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ACKNOWLEDGEMENTS. We acknowledge financial support from HEART and SHORE programmes of CSIR-NGRI. We appreciate comments from anonymous reviewer, which helped bringing clarity.

Received 23 September 2014; revised accepted 24 February 2015

Nest site characterization of sympatric hornbills in a tropical dry forest

Ushma Shukla¹, Soumya Prasad^{1,2,5,*},
Mohan Joshi^{1,2}, Sachin Sridhara³ and
David A. Westcott⁴

¹Centre for Ecological Sciences, TE-13, Biological Sciences Building, Indian Institute of Science, Bengaluru 560 012, India

²Nature Science Initiative, 36, Curzon Road, Dehradun 248 001, India

³School of Marine and Tropical Biology, James Cook University, Australia

⁴CSIRO Ecosystem Sciences, Maunds Road, Atherton Qld 4883, Australia

⁵Present address: School of Life Sciences, Jawaharlal Nehru University, New Mehrauli Road, New Delhi 110 067, India

Hornbills, among the largest and most threatened tropical frugivores, provide important seed dispersal services. Hornbill nest site characteristics are known primarily from wet tropical forests. Nests of the Indian grey hornbill *Ocyrceros birostris* and Oriental pied hornbill *Anthracoceros albirostris* were characterized in a tropical dry forest. Despite *A. albirostris* being twice the size of *O. birostris*, few of the nest cavity attributes were different. *A. albirostris* nests were surrounded by higher proportion of mixed forest and lower sal forest compared to *O. birostris*. In this landscape, the larger *A. albirostris* may prefer to nest in sites with more food plants compared to the smaller *O. birostris*.

Keywords: *Anthracoceros albirostris*, nesting ecology, *Ocyrceros birostris*, tropical forests.

HORNIBILLS are a wide-ranging, diverse group of birds occurring in Asia and Africa. Within Asia, 31 species of hornbills are found in a variety of habitats ranging from rainforests to dry and arid zones. Being primarily frugivorous and large-bodied, they consume a wide spectrum of fruit types in varying sizes¹ and are important seed dispersers. They also provide unique dispersal services to several large-seeded plants^{1,2}. Despite their ecological importance, our knowledge of hornbill ecology is limited to a few species and to particular landscapes. Most studies examining hornbill ecology emerge from wet tropical forests, although hornbills inhabit a wide range of habitats, including dry tropical forests and human modified landscapes. Since resources required by hornbills, such as fruiting trees and nesting sites may differ significantly across these habitats³, it is important to examine their nesting and landscape use in diverse habitats to understand their ecological tolerance and to design appropriate conservation strategies. This knowledge gap is particularly heightened given the special requirements of hornbills for breeding and nesting.

*For correspondence. (e-mail: prasadsoumya@gmail.com)

The breeding and nesting seasons of hornbills are generally timed with the peak in fruiting^{4,5}. The availability of fruiting trees and suitable nest sites are considered the prime factors affecting nest site selection by hornbills⁶. They are secondary cavity nesters and use cavities created by broken branches or those excavated by other birds for nesting⁷. Earlier reports have suggested that hornbills choose elongated cavities relative to their body size^{7,8} and also display high nest fidelity, often returning to the same nest site year after year^{9,10}. While the larger species such as the Great pied hornbill *Buceros bicornis* and wreathed hornbill *Rhyticeros undulatus* are known to nest in intact and undisturbed forest areas, some medium-sized hornbills such as the Oriental pied hornbill (hereafter, 'OPH') *Anthracoceros albirostris* are more tolerant to disturbance and have been documented to nest in logged forests and plantations¹¹. Nevertheless, hornbills appear to prefer undisturbed forests, with their numbers reducing with increasing intensity of habitat alteration¹², regardless of the kind of forests they occupy.

Reports of hornbill nest characteristics are mainly from the tropical wet forests, which have high plant species richness and less seasonality with respect to reproductive phenology. Most dry forests show marked peaks in fruiting of bird-dispersed fruits towards the onset of the wet season, while in contrast, wet forests showcase more staggered and mast fruiting strategies^{3,13}. Tropical dry forests also have lower diversity of fruiting plants and a pronounced seasonality in fruit availability¹³. They may also have smaller trees of lower girth compared to wet forests¹³, thereby, limiting the availability of nesting trees of suitable size. Although these differences in key resources are acknowledged, few empirical studies have examined nest site requirements of hornbill species from tropical dry forests.

In the present study, we examined nest site selection and nest characteristics of two sympatric species – OPH and the Indian grey hornbill (hereafter, 'IGH') *Ocyrceros birostris* in a tropical dry forest site in the Western Himalayan region of India. The nominate sub-species of the OPH occurs along the Himalayan foothills in the north and hills of East India, whereas the monotypic IGH is found in most of the Indian subcontinent in tropical dry habitats¹⁴. IGH is widespread in its range and is found in forests, agricultural and urban areas across India⁵, whereas OPH is rarely observed outside forest areas within the Indian subcontinent (Prasad *et al.*, unpublished). To examine if differences in nest characteristics could drive this differentiation in tolerance to land-use change between these two hornbill species, we examined characteristics of (a) nest trees, including small-scale disturbances at nest trees, (b) nest cavities and (c) landuse and habitat surrounding the nest sites.

We undertook the study in the Chilla range section of Rajaji National Park (820 sq. km; 29°54'–30°00'N and 77°50'–78°16'E; elevation range between 280 and

1000 m). The park is part of the Shiwalik ranges, which are formed from the debris of the main Himalayas. The topography is rugged, with parallel ridges separated by broad, flat, alluvial streambeds. Shielded by the high Himalayan ranges, this region experiences a tropical monsoon climate (rainfall 1300–1900 mm per annum; temperature 0–47°C). Rainfall is highly seasonal (July–September), with the wet season being followed by a cool dry season (winter: October–February, spring: March–April) and a very hot summer (May–June). Forests along flat valleys are dominated by the dipterocarp *Shorea robusta* (hereafter referred to as 'sal forest'), while 'mixed forests' are found along ridges and undulating terrain. Mixed forests are composed of tropical dry forest tree species such as *Anogeissus latifolia*, *Lagerstroemia parviflora* and *Terminalia* spp. Chilla also has plantations of *Tectona grandis* and *Haplophragma adenophyllum*. Gujjars, a pastoral community, were resettled from Chilla during 2004–2005. They use the periphery of the Chilla range for fodder and fuelwood. Trees are lopped for fodder and tree density reduces towards the forest edge.

Rajaji National Park has a very high avifaunal diversity¹⁵. Of the three hornbill species found in the Western Himalayas, the largest species – the Great hornbill (up to 3 kg) is relatively rare in Chilla, with the smallest species, the IGH (300–400 g), being more numerous than the medium-sized OPH (800–1000 g). Canopy trees, including *Putranjiva roxburghii*, *Bridelia retusa*, *Syzygium cumini*, *Lannea coramandalica*, several figs and understory trees such as *Ehretia laevis*, *Ehretia acuminata* and *Limonia* spp. are important hornbill food plants at Chilla.

Observations of hornbill nesting behaviour were made between April and July 2012. In most hornbill species the female first enters the cavity and seals it from the inside using a mortar of droppings, mud and saliva. They sometimes also use bark of trees and cow dung to plaster the opening¹⁶. The male feeds the female and the chick for the next few months until the chick is ready to fledge. At our study site, the females entered the nests from the end of April through to the first half of May. Nests were located by following male birds to the cavity, either by calls or by locating fresh seeds and droppings under tree cavities. Observers took care to hide themselves and avoid disturbing the nesting hornbills and the nest sites.

Nest characteristics were measured after the female and chicks had vacated it. The nest tree species, its diameter at breast height (DBH), tree height, height of the nest cavity location on the tree (hereafter called 'cavity height'), surrounding forest type and height of first branching of the tree were noted. The length, width and depth of the cavities were also noted, along with girth of tree at the level of the cavity. We also noted lopping activity at the nesting tree, to ascertain whether hornbills nest on trees lopped by people for fodder. The nest cavity

characteristics of the two hornbill species were compared using two-sample t -tests (with the Welsch approximation to correct for differences in sample sizes). We used chi-square tests to compare differences in tree species used by the two hornbills species for nesting.

Given the intensive foraging by male hornbills from the habitat surrounding the nest site during the breeding season, these sites may be located in areas with higher density of hornbill food plants. Therefore, we examined the differences between the two hornbills species with respect to habitats surrounding the nest sites (within 1 km radius), to check if these differed from random locations in the study area. We used a thematic land-use classification map developed for the study area in GRASS v6.4.2 (<http://grass.osgeo.org>)¹⁷, using a LANDSAT 5 (TM) image from December 2010 (<http://earthexplorer.usgs.gov/>). We carried out extensive ground truthing across the study area and combined these points to generate training sites to carry out a supervised classification of the LANDSAT image using a maximum likelihood algorithm. Training sites were combined to form 'pure' or 'training polygon' classes, based on which the in-built classifier of GRASS, classified the rest of the image under the desired land-use classes. Our classification was unable to tell apart plantations from mixed forests, given the overlap in signatures. This is probably due to over-lumping of mixed forest and plantation mosaic, making it difficult for the classification function to tell them apart with certainty. These two classes were, therefore, merged to give a 'mixed forest-plantation' class. The Ganges river was the main water body in the LANDSAT image used for landcover analyses and areas covered by water bodies were classified as 'water'. While riverine forests did not have a distinct spectral signature in the LANDSAT image, they are floristically distinct from other mixed forests in the landscape as they have taller evergreen trees.

For each nest site location, we laid a buffer area of 1 km radius on the map output derived from the supervised land-cover classification using QGIS v1.8.0 (www.qgis.org)¹⁸. The proportion of each land-cover type within 1 km radius (mixed forest-plantation, sal forest, built-up areas, water, agricultural areas) was then calculated for the nest sites and random sites in R v2.15 (ref. 19). The random sites ($n = 42$) were drawn from the habitats used by both hornbill species for nesting, utilizing an inbuilt randomization function in QGIS, with the classified land-use map as base layer.

For habitat types that constituted more than 5% of the 1 km radius around the nest or random sites (i.e. mixed forest-plantation, sal forest and water bodies), we used generalized linear models (GLMs) of the binomial family (with logit link) to examine differences between the two hornbill species and the random locations. For the GLMs, we considered the proportion of habitat type within 1 km radius as the response variable and the site type as the predictor (OPH nest, IGH nest, random). Pairwise differ-

ences between random, OPH and IGH nest sites were examined using post-hoc Tukey's tests in R v2.15.

Of the 42 nests located, 13 belonged to OPH and 29 were occupied by IGH. Cavity width was marginally larger in IGH nests (9.54 ± 0.81 cm) compared to OPH (7.6 ± 0.65 cm; $t = 1.8653$, $df = 18$, $P = 0.08$). Cavity length and depth were not significantly different between the two sympatric hornbills, although the depth of IGH nest cavities was more variable (Figure 1). The girth of the tree at the location of the cavity was larger for OPH nests (243 ± 27.71 cm) compared to IGH (220.24 ± 17.14 cm; $t = -2.1974$, $df = 12$, $P = 0.05$). The height at which the nest cavity was located was highly variable for both species, ranging from 5 to 23 m and 1 to 18 m for the IGH and OPH respectively (Figure 1).

OPH nests were concentrated in mixed forest-plantations, while IGH nests were found across all habitats, including sal forests within the study area. Among the 14 tree species on which the two hornbill species nested (Table 1), five were common to both hornbills (*S. robusta*, *S. cumini*, *Terminalia belerica*, *Bombax ceiba*, *L. parviflora*). Neither of the hornbill species exhibited any preference towards any particular tree species for nesting ($X^2 = 15.608$, $df = 14$, $P = 0.3$). Trees used for nesting by the two hornbills were located between 315 and 455 m asl, in both flat and hilly terrains.

The GLMs showed that the two hornbill species differed from each other and from random sites in the proportion of different forest habitats within 1 km radius (Figure 2). Post-hoc Tukey's test showed that OPH nest locations had significantly lower proportion of sal forest ($28 \pm 6\%$) and higher proportion of water bodies ($8 \pm 3\%$) within 1 km radius from nest locations compared to random locations (sal forest: $34 \pm 3\%$; water: $5 \pm 1\%$; Figure 2 *b* and *c*; $P < 0.01$). OPH nest sites had significantly lower proportion of sal forest and higher proportion of mixed forest-plantation compared to IGH nest sites (sal forest: $35 \pm 4\%$; $P < 0.01$). IGH nest sites had a significantly lower proportion of water ($3 \pm 1\%$) within 1 km radius compared to OPH nests and random points (Figure 2 *c*; $P < 0.01$). The proportion of mixed forest-plantation within 1 km from the nests was not different between OPH nest sites and random locations (Figure 2 *a*). The other land-cover strata, i.e. built-up areas and crop occupied less than 5% of landcover within 1 km radius of nests of both hornbill species in the study area.

On an average, OPH nested further away from human habitation (1769.23 ± 391.76 m, $n = 13$) compared to IGH (1217.24 ± 189.34 m, $n = 29$), although this difference was not significant ($t = -1.2686$, $df = 17$, $P = 0.22$). Both hornbill species showed some tolerance to lopping, with six out of 29 (21%) nests of IGH and three out of 13 (23%) nests of OPH found on trees whose branches had been lopped for fodder previously.

This study examines nesting requirements of the sympatric OPH and IGH in tropical dry forests. Despite OPH

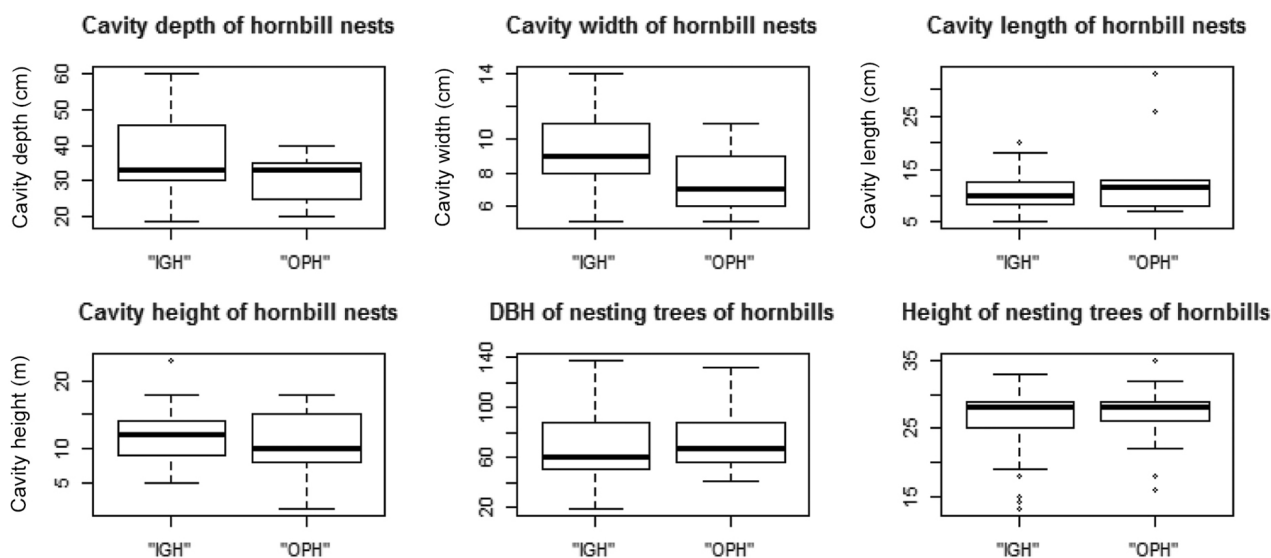


Figure 1. Box-plot of nest cavity and nest tree attributes of sympatric Indian grey hornbill and oriental pied hornbill at Rajaji National Park, Uttarakhand, India.

Table 1. Tree species used by Indian grey hornbill and Oriental pied hornbill for nesting

Tree species	Number of nests	
	Indian grey hornbill	Oriental pied hornbill
<i>Acacia catechu</i>	1	0
<i>Anogeisus latifolia</i>	4	0
<i>Bombax ceiba</i>	4	2
<i>Careya arborea</i>	0	1
<i>Cordia myxa</i>	0	1
<i>Grevillea robusta</i>	1	0
<i>Holoptelea integrifolia</i>	1	0
<i>Lagerstroemia parviflora</i>	1	1
<i>Mitragyna parviflora</i>	0	1
<i>Shorea robusta</i>	6	1
<i>Syzigium cumini</i>	3	1
<i>Terminalia belerica</i>	2	3
<i>Terminalia tomentosa</i>	3	0
Unidentified (local name: kala bakli)	1	0

being twice the size of IGH, they differed only in two out of the six nest cavity attributes measured in this study. On the other hand, the two sympatric hornbills showed distinct preferences in the location of their nests in different habitats.

While the two hornbill species overlapped in two-thirds of the measured nest cavity attributes, the larger OPH selected trees of larger girth at the level of the nest, while the cavities of the smaller IGH were marginally wider. Nest attributes of IGH were more variable and those of OPH were within the range of attributes of IGH. This may explain our observations of the smaller IGH taking over nests of the larger OPH during the ‘nest search’ phase (when bird pairs examine cavities for nesting).

Our observations of nest attributes of IGH are comparable to an earlier study from tropical dry forests in Eastern Ghats in India¹⁶, which reported that IGH uses tall trees (mean 23 ± 7 m) with large girth (mean 3 ± 1 m) for nesting. Nest site attributes of IGH also match the characteristics of the Malabar grey hornbill nests from wetter forests^{10,20}, where the Malabar grey hornbills are known to use tall trees with larger girths for nesting. Nest characteristics of OPH at Chilla were similar to those recorded from wet evergreen forests of Thailand⁷. Although OPH in Northeast India are reported to nest very high in trees⁸, our results match with the findings from Thailand, where nests were located as close as 2 m to the ground (range: 2–45 m, 15.8 ± 9.5)⁷.

Our results indicate that there are no differences in the use of tree species for nesting by the two hornbill species, which is similar to the findings from Southeast Asia⁷. Compared to this, in tropical wet forests of NE India, Datta and Rawat⁸ reported that the three sympatric hornbills (including OPH) showed a preference for certain tree species such as *Tetrameles nudiflora*, *Ailanthus* sp. and *Syzigium* sp. for nesting.

Both, IGH and OPH may follow the ‘small bird’ strategy by intensively using small territories to forage for fruits and invertebrates, especially during the breeding season¹. While there are no movement data available for IGH, limited data on movement patterns of OPH indicate that over 95% of their daily foraging movements is less than 1 sq. km (Prasad *et al.*, unpublished). Thus, land cover within 1 km radius of the nest is likely to influence nest site selection, especially since the movement patterns of male hornbills are severely constrained in the breeding season owing to the high frequency of food delivery required by females and chicks¹. The larger OPH had the

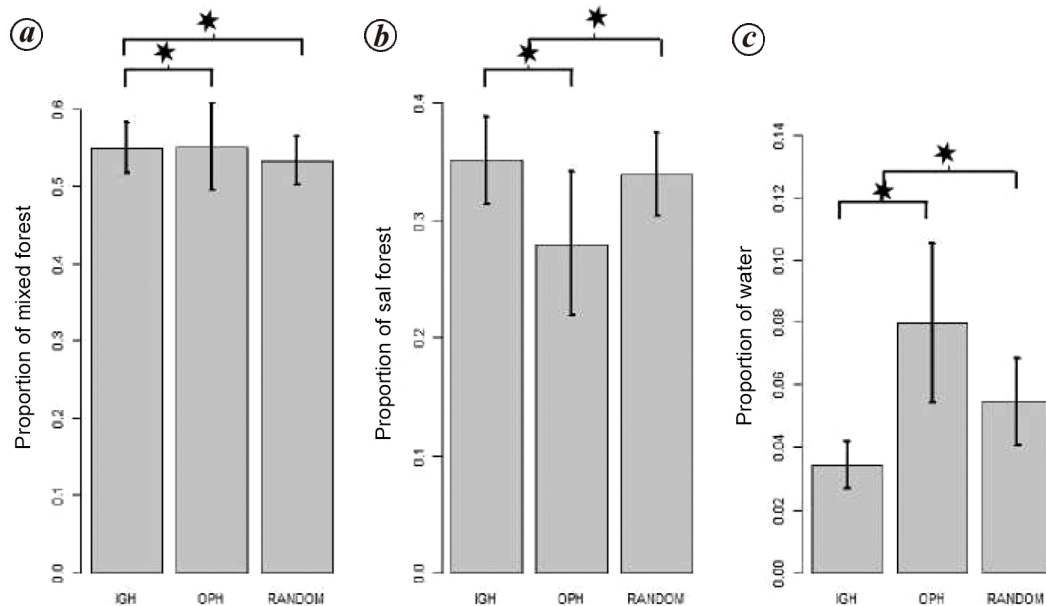


Figure 2. Average proportion of (a) mixed forest, (b) sal forest and (c) water bodies within 1 km radius of the Indian grey hornbill and Oriental pied hornbill nests, and random locations within Rajaji National Park. Error bars represent standard error. The connected lines with * indicate significantly different pairs ($P < 0.01$, Tukey's pairwise comparisons following generalized linear models of the binomial family).

more nests in mixed forest-plantation and a lower proportion in sal forest within 1 km from the nest, compared to the smaller IGH, probably due to higher food requirements of the larger hornbill. Data on vegetation in the study area from an earlier study indicate mixed forests-plantation to have higher densities of hornbill food plants compared to dipterocarp-dominated sal forests²¹. OPH located its nests closer to water bodies, which in the case of our study landscape, is the Ganges river. Riverine forests in this tropical dry landscape are dense and evergreen. IGH on the other hand appeared to avoid riverine forests, with its nests located in areas with lesser water body than random sites. This is in contrast to the findings from an earlier study from tropical dry forests in the Eastern Ghats (which is drier than our study area), which reported all the nests sites of IGH to be located nearer the riverine habitat¹⁶.

Both OPH and IGH used lopped trees for nesting, indicating a certain tolerance to human use. We did not detect any differences between the two hornbill species with respect to the distance of their nests from human habitation within the forested habitats where this study was carried out. Across most of the Indian subcontinent, IGH tends to be more common in rural and urban habitats, with OPH remaining largely restricted to forested areas. IGH has also been noted to nest in intensively modified habitats such as cities, towns and villages (S. Prasad, pers. obs.), while OPH is rarely seen outside forest habitat in dry tropical landscapes. Given the overlap in their nest tree and cavity attributes, the differences between OPH and IGH in their distribution in urban and rural habitats may

be driven by limitations imposed by the quantity of available fruiting resources in the vicinity of nest sites.

Large-gaped birds such as hornbills are able to disperse a wide range of seed sizes in tropical forests²². The ability of hornbills such as IGH to persist in intensively modified landscapes could therefore facilitate seed dispersal within and across human-modified habitats. Further examination of nest site characteristics and seed dispersal by IGH in rural and urban landscapes will help understand the role of hornbills in the movement of seeds across changing landscapes²³.

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ACKNOWLEDGEMENTS. We thank the Uttarakhand Forest Department for permissions and Inam Ali and Dhumman for field support. This work was funded by the Australia–India Strategic Research Fund.

Received 3 November 2014; revised accepted 11 January 2015
