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Birds beyond borders:

hornbill populations, nesting and conservation in contiguous rainforests and adjoining plantation landscape in Anamalai Hills, India

Pooja Yashwant Pawar

nature conservation foundation

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Report

Submitted to
Rufford Fouundation,
United Kingdom

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CONTENTS

ACKNOWLEDGMENTS

We would like to thank Tamil Nadu and Kerala State Forest Departments for providing the necessary permits to conduct the study in the Anamalai and Parambikulam Tiger Reserves and adjoining Reserved Forests. We are deeply indebted to Mr. V. Ganesan (IFS), Chief Conservator of Forests and Field Director of Anamalai Tiger Reserve. We would like to thank all the Range Forest Officers of Ulandy, Valparai, and Manamboli ranges for their encouragement and support while we were on field. We would also like to thank all the forest department staff who made this study possible, particularly Mr. Krishnasamy and Mr. Muniyandi for their help and cooperation during the course of our fieldwork. We are also indebted to Mr. N. Rajesh (IFS), Deputy Conservator of Forests, Vazhachal Forest Division, and Mrs. Veena Devi, Range Forest Officer, Charpa Range, for logistical help during the study. We are grateful to Dr. K. H Amitha Bachan of Western Ghats Hornbill Foundation for valuable discussions during the study.

We are grateful to the Rufford Foundation, UK, for providing funding for this study, and Rohini Nilekani Philanthropies and Arvind Datar for grants supporting our research in this region.

We would like to thank Mr. K. A. Vivek Ayanna, Mr. B. D. Appaiah, Mr. C. S. Ayyappa, and Mr. A. J. Nachappa of Tata Coffee Ltd, and Mr. Venky Muthiah, Arunkumar Menon, Mahesh Nair, and Oliver Praveenkumar of Parry Agro for letting us carry out the study in their plantations. We would like to express our sincere gratitude towards all the assistants without whom the fieldwork wouldn't have been possible, especially Manikraj, A. Sathish Kumar, and T. Sundar Raj from NCF team and S. Ganesan from Parambikulam Tiger Reserve. We are grateful to people from various tribal settlements who guided us in the beautiful forests. We thank Ganesh Raghunathan, Ashni K. Dhawale, Sreedhar Vijaykrishnan, M. Ananda Kumar, K. Srinivasan, Abhishek Gopal and other researchers for fruitful discussions, suggestions and for their jovial company.

EXECUTIVE SUMMARY

Across the Asian tropics, many species of hornbills are threatened by the loss of their habitats at alarming rates. In the Western Ghats, India, an important hornbill conservation area lies in the Anamalai Hills. This region has suffered historical forest loss and fragmentation, particularly on the 220 km² Valparai Plateau that is now a mid-elevation (600 m – 1500 m) landscape mosaic of tea, coffee, cardamom, and *Eucalyptus* plantations interspersed with rainforest fragments and surrounded by Protected Areas (PA). A wide range of wildlife uses this plantation landscape including hornbills. We conducted a study from January 2017 to April 2018 in the Anamalai Tiger Reserve and in shade coffee plantations on the Valparai Plateau to estimate populations of Great Hornbill and Malabar Grey Hornbill. Along with population monitoring, we estimated density and monitored fruiting of figs (*Ficus* sp.) which is an important food resource of hornbills. We also monitored 120 hornbill nests spread across Parambikulam Tiger Reserve, Vazhachal Reserved Forest, Anamalai Tiger Reserve and Valparai Plateau.

The Great Hornbill density in the PA was estimated to be 4 (±0.9) birds/km²; whereas in plantation, estimated Great Hornbill density was 3 (±0.8) birds/km². Malabar Grey Hornbill densities in the PA and plantation were 17 (±2.2) and 9 (±1.5) birds/km², respectively. Our study showed that hornbills are using coffee plantation landscape throughout the year although in lower densities than the PA. The density of fig trees was higher in the plantations (4.7 ± 2.1 trees/ha) as figs are planted for shade purposes, than in the protected area (2.5 ± 0.6 trees/ha). The abundance of Great Hornbill is most influenced by the habitat, highlighting the importance of relatively undisturbed protected rainforest areas for the species. Malabar Grey Hornbill abundance is influenced by a combination of habitat, availability of food resources, and season.

The 120 hornbill nests monitored during the study period included 50 Great Hornbill nests, 66 Malabar Grey Hornbill nests, and 4 nests of Malabar Pied Hornbill. Of the 120 nests, 25 nests were located in plantations. On an average 57% of Great Hornbill and 59% of Malabar Grey Hornbill nests were active. Nests were recorded on 34 different tree species including non-native species like Silver Oak (*Grevillea robusta*), African Tulip (*Spathodea campanulata*) and *Eucalyptus* sp. Four Great Hornbill nests first located in earlier studies during 1991 were found to be still active in 2018, 27 years later, highlighting the importance of critical resources like individual nest trees. The study provides useful crucial information on hornbill populations and status of their resources, which would benefit long-term planning for hornbill conservation strategies in the Anamalai Hills.

INTRODUCTION

Biodiversity hotspots are the critical areas that occupy only 2.3% of the earth's land, but support more than 50% of diversity. The rapid habitat loss and high anthropogenic disturbances are the characteristics of these hotspots, making them conservation priority areas (Myers et al., 2000). Protected area networks aim to provide some degree of protection to such fragile and threatened ecosystems; but the extent of protected areas is not enough. As mature forests are shrinking throughout the tropics, there is increasing effort to quantify the biodiversity value of degraded forests and other human-modified areas (Gardner et al., 2009). Despite habitat turmoil and human disturbances, species continue to use and adapt to their changing environments, including human-modified countryside habitats such as agricultural fields and commercial plantations (Daily et al., 2003; Bhagwat et al., 2008; Billeter et al., 2008).

Hornbills are among the largest birds in tropical forests of Asia and Africa. They are large-bodied, wide-ranging birds that play an important role in seed dispersal (Kemp, 1995; Kemp, 2001; Kinnaird & O'Brien, 2007). Hornbills, although threatened by habitat loss, fragmentation, and hunting in tropical forests may survive and breed in degraded and modified habitats provided large nest and food trees are available (Rane & Datta, 2015; Naniwadekar et al., 2015; Pawar 2016). Their persistence is determined by the size of forest patches, abundance of food plants, high tree densities in the fragments, and logged forests (Datta, 1998, Sitompul et al., 2004; Naniwadekar et al. 2015). In this study, we examined the population of hornbills and their resources in the tropical wet evergreen forests, adjoining commercial plantations and forest fragments in the Anamalai Hills, India.

Hornbill conservation in the Anamalai Hills

The pioneering research on hornbills in the Anamalai Hills began in early 90s, focused on understanding the breeding biology of Great Hornbill and Malabar Grey Hornbill in their natural habitats (Kannan & James, 1997; Mudappa & Kannan, 1997; Mudappa, 2000). The resource requirements of hornbills were quantified by characterising nests, nesting habitat and tracking food resources (Mudappa & Kannan, 1997; Kannan & James, 1999; James & Kannan, 2009). Surveys in the Anamalais and across Western Ghats highlighted the use of modified habitats by hornbills in the region and the Anamalai Hills was recognised as one of the hornbill hotspots (Raman & Mudappa, 2003, Mudappa & Raman, 2009). The conservation of hornbill nests was started by locating nests and monitoring their status during breeding season later with participation of tribal communities in the region (Mudappa, 2005; Amitha Bachan et al., 2010). Recent study on breeding behaviour of Great Hornbills indicated that they also breed in the plantation landscape (Pawar 2016).

The present study aimed to estimate hornbill population and map critical hornbill resources (nest and fig trees) that would enable long-term monitoring and conservation measures in the Anamalai Hills. Three hornbill species occur in the study area, the Western Ghats endemic Malabar Grey Hornbill (*Ocyceros griseus*), the South Asia endemic Malabar Pied Hornbill (*Anthracoceros coronatus*) and the globally threatened species, the Great Hornbill (*Buceros bicornis*) that is distributed in India and large parts of the Southeast Asia.

OBJECTIVES

The major objectives of the present study were to:

a) estimate hornbill population and monitor seasonal variation in their abundances in the protected area of the Anamalai Tiger Reserve and adjoining Valparai plantation landscape,
b) assess the nesting status of historically known hornbill nests in the region, and
c) monitor fruiting phenology of figs (*Ficus* species) to estimate their fruit availability.

STUDY AREA

The Anamalai Hills are located to the south of the Palghat Gap and is a part of the Western Ghats biodiversity hotspot. The Anamalai Hill range spreads over two states viz. Tamil Nadu and Kerala. The Anamalai Hills has a good network of protected forests including Anamalai Tiger Reserve (formarly known as Indira Gandhi Wildlife Sanctuary), Parambikulam Tiger Reserve and Vazhachal Reserved Forest.

The Valparai plateau (10.26°– 0.37° N and 76.87°–76.99° E) is a 220 km2 mosaic of commercial plantations and rainforest fragments. The plantations include tea (*Camellia sinensis*), coffee (*Coffea arabica* and *C. canephora*), cardamom (*Elettaria cardamomum*), and Eucalyptus spp. along with human settlements. Over 40 tropical wet evergreen forest (rainforest) fragments of varying sizes (0.5ha to 300ha) are interspersed within this plantation landscape (Raman & Mudappa, 2003). The elevation of the Valparai plateau ranges between 600m and 1500m above mean sea level. The natural vegetation of the plateau is classified as the mid-elevation (600–1400
m) tropical wet evergreen forest of the *Cullenia exarillata – Mesua ferrea – Palaquium ellipticum* type (Pascal, 1988). In the plantations, exotic tree species like silver oak *Grevillea robusta* and *Maesopsis eminii* are planted as shade trees and *Eucalyptus* spp. in wood lots for fuel. The Valparai plateau was referred to as 'plantation' for the scope this study.

Valparai plateau is surrounded by relatively undisturbed tropical wet evergreen forests that occur in the Anamalai Tiger Reserve (ATR), Tamil Nadu and the adjoining Vazhachal Reserved Forests (VRF) and Parambikuam Tiger Reserve (PTR) in Kerala (10.31°–10.33° N and 76.70°– 76.81° E). The forest is dominated by woody evergreen plant species, with a canopy at around 30 m, and emergent trees such as *Calophyllum* spp., *Bombax ceiba* and *Tetrameles nudiflora*. This is the main watershed region of the Sholayar and Chalakudy rivers. Two major reservoirs, Sholayar and Ambalapara, are situated in this area. The average annual rainfall received in the region is 3000–3500 mm, the bulk of which falls during the south-west monsoon (June to September). Anamalai Tiger Reserve (ATR), Parambikulam Tiger Reserve (PTR) and Vazhachal Reserved Forests (VRF), together were referred to as 'Protected Area' or 'PA'.

METHODS

Line transect surveys

Line transect method was adopted to estimate the hornbill population in the study area. We marked seven transects of 2 km length along the forest trails in the wet evergreen tropical forests of Anamalai Tiger Reserve. The sites we surveyed included Karian shola, Anaigundi (Anaikundhi), Varagaliar, Panathiar, Manamboli and Akkamalai-Iyerpadi complex.

In the plantation landscape of Valparai Plateau, we marked four transects (3 of 2 km length and 1 of 4 km length). All transects in plantations covered forest fragments, coffee plantations and small patches of tea plantations. In Valparai plateau, we surveyed Puthuthottam, Varatuparai, Korangumudi and Candura.

The transect surveys were carried out from January 2017 to April 2018. Each transect was surveyed once every month (except March 2017) between 6 am and 10 am. The minimum interval between two consecutive surveys of the same transect was two weeks to ensure the independence of detections. Hornbill species seen, heard or flying were recorded. Time of detection, distance of the bird (in case of single bird) or the distance to the centre of the flock (for a flock of birds) from the point and number of individuals was noted. Whenever possible, sex (male or female) of detected individuals were also recorded. Distance of the hornbills from transect was measured in meters using Bushnell Laser Rangefinder for sightings and estimated aurally for calls. The angle of detection was measured using compass. We walked 361.8 km of transect during the study.

Fig density, diversity and phenology monitoring

To estimate the *Ficus* tree density and diversity, we surveyed and noted *Ficus* species within 10 m belt on either sides of transects. For phenology monitoring, we considered trees that are more than or equal to 100 cm girth at breast height (GBH measured at 1.3 m from the base of the tree). The fruiting status of figs was monitored once every month. Fruiting (ripe/unripe) of *Ficus* was scored on a scale of 0 to 4. Zero indicating no fruiting and 1-4 scores indicating the proportion of the fig canopy with fruits (1 = 1-25%; 2 = 25-50%; 3 = 50-75%; 4 = 75-100%).

Nest monitoring

Nest monitoring was carried out in the Anamalai Tiger Reserve, Parambikulam Tiger Reserve, Vazhachal Reserved Forest and Valparai Plateau. To document and monitor the nesting status of hornbills, we located the historically know nests in the region using information from the previous studies (Mudappa and Kannan, 1997; Mudappa 2005; James & Kannan, 2009; Bachan et al., 2010; Pawar, 2016). These nests were monitored during the hornbill breeding season (Dec to April). Newly found nests were also monitored. On locating the nest, we measured nest tree characteristics. The parameters included: nest tree species, height of the tree and nest, cavity shape, orientation, tree girth. The status of each nest-cavity was recorded by following Mudappa (2005):

a) **Active:** if the nesting was in progress, the nest entrance was sealed, and/or the midden had fresh droppings
b) **Inactive:** if no nesting had commenced and no sign of fresh defecation in the midden
c) **Defunct:** when the tree and/or nest cavity itself had become unusable
d) **Uncertain:** uncertain about the nesting status and/or nests that were not monitored during the study period.

Data analysis

Hornbill detections from line transect surveys were used to estimate overall and seasonal (nesting and non-nesting) population densities of Great Hornbill and Malabar Grey Hornbill in the Anamalai Tiger Reserve and Valparai plateau, using distance sampling functions in package 'Distance' in R (Miller, 2017). All detections were categorized into perpendicular distance classes in meters: 0–20, 20–30, 30-40, 40–60, 60–80, 80–100, 100–120, 120–150, 150–200 and 200–300 m. Only detections within 150 metres (truncation distance) from the transect were used for estimation of densities. Each detection (cluster) represented an individual or a flock of hornbills foraging or moving together. We estimated average cluster size and individual hornbill density. Detection probability was assumed to be invariable within two habitats (ATR and Valparai Plateau). Using stratification for two habitats, overall and seasonal hornbill densities were estimated. Candidate models run were half-normal, uniform and hazard-rate to estimate detection probability with cosine adjustment terms and standard model selection procedures were followed to select the best fit models to estimate hornbill density using R package "Distance" (Miller, 2017). The candidate model with the least Akaike's Information Criterion (AIC) value was chosen for density estimates.

Using Species-Rank Abundance, the abundance and species richness between habitats were compared. The density of fig trees was calculated for each site surveyed and their average across habitats. The monthly proportion of fig trees with ripe fruits was calculated for each site. To compare and correlate hornbill encounter rates with fruiting figs, only data during May 2017 to April 2018 was used.

We used Generalised linear mixed effects regressions to correlate hornbill abundance to covariates like habitat, season and fruiting figs. Additive and interactive models were tested for relation between covariates. Models with the least AIC values were selected to identify key determents of hornbill abundances.

RESULTS

Hornbill densities

The total survey effort was 361.8 km across all transects. In Anamalai Tiger Reserve (protected area, PA) we conducted surveys of 209.8 km, and in Valparai Plateau (plantation) we surveyed 152 km during January 2017 to April 2018. Out of 778 detected hornbill clusters (flocks), 200 clusters were of Great Hornbill and 578 clusters were of Malabar Grey Hornbill. For GH, 140 and 60 flocks were recorded in PA and plantation respectively. The mean (± se) cluster size in PA was 1.46 (±0.06) and in plantation was 1.59 (±0.16). For MGH, total of 427 flocks were recorded in PA and 151 flocks in plantation. The cluster sizes (mean ±se) of MGH were similar in PA (1.4 ±0.03 birds per flock) and in plantation (1.5 ±0.11 birds per flock). (For details, see Appendix 1).

Great Hornbill (GH) density

Half-normal model with cosine adjustment term was the best (with the least AIC value) among the candidate models for overall GH density estimates in PA and plantation. Overall GH density was 1.3 times higher in PA (mean±se: 4±0.9 birds/sq km; Fig.1) than plantation (3±0.8 birds/sq km; Fig 1). During nesting season, GH density in PA (4±1.05 birds/sq km) was 1.3 times higher than density of GH in plantation (3±1.1 birds/sq km). Similarly, during non-nesting season, GH density was 1.3 times higher PA (4±1.05 birds/sq km) as compared to that of plantation (3±1.07 birds/sq km). However, GH densities during both seasons in respective habitats were found to be similar. (Fig. 1 and Appendix 2).

Malabar Grey Hornbill density

Half-normal model with cosine adjustment term was the best (with the least AIC value) among the candidate models for overall MGH density estimates in both, PA and plantation. Overall MGH density was 1.8 times higher in PA (mean ±se: 17±2.2 birds/sq km; Fig.2) than plantation (9±1.5 birds/sq km; Fig 2). During nesting season, MGH density was twice in PA (20±3.03 birds/sq km) than in plantation (10±2.1 birds/sq km). And, during non-nesting season, MGH density was 1.6 times higher in PA (13±2.1 birds/sq km) than in plantation (8±1.8 birds/sq km). (Fig. 2 and Appendix 2)

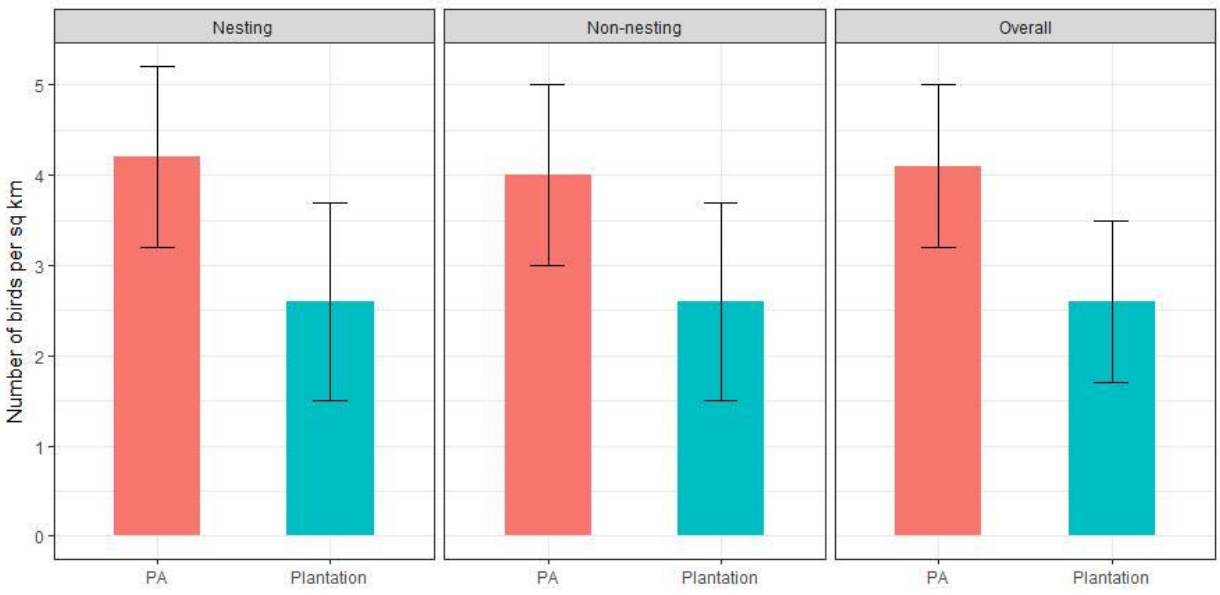


Fig. 1: Seasonal and overall densities (mean ± se) of Great Hornbill in the Protected Area (PA) and adjoining plantations in the Anamalai Hills, Western Ghats.

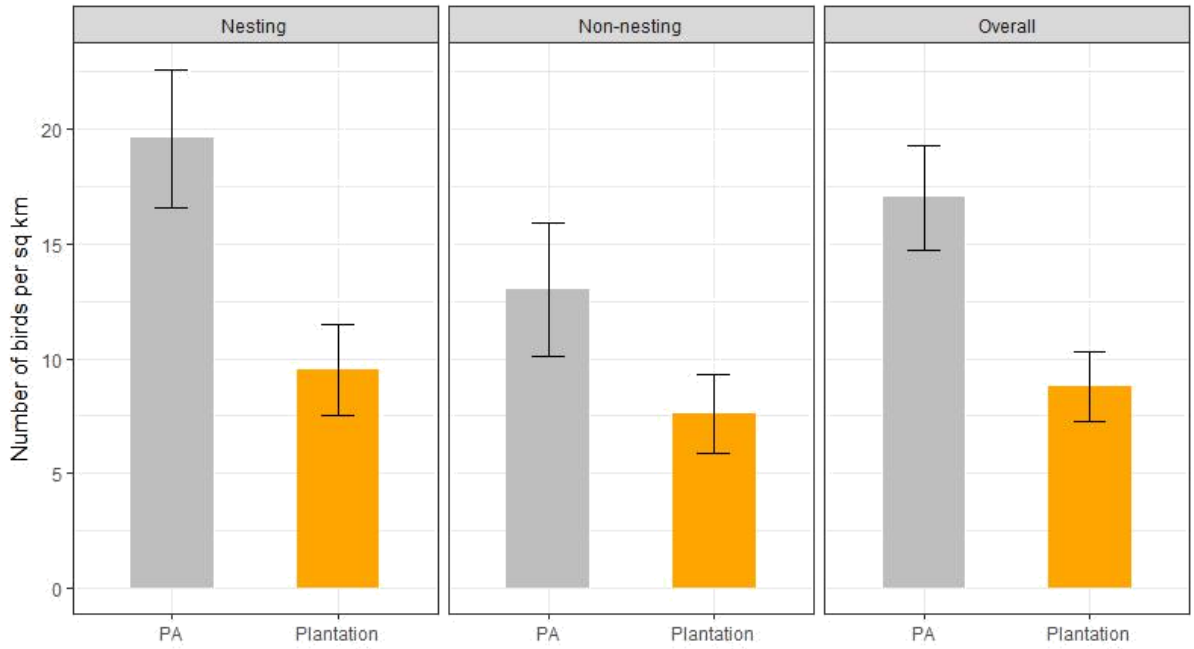


Fig. 2: Seasonal and overall densities (mean ± se) of Malabar Grey Hornbill in the Protected Area (PA) and adjoining plantations in the Anamalai Hills, Western Ghats.

Fig Diversity and Density

We recorded 13 different species of figs along transects surveyed in study area. In the protected area, 10 *Ficus* species were recorded and in plantation 12 species were recorded. The list of fig species is given below (Table 1). Three species of figs – *Ficus exasperata, Ficus hispida, Ficus racemosa* – were recorded only in the plantation. *Ficus mysorensis* (earlier known as *F. drupacea*) was found only in the PA. The most abundant fig in PA was *F. microcarpa*; whereas in plantations, *F. racemosa* was the most abundant fig. The mean ±se density of figs was 2.5 ± 0.6 trees/ha in PA; whereas the fig density in plantation was 4.7 ± 2.1 trees/ha.

Species	Number of trees
Ficus racemosa*	36
Ficus microcarpa	29
Ficus nervosa	12
Ficus tsjahela	12
Ficus virens	11
Ficus exasperata*	10
Ficus beddomei	9
Ficus callosa	8
Ficus amplissima	7
Ficus tinctoria	6
Ficus mysorensis¶	5
Ficus travancorica	2
Ficus hispida*	1

Table 1: A list of fig species recorded along transects distributed in PA and plantation.

¶Species recorded only in PA

*Species recorded only in plantation

Hornbill nest monitoring

We monitored 120 hornbill nests from the Anamalai Hills. Out of 120, 50 nests were of Great Hornbill (GH), 66 of Malabar Grey Hornbill (MGH) and 4 nests of Malabar Pied Hornbill (MPH). The site-wise details of the nests are given below (See Table 2). Totally, 95 nests were located and monitored in the PA that included the Anamalai Tiger Reserve, Parambikulam Tiger Reserve and Vazhachal Reserved Forest. In the plantation landscape of Valparai plateau, we recorded and monitored 25 hornbill nests (for details, see Appendix 3).

Table 2: Summary of hornbill nests monitored in the Anamalai Hills.

Species	Anamalai Tiger Reserve	Valparai Plateau	Parambikulam Tiger Reserve	Vazhachal Division	Total
Great Hornbill	8	9	10	23	50
Malabar Grey Hornbill	27	16	16	7	66
Malabar Pied Hornbill	0	0	0	4	4
Total	35	25	26	34	120

Great Hornbill nests and their status

Out of 50 Great Hornbill nests monitored, 41 were located in the PA and 9 were located in the plantation. GH nests were found in 23 different tree species. One nest in plantation was found on *Grevillea robusta* (Silver Oak)—an exotic species to the region.

The mean (± se) GBH of nest trees in PA was 425 (±27)cm; whereas in plantation, it was recorded to be 326 (±25) cm. Nest tree height in PA was 35 (±1.2)m and in plantation was 33 (± 2.3)m. the height of the nest cavities was 21 (± 1)m and 17 (± 3.5)m in PA and plantation, respectively.

Among 49 monitored nests in PA, 60.1 (± 2.36) % nests were active, 22.2 (± 0.85) % were inactive and 16.2 (± 3.1) were defunct and we were uncertain about status of 4.35% nests. In plantation, 55.6%, 33.3% and 11.1% of nests were active, inactive and defunct, respectively (Fig. 3).

Malabar Grey Hornbill nests and their status

During the study, we monitored 66 Malabar Grey Hornbill nests. Out of 66, 50 nests were located inside PA and 16 nests were found in plantation. Malabar Grey Hornbill nests were seen on 25 different tree species, including exotic species like *Grevillea robusta* (Silver Oak), *Spathodea campanulata* and *Eucalyptus* sp in the plantation.

The mean GBH of nest trees in PA was 286 (± 22.4)cm and 246 (± 24.2) cm in plantation. In PA, mean nest tree height and nest cavity height was 26.7 (± 0.87)m and 17.6 (± 2.5)m, respectively. In plantation, mean nest tree height and nest cavity height was 22 (± 2.1)m and 13.3 (± 1.3)m, respectively.

In PA, 56.1 (± 3.3) % of Malabar Grey Hornbill nests were active. 31.4 (± 2) % nests were inactive and 37.5% were defunct. In plantation, proportion of active, inactive and defunct nests was 62.5%, 6.25% and 6.25 %, respectively. Nesting status of 25% of Malabar Grey Hornbill nests in plantation was unknown (Fig. 3).

Table 3: Summary of nesting status of monitored hornbill nests during 2017 – 2018 in the Anamalai Hills, Western Ghats.

Status	Anamalai **Tiger Reserve**		Valparai **Plateau**		Parambikulam **Tiger Reserve**		Vazhachal Division		
	GH	MGH	GH	MGH	GH	MGH	GH	MGH	MPH
Active (%)	62.5	59.3	55.6	62.5	70	37.5	47.8	71.4	100
Inactive (%)	25	40.7	33.3	6.25	20	25	21.8	28.6	-
Defunct (%)	12.5	-	11.1	6.25	10	37.5	26.1	-	-
Unknown (%)	-	-	-	25	-	-	4.34	-	-
N	8	27	9	16	10	16	23	7	4
GH—Great Hornbill; MGH—Malabar Grey Hornbill; MPH—Malabar Pied Hornbill									

Malabar Pied Hornbill nests and their status

MPH nests were recorded from the Vazhachal Reserved Forest only along the riparian forest. All four nests monitored were active. The nests were seen on three tree species viz. *Kingiodendron pinnatum* , *Terminalia bellerica*, *Tetramelis nudiflora*. The mean girth (including buttress) of nest trees was 806.5 (± 111.21) cm. Mean tree height and nest cavity height was recorded to be 33.25 (± 4.5) m and 25.3 (± 0.9) m, respectively.

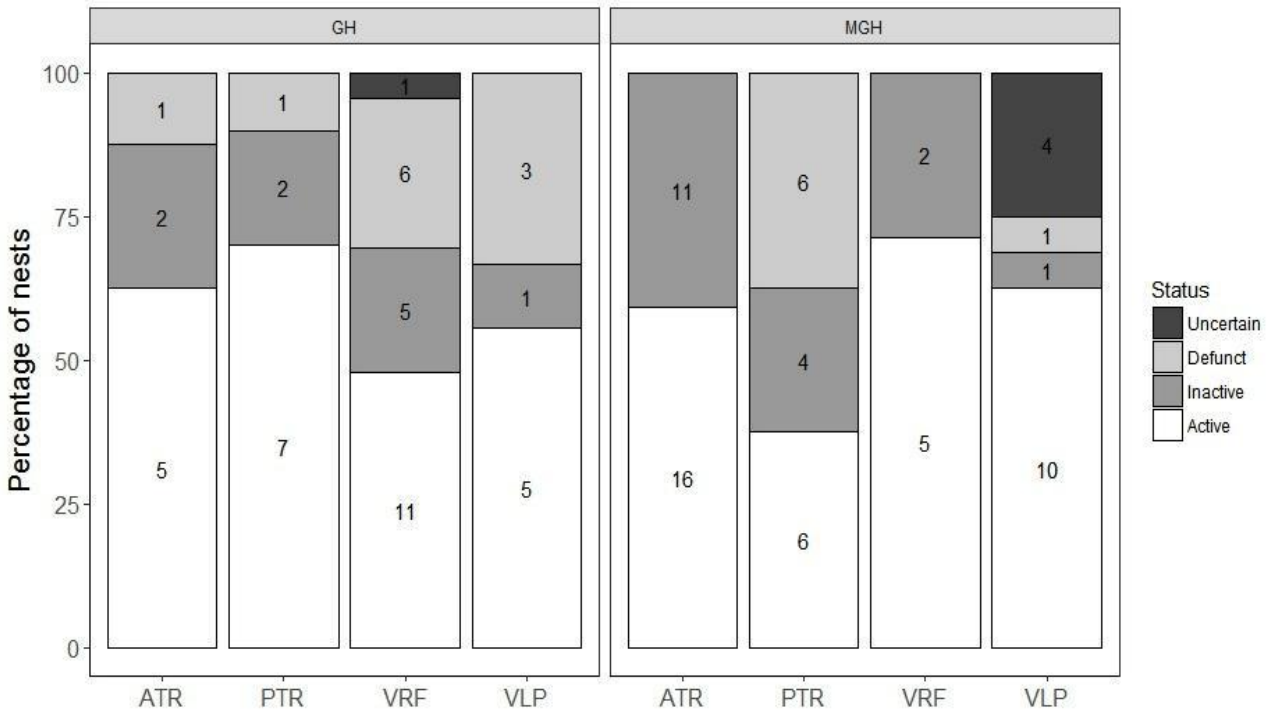


Fig. 3: Hornbill nest status in the Anamalai Hills; numbers indicate number of nests.

GH—Great Hornbill; MGH—Malabar Grey Hornbill

ATR—Anamalai Tiger Reserve; PTR—Parambikulam Tiger Reserve; VRF—Vazhachal Division; VLP—Valparai Plateau

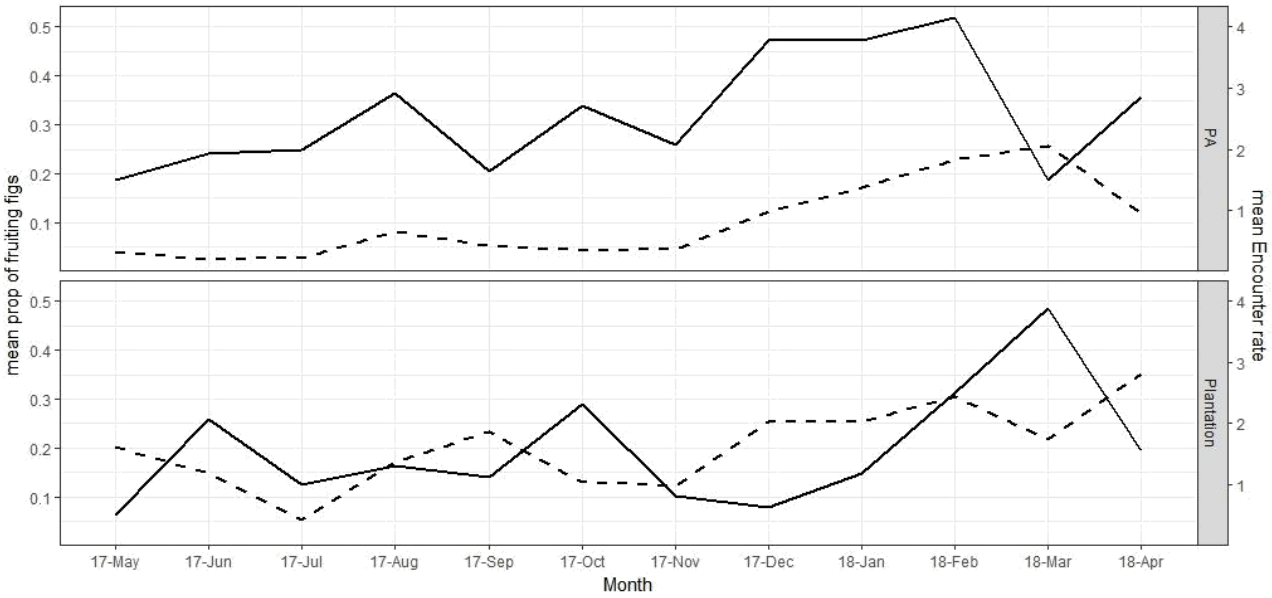


Fig. 4: Monthly variation in the Malabar Grey Hornbill encounter rates (——) and proportion of fruiting figs (- - -) in protected area and plantation habitats, Anamalai Hills.

Correlates of hornbill abundance

For Great Hornbill, habitat appeared to be the key determinant of their abundance (R^2= 0.34, $p < 0.001$). Great Hornbill abundance was higher in PA than in plantation. Covariates like season and number of fruiting figs did not show any significant correlation with Great Hornbill abundance (Table 4). Abundances of Malabar Grey Hornbill are seems to be positively correlated with number of fruiting trees (R^2= 0.77, $p < 0.001$; Fig. 4). Malabar Grey Hornbill abundance was also found higher in PA than in plantation ($p < 0.05$). Malabar Grey Hornbill abundance was higher during the nesting season than in non-nesting season ($p < 0.01$). Table 4 presents details of regression models.

Table 4: Correlates of hornbill abundances—summary of final generalised linear mixed effects regression models.

Details	Great Hornbill	Malabar Grey Hornbill
Final selected model	~Habitat+ (1|Site)	~Fruiting trees + Habitat*Season + (1|Site)
Intercept	-1.37*** (0.11)	-0.43 (0.29)
Fruiting trees	-	0.19*** (0.05)
Habitat (Plantation)	-1.03 (0.21)	-1.15* (0.48)
Season (Non-nesting)	-	-0.27** (0.10)
Habitat:Season	-	0.33 (0.19)
N, transect surveys (sites)	132 (11)	132 (11)
AIC	532.58	778.42
R^2 fixed	0.30	0.23
R^2 total	0.34	0.77
***** p < 0.001; ** p < 0.01; * p < 0.05.**		

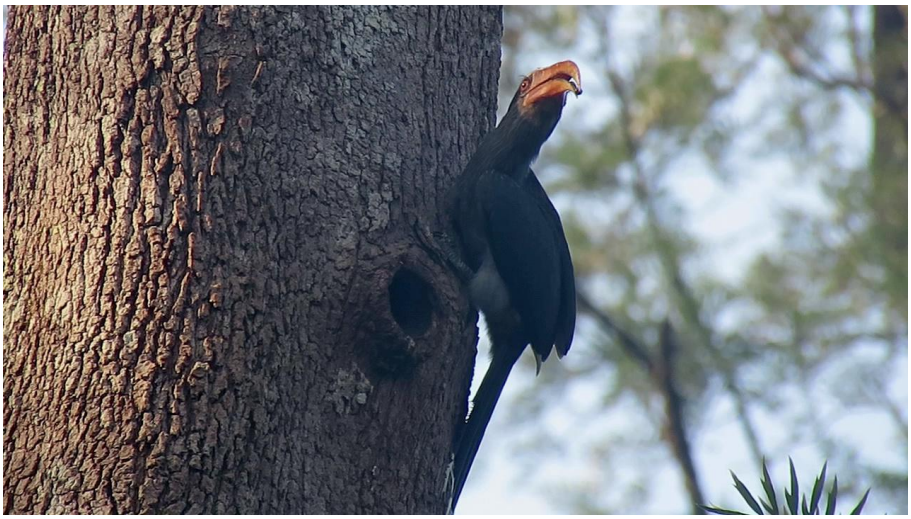
DISCUSSION

The hornbill populations in the Anamalai Hills were estimated and their nests were monitored last over a decade ago. The present study assesses the current status of hornbill populations and their nest occupancy in the Anamalai Hills. The key finding of this study indicate that hornbills are using plantations throughout the year, although they occur in lower densities than in protected forests. Great Hornbill abundance is mainly determined by the habitat, they were more abundant in the contiguous rainforests than in plantations. Whereas, Malabar Grey Hornbill abundances seems to be influenced by the number of fruiting trees in a habitat. Encounter rates for Malabar Grey Hornbill was higher during nesting season, while, Great Hornbill encounter rates remained relatively unchanged throughout. MGH density estimates from this study are lower than the reported MGH densities in protected areas and fragments (Mudappa & Raman, 2009). Great Hornbill densities were comparable to the earlier estimates from the region (Mudappa & Raman, 2009).

The fig density and monthly fruiting trees were higher in the plantations. It is mainly influenced by the planted fig trees in the plantation, particularly *Ficus racemosa* planted as shade for the crop. The fig tree densities in the protected area were similar to that of reported fig densities from Karian Shola National Park (Athreya, 1994). Kannan & James (1999) reported asynchronous fruiting of figs was higher from January to April. Our study also shows that fig fruiting is higher during January to April which also coincides with the nesting season of hornbills (Fig. 5).

Figs are considered to be the key food resource for hornbills, and studies have reported tracking of fruiting figs by hornbills (Kinnaird et al., 1996); however, Datta (1998) has shown that hornbill abundances are not correlated to the density of figs or availability of fruiting figs in the northeast India. In our study, Great Hornbill abundances did not show significant correlation with number of fruiting figs, on the other hand, MGH abundances were found to be significantly correlated with number of fruiting figs. Given that figs are low in densities and asynchronous in fruiting, hornbills that covers larger distance could potentially be tracking figs over larger area.

We monitored 120 hornbill nests, most of which were located between year 1991 to 2008 (Mudappa & Kannan, 1997; Mudappa, 2005; Kannan & James, 2009; Bachan et al, 2011). Large proportion of nests was still being used, that suggests the importance of protecting individual nest trees. In plantations, MGH nests were also found in exotic trees, indicating absence or a fewer number of large native trees in the plantations. The defunct nests were mainly because of nest cavities have become unusable and fallen nest trees. The proportion of active MGH nests were comparable to the average MGH nests reused between year 1993 to 2000 (Mudappa, 2005).



Malabar Grey Hornbill male feeding the female incarcerated in a nest hollow in a silver oak (*Grevillea robusta*) tree on the Valparai Plateau, Anamalai Hills

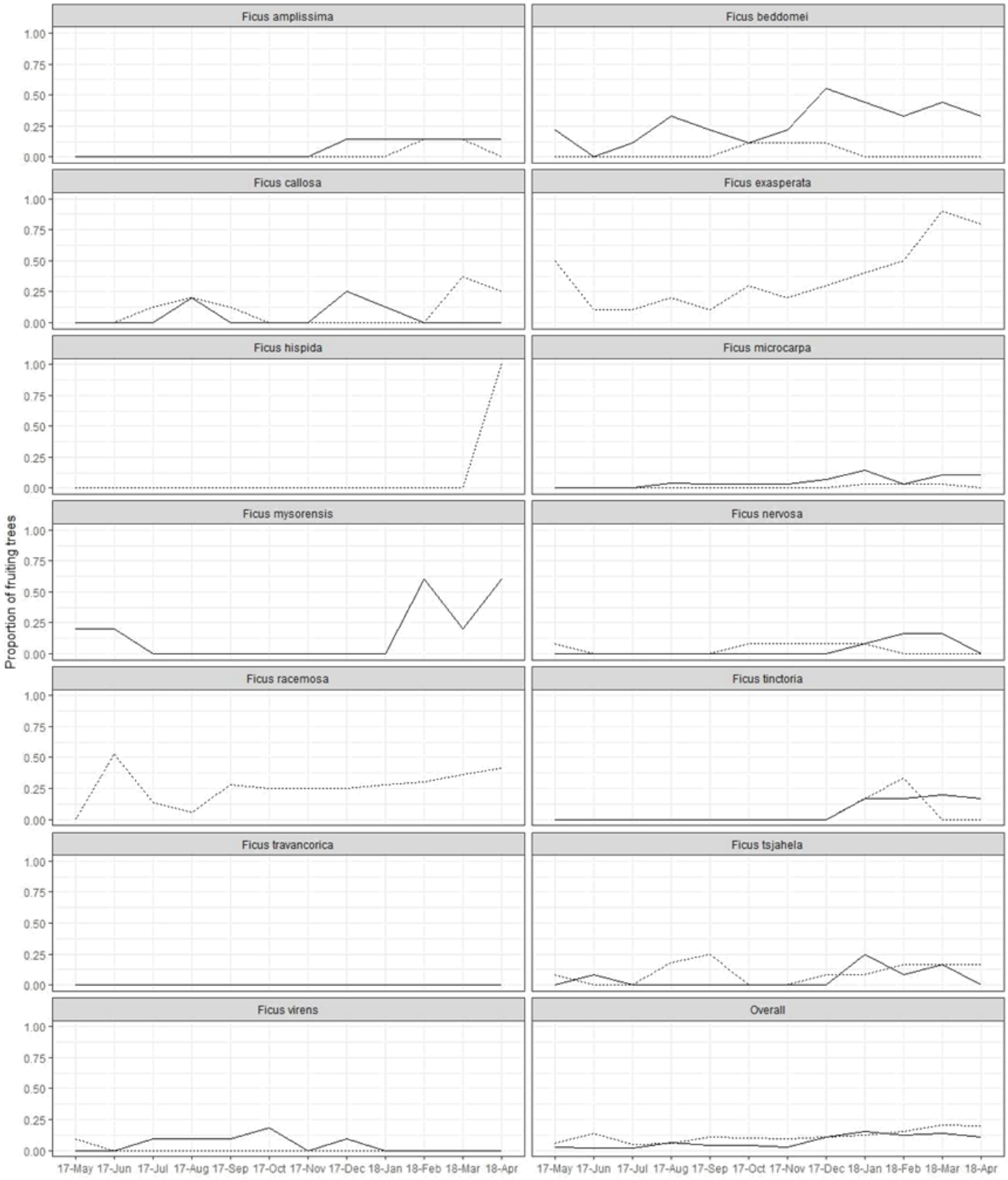


Fig. 5: Phenology of 13 *Ficus* species in the Anamalai Hills showing proportion of individual species in ripe fruit and overall.

CONSERVATION IMPLICATIONS

The Anamalai Hills have been identified as one of the important hornbill conservation areas in the Western Ghats (Mudappa & Raman, 2009). This study highlights the importance of the Valparai Plateau as an additional habitat for hornbills. Malabar Grey Hornbills seem to be more abundant in plantations than the Great Hornbills, emphasizing the variation in adaptability of both species to the habitat modification. Hornbills used cavities in non-native trees also; hence protection of such nest trees is crucial within protected areas and in adjoining plantations. Considering that hornbills show nest site fidelity, retention of existing nest trees, large trees, figs, native trees including hornbill food plants could assure the persistence of these birds in the present landscape. In the current context of large-scale habitat conversion in Asian tropics, this study gives insights into the potential of rainforest fragments and commercial for conservation of hornbills. The improvement in density and diversity of hornbill food plants (figs and non-figs) through ecological restoration in rainforest fragments would be helpful in long-term conservation of hornbills and their resources. In the Valparai Plateau, the embedded rainforest fragments serve as habitats and bridges between mature forests in the surrounding protected areas and the matrix of commercial plantations. This study highlights the need for identifying and retaining such crucial habitats in plantation landscapes.

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APPENDICES

Appendix 1: Summary of the sampling effort and the estimated population parameters for hornbills in the protected area (PA) and adjoining plantations in the Anamalai Hills in Western Ghats, India. Numbers in parantheses are standard error (SE).

Details	Great Hornbill		Malabar Grey Hornbill	
	Protected area	**Plantation**	**Protected area**	**Plantation**
Number of transects	7	5*	7	5*
Number of repeats	15	15*	15	15*
Total effort (km)	209.8	152	209.8	152
Model	Half-normal	Half-normal	Half-normal	Half-normal
Adjustment term	Cosine	Cosine	Cosine	Cosine
Clusters detected (N)	128	56	395	141
Average cluster size	1.46 (0.06)	1.59 (0.16)	1.4 (0.03)	1.5 (0.11)
Detection probability	0.74 (0.15)	0.74 (0.15)	0.56 (0.05)	0.56 (0.05)
Effective strip width (m)	111 (22.5)	111 (22.5)	84 (7.5)	84 (7.5)
Encounter rate				
(hornbills/km)	0.63	0.37	2.02	0.9
Individual density,				
(hornbills/km²)	4.1 (0.9)	2.6 (0.8)	17.13 (2.2)	8.8 (1.5)
% Coefficient of variation	22.9	34.1	13.4	17.5
95% Confidence interval	2.6-6.4	1.3-5.4	14.7-21.4	6.8-13.6

Appendix 2: Summary of the sampling effort and the estimated population parameters for hornbills in the protected area and adjoining plantations across nesting and non-nesting seasons in the Anamalai Hills, Western Ghats. Numbers in parantheses are standard error (SE).

	Protected area		Plantations	
	Nesting	**Non-nesting**	**Nesting**	**Non-nesting**
Great Hornbill				
Total effort (km)	126	83.8	92	60
Model	Half-normal	Half-normal	Half-normal	Half-normal
Adjustment term	Cosine	Cosine	Cosine	Cosine
Number of clusters	81	47	31	25
Average cluster size	1.36 (0.056)	1.63 (0.12)	1.69 (0.25)	1.46 (0.13)
Detection probability	0.74 (0.15)	0.74 (0.15)	0.74 (0.15)	0.74 (0.15)
Effective strip width (m)	111 (22.5)	111 (22.5)	111 (22.5)	111 (22.5)
Encounter rate (hornbills/km)	0.68	0.54	0.35	0.40
Hornbill density (hornbills/km²)	4.2 (1.05)	4 (1.05)	2.63 (1.1)	2.61 (1.07)
% Coefficient of variation	25.2	26.3	44.2	41.2
95% Confidence interval	2.5 – 6.8	2.4 – 6.7	1.1 – 6.1	1.2 – 5.8
Malabar Grey Hornbill				
Total effort (km)	126	83.8	92	60
Model	Half-normal	Half-normal	Half-normal	Half-normal
Adjustment term	Cosine	Cosine	Cosine	Cosine
Number of clusters	280	115	96	45
Average cluster size	1.4 (0.36)	1.43 (0.66)	1.46 (0.15)	1.51 (0.15)
Detection probability	0.56 (0.05)	0.56 (0.05)	0.56 (0.05)	0.56 (0.05)
Effective strip width (m)	84 (7.5)	84 (7.5)	84 (7.5)	84 (7.5)
Encounter rate (hornbills/km)	3.2	2.2	1.6	1.2
Hornbill density (hornbills/km²)	19.76 (3.03)	13.17 (2.2)	9.5 (2.1)	7.7 (1.8)
% Coefficient of variation	15.3	17.5	22.12	22.77
95% Confidence interval	14.6 – 26.7	9.3 – 18.6	6.1 – 14.7	4.12 – 12.2

Appendix 3: Details of hornbill nests in the four main study areas with details of nest tree species, year of identification, and current status of the nests in the Anamalai Hills. GH—Great Hornbill; MGH—Malabar Grey Hornbill; MPH—Malabar Pied Hornbill TR—Tiger Reserve; RF—Reserved Forest

Place	Species	Nest Tree	Year of ID	Nest tree status	Current nesting status
Anamalai TR	GH	*Hopea parviflora*	1993	Alive	Inactive
Anamalai TR	GH	*Cassine glauca*	2014	Alive	Inactive
Anamalai TR	GH	*Alseodaphne semecarpifolia*	1991	Alive	Active
Anamalai TR	GH	*Syzigium cumini*	1992	Alive	Active
Anamalai TR	GH	*Aglaia elaeagnoidea*	1991	Alive	Active
Anamalai TR	GH	*Cassine glauca*	1991	Alive	Active
Anamalai TR	GH	*Mesua ferrea*	1993	Alive	Defunct
Anamalai TR	GH	*Tetramelis nudiflora*	2015	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	2012	Alive	Active
Anamalai TR	MGH	*Cassine glauca*	1994	Alive	Inactive
Anamalai TR	MGH	*Aglaia elaeagnoidea*	1994	Alive	Inactive
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	1999	Alive	Inactive
Anamalai TR	MGH	*Artocarpus lacoocha*	1994	Alive	Inactive
Anamalai TR	MGH	*Aglaia elaeagnoidea*	1994	Alive	Inactive
Anamalai TR	MGH	*Artocarpus lacoocha*	1994	Alive	Inactive
Anamalai TR	MGH	*Aglaia elaeagnoidea*	1994	Alive	Inactive
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	1994	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	1994	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	2014	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	1994	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	1994	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	1994	Alive	Active
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	2002	Alive	Inactive
Anamalai TR	MGH	*Hopea parviflora*	1994	Alive	Active
Anamalai TR	MGH	*Mimusops elengi*	1994	Alive	Active
Anamalai TR	MGH	*Pterospermum reticulatum*	1994	Alive	Inactive
Anamalai TR	MGH	*Hopea parviflora*	1994	Alive	Active
Anamalai TR	MGH	*Artocarpus lacoocha*	1994	Alive	Inactive
Anamalai TR	MGH	*Alseodaphne semecarpifolia*	2014	Alive	Active
Anamalai TR	MGH	*Lagerstromia lanceolata*	2000	Alive	Inactive
Anamalai TR	MGH	*Lagerstromia lanceolata*	1993	Alive	Active
Anamalai TR	MGH	*Hopea parviflora*	2018	Alive	Active
Anamalai TR	MGH	*Margariteria indica*	2018	Alive	Active

Place	Species	Nest Tree	Year of ID	Nest tree status	Current nesting status
Anamalai TR	MGH	*Palaquium ellipticum*	2018	Alive	Active
Anamalai TR	MGH	*Mesua ferrea*	2018	Alive	Active
Parambikulam TR	GH	*Mimusops elengi*	1993	Alive	Inactive
Parambikulam TR	GH	*Alseodaphne semecarpifolia*	1991	Alive	Active
Parambikulam TR	GH	*Lagerstromia lanceolata*	1991	Alive	Active
Parambikulam TR	GH	*Calophyllum polyanthum*	1993	Alive	Active
Parambikulam TR	GH	*Calophyllum polyanthum*	1993	Alive	Active
Parambikulam TR	GH	*Calophyllum polyanthum*	2014	Alive	Defunct
Parambikulam TR	GH	*Dysoxylum malabaricum*	1994	Alive	Inactive
Parambikulam TR	GH	*Alstonia scholaris*	-	Alive	Active
Parambikulam TR	GH	*Palaquium ellipticum*	-	Alive	Active
Parambikulam TR	GH	*Dysoxylum malabaricum*	-	Alive	Active
Parambikulam TR	MGH	*Bombax ceiba*	1994	Alive	Active
Parambikulam TR	MGH	*Vitex altissima*	1994	Alive	Defunct
Parambikulam TR	MGH	*Artocarpus lacoocha*	1994	Dead	Defunct
Parambikulam TR	MGH	*Aglaia elaeagnoidea*	2002	Alive	Inactive
Parambikulam TR	MGH	*Alseodaphne semecarpifolia*	2002	Alive	Inactive
Parambikulam TR	MGH	*Syzigium cumini*	2014	Alive	Inactive
Parambikulam TR	MGH	*Syzigium cumini*	2014	Alive	Active
Parambikulam TR	MGH	*Artocarpus lacoocha*	1995	Alive	Defunct
Parambikulam TR	MGH	*Mesua ferrea*	2018	Alive	Active
Parambikulam TR	MGH	*Alseodaphne semecarpifolia*	2014	Alive	Inactive
Parambikulam TR	MGH	*Aglaia elaeagnoidea*	1995	Alive	Defunct
Parambikulam TR	MGH	*Alseodaphne semecarpifolia*	1997	Alive	Defunct
Parambikulam TR	MGH	*Aglaia elaeagnoidea*	2014	Alive	Defunct
Parambikulam TR	MGH	*Albizzia amara*	-	Alive	Active
Parambikulam TR	MGH	*Tectona grandis*	-	Alive	Active
Parambikulam TR	MGH	*Albizzia amara*	-	Alive	Active
Valparai Plateau	GH	*Palaquium ellipticum*	2018	Alive	Active
Valparai Plateau	GH	*Mangifera indica*	2008	Alive	Inactive
Valparai Plateau	GH	*Grevillea robusta*	2004	Alive	Active
Valparai Plateau	GH	*Dysoxylum malabaricum*	2015	Alive	Active
Valparai Plateau	GH	*Mesua ferrea*	2001	Alive	Active
Valparai Plateau	GH	*Syzigium cumini*	2016	Alive	Active
Valparai Plateau	GH	*Mesua ferrea*	2000	Dead	Defunct
Valparai Plateau	GH	Unidentified	2000	Alive	Defunct
Valparai Plateau	GH	*Mesua ferrea/Calophyllum sp*	2000	Dead	Defunct

Place	Species	Nest Tree	Year of **ID**	Nest tree **status**	Current **nesting status**
Valparai Plateau	MGH	*Cullenia exarillata*	2016	Alive	Active
Valparai Plateau	MGH	*Grevillea robusta*	2017	Alive	Active
Valparai Plateau	MGH	*Grevillea robusta*	2017	Alive	Active
Valparai Plateau	MGH	*Mesua ferrea*	2018	Alive	Active
Valparai Plateau	MGH	*Mesua ferrea*	2018	Alive	Active
Valparai Plateau	MGH	*Eucalyptus sp*	2018	Dead	Active
Valparai Plateau	MGH	*Spathodea campanulata*	2018	Alive	Active
Valparai Plateau	MGH	*Spathodea campanulata*	2018	Alive	Active
Valparai Plateau	MGH	*Eleocarpus tuberculatous*	2018	Alive	Active
Valparai Plateau	MGH	*Grevillea robusta*	2018	Alive	Active
Valparai Plateau	MGH	*Mesua ferrea*	1996	Alive	Inactive
Valparai Plateau	MGH	Unidentified	2000	Uncertain	Uncertain
Valparai Plateau	MGH	*Canarium strictum*	2000	Alive	Uncertain
Valparai Plateau	MGH	*Myristica dactyloides*	2002	Uncertain	Uncertain
Valparai Plateau	MGH	*Eucalyptus sp*	2003	Uncertain	Uncertain
Valparai Plateau	MGH	*Mesua ferrea*	2001	Dead	Defunct
Vazhachal RF	GH	*Kingiodendron pinnatum*	-	Alive	Defunct
Vazhachal RF	GH	*Kingiodendron pinnatum*	-	Alive	Active
Vazhachal RF	GH	*Kingiodendron pinnatum*	-	Alive	Active
Vazhachal RF	GH	*Palaquium ellipticum*	-	Dead	Defunct
Vazhachal RF	GH	*Aglaia elaeagnoidea*	-	Alive	Inactive
Vazhachal RF	GH	*Palaquium ellipticum*	-	Alive	Defunct
Vazhachal RF	GH	*Kingiodendron pinnatum*	-	Alive	Active
Vazhachal RF	GH	*Syzygium gardneri*	-	Alive	Defunct
Vazhachal RF	GH	*Dysoxylum malabaricum*	-	Alive	Inactive
Vazhachal RF	GH	*Dysoxylum malabaricum*	-	Alive	Inactive
Vazhachal RF	GH	*Vateria indica*	-	Alive	Active
Vazhachal RF	GH	*Vateria indica*	-	Alive	Active
Vazhachal RF	GH	*Dipterocarpus indicus*	-	Alive	Active
Vazhachal RF	GH	*Aglaia elaeagnoidea*	-	Alive	Defunct
Vazhachal RF	GH	*Bombax ceiba*	-	Alive	Active
Vazhachal RF	GH	*Mesua ferrea*	-	Dead	Defunct
Vazhachal RF	GH	*Terminalia bellerica*	-	Alive	Active
Vazhachal RF	GH	*Ficus nervosa*	-	Alive	Active
Vazhachal RF	GH	*Terminalia bellerica*	-	Alive	Uncertain
Vazhachal RF	GH	*Palaquium ellipticum*	-	Alive	Active
Vazhachal RF	GH	*Mesua ferrea*	-	Alive	Inactive

Place	Species	Nest Tree	Year of **ID**	Nest tree **status**	Current **nesting status**
Vazhachal RF	GH	*Cullenia exarillata*	-	Alive	Inactive
Vazhachal RF	GH	*Cullenia exarillata*	-	Alive	Active
Vazhachal RF	MGH	*Tetramelis nudiflora*	-	Alive	Inactive
Vazhachal RF	MGH	*Terminalia bellerica*	-	Alive	Inactive
Vazhachal RF	MGH	*Tetramelis nudiflora*	-	Alive	Active
Vazhachal RF	MGH	*Terminalia chebula*	-	Alive	Active
Vazhachal RF	MGH	*Eleocarpus tuberculatus*	-	Alive	Active
Vazhachal RF	MGH	*Palaquium ellipticum*	2018	Alive	Active
Vazhachal RF	MGH	*Tetramelis nudiflora*	2018	Alive	Active
Vazhachal RF	MPH	*Terminalia bellerica*	2005	Alive	Active
Vazhachal RF	MPH	*Tetramelis nudiflora*	2005	Alive	Active
Vazhachal RF	MPH	*Tetramelis nudiflora*	2005	Alive	Active
Vazhachal RF	MPH	*Kingiodendron pinnatum*	2007	Alive	Active