December 2019; re-revised accepted 7 November 2022

doi: 10.18520/cs/v124/i5/617-625