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Characteristics of trees used as nest sites by *Apis dorsata* (Hymenoptera, Apidae) in the Nilgiri Biosphere Reserve, India

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Nest site selection is critical for social insects since poor choices can heighten predation risks and result in reproductive failure (Franks *et al*. 2002). Social bees vary in their nest site requirements and among the *Apis* bees in south Asia, *Apis dorsata* and *A. florea* nest in open combs, whereas *Apis cerana* nests in cavities (Crane 1999). *Apis dorsata* often nests in aggregations, and the large open nests can be about 1.5 m wide and are located in sites such as cliff faces or on the underside of branches of tall trees that are inaccessible to most predators except skilled fliers and climbers (Crane 1999, Seeley *et al.* 1982). *Apis dorsata*, which is widely distributed in tropical and subtropical Asia, is an important source of honey and wax for local communities, and understanding its nesting biology would help in the management and conservation of this economically important species.

We surveyed trees occupied by *Apis dorsata* nests in two sites in the Nilgiri Biosphere Reserve in the Western Ghats of India, within the major flowering season in both forests (unpublished data), and prior to the annual migration of *A. dorsata* in late June-July, during the south-west monsoon. The sites were Appankappu in the wetter Nilambur region of Kerala (latitude 11º27'N, longitude 76º17'E, altitude 300m asl), which is covered with degraded wet evergreen forests, and Bedaguli (latitude 11º49'N, longitude 77º 11'E, altitude1355m asl) in the Chamraj Nagar region of Tamilnadu, which has moderately disturbed semi-evergreen forests and grasslands. Appankappu was surveyed in April 2008 and Bedaguli in May 2008. We tested the null hypothesis that nests of *A. dorsata* were randomly located with regard to tree species, tree height, girth and bark texture.

We used data from 100 plots of 10 × 10 m covering a total area of 1 ha in each study site. The plots were randomly placed in the forests at different distances and different directions from the focal villages of Appankappu and Bedaguli, over a radius of approximately 2-4 km. Within

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plots, all trees and lianas ≥10 cm dbh were measured at 1.3 m above ground level, and in trees with buttresses, the measurements were taken above the buttresses. The height (m) was measured using a clinometer. Inventoried plants were identified to species whenever possible. The canopy cover of each plot was measured using a densitometer and percentage values were arcsine transformed for analysis. Each 10 × 10-m plot was intensively searched for a colony of *A. dorsata* with the help of local indigenous honey hunters. If the nest was observed, the species of tree was identified. To see whether the colony sizes differed between sites, the distribution of nests per tree was tested using a Kolgomorov-Smirnov test.

To see whether nests were located predominantly on large trees, the dbh (cm) and heights of trees (m) with and without nests was correlated for each site. A curve was fitted to see whether the sizes of nesting trees were larger than the average sizes of trees in each site. Only trees above the minimum height of *Apis dorsata* nesting trees in each site were used in the analysis. The data were transformed, if necessary, to normalise the distribution. A logistic regression was used to see whether tree cover (arcsine proportion) in each of the 10 × 10-m plots was associated with the likelihood of hosting nests. Data from both sites were pooled for the analysis.

The tree species with and without *Apis dorsata* nests was listed for each site. To see whether nests were disproportionately located on more abundant tree species, we selected species that occurred at densities ≥10 ha^{-1}, and were within the range of heights of *A. dorsata* nesting trees. The relationship between density of these trees and the probability of hosting nests were tested using Spearman rank correlation. The bark characteristics of each tree was assessed using floras (Gamble 1935, Matthew 1983) and by personal observation and classified as 'rough' or 'smooth'. A χ^2 test was used to see whether there was an association between bark

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characteristics and the probability of hosting *A. dorsata* nests. Systat (2000) was used for the statistical tests.

The forest at Bedaguli was more diverse and dense with significantly more individuals (mean plants± SD, Appankappu =7.5±3, Bedaguli=15±4, t test, t=3.66, df=190, p<0.0001) and species (mean species± SD, Appankappu =5.5 ± 2, Bedaguli=7.8±3, t test, t=6.68, df=184, p<0.0001) per plot than in Appankappu. The trees were significantly taller in Appankappu (mean height (m) ± SD, Appankappu =17± 4, Bedaguli=15±4, t test, t=3.66, df=190, p<0.001). However, the density of *Apis dorsata* nests per plot did not differ significantly (mean number of nests ± SD, Appankappu =0.26± 1.3, Bedaguli=0.34±1.3, t test, t=-0.44, df=190, ns). The distribution of colonies among trees did not significantly differ between sites (Kolmogorov-Smirnov two-tailed test, k = 0.19, ns).

In Appankappu, 1060 trees and lianas from 90 species were inventoried and 24 nests were recorded on 11 trees belonging to six species. The shortest nesting tree was 20m tall. A single *Tetrameles nudiflora*, which was the tallest tree (40 m) in the site, hosted 11 nests whereas eight of the nests were solitary. In Bedaguli, 1439 trees and lianas from 99 species were recorded and of these 16 trees from 11 species hosted 46 nests. A single 25-m-tall wild *Mangifera indica* tree hosted 10 nests. The shortest nesting tree in Bedaguli was 18m tall.

The heights of trees in Appankappu (Wilks-Shapiro test = 0.97, ns) and in Bedaguli (Wilks-Shapiro test = 0.97, ns) did not significantly differ from a normal distribution, dbh values were skewed and were $\log_2$-transformed to normalise the distribution.

The mean (± SD) heights of nesting trees (34 ± 6 m) differed significantly from that of non-nesting trees in Appankappu (non-nesting trees: 12.8 ± 8 m; t test: t = 13.7, df = 1058, P < 0.0001) and Bedaguli (nesting trees: 28.5 ± 4 m; non-nesting trees: 15 ± 5 m, t test: t = 15.7, df

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=1448, P < 0.0001). The mean (± SD) $\log_2$ dbh values also significantly differed (Appankappu: Nesting trees, 139 ± 42 cm; Non-nesting trees, 21± 24 cm, t test: t = 10.9, df = 1058, P < 0.0001. Bedaguli: Nesting trees, 125 ± 29 cm; Non-nesting trees, 29± 20 cm, t test: t = 15.7, df = 1448, P < 0.0001). Figure 1 indicates that nesting trees in both sites were larger than the standard sizes of trees in each site.

There was no correlation between the densities of nesting and non-nesting tree species (≥10 ha^{-1}) in Appankappu (Spearman rank correlation r_s = -0.17, n = 24, ns), indicating that nest location was not related to the local abundance of species, whereas there was a significant negative correlation between the densities of nesting and non-nesting tree species (≥10 ha^{-1}) in Bedaguli (Spearman rank correlation r_s = -0.70, n = 22, P < 0.001), suggesting that the nesting tree species were uncommon in the site. The occurrence of *Apis dorsata* nests in the 10 × 10-m plots was negatively related to tree canopy cover (Log likelihood ratio = -62.0; y = 0.77 - 2.92x, t-ratio = -2.89, P = 0.004), suggesting that the nests were located on trees within plots with more open canopies.

In all we listed 16 nesting and 15 non-nesting trees from both sites. The non-nesting trees were tall (≥20 m in Appankappu and ≥18 m in Bedaguli) and common (densities ≥10 trees ha^{-1}). Fourteen species had smooth bark and 17, rough bark (Table 1). There was no association between the bark characteristics of nesting and non-nesting trees (χ^2 = 1.64, df =1, ns). The trees belonging to the family Combretaceae did not host nests whereas *Ficus* trees appear to be preferred (Table 1).

Our study shows that *Apis dorsata* nests were preferentially located on trees that were larger than average in two sites in the Nilgiri Biosphere Reserve, and were more isolated than the other trees. However, there was no clear preferences based on taxonomic criteria or bark

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characteristics, although families such as the Combretaceae which tend to have a rough or peeling bark did not host a single nest. This supports that observation of Seeley *et al*. (1982) in Thailand that *A. dorsata* nested at heights of about 18 m on tall trees of particular families that did not branch for about 13 m. Tree architectural features such as spreading branches can increase the space for more nests to congregate; bark texture, especially smooth bark, seems also to be important criteria for nest site selection, although there was no trend in our database. This suggests that structural features and tree isolation, which probably ensured protection against predators, were the primary criterion used for locating nests. *Apis dorsata* nests face a range of predators, from birds to bears and humans (Crane 1999, Seeley *et al.* 1982) and therefore nest location is crucial for the survival of colonies. Our findings, indicating the importance of particular nesting trees, may have profound implications for the conservation and management of *A. dorsata* at the landscape scale. *Apis dorsata* colonies migrate over distances of 100 km (Koeniger & Koeniger 1980) and return to their original nest site (Paar *et al.* 2000). Particular nesting sites such as large trees and cliffs are used year after year, and the loss of such trees and cliff faces may limit nest densities in the wild. Tall trees are more frequent in primary unlogged forests and intensive logging over the geographical range of *A. dorsata* in Asia removes many potential nesting sites (Laurance 2007).

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Table 1. Species of trees with *Apis dorsata* nests and abundant (densities≥10 ha^{-1}) tall trees in both sites (height at Appankappu ≥20 m and Bedaguli ≥18 m) with no recorded nests.

Family	Species	Nests present Y/N	Bark texture
Anacardiaceae	*Mangifera indica* L.	Yes	rough
Bignoniaceae	*Stereospermum colais (Dillwyn) Mabb.*	Yes	rough
Caprifoliaceae	*Viburnum punctatum Buch.-Ham. ex D. Don*	No	smooth
Combretaceae	*Terminalia bellericaRoxb.*	No	rough
Combretaceae	*Terminalia paniculata Roth*	No	rough
Combretaceae	*Terminalia* sp.L.	No	rough
Datiscaceae	*Tetrameles nudifloraR. Br.*	Yes	smooth
Dipterocarpaceae	*Hopea parviflora Bedd.*	No	smooth
Ebenacaee	*Diospyros meloxylon Roxb.*	Yes	rough
Elaeocarpaceae	*Elaeocarpus serratus L.*	No	rough
Elaeocarpaceae	*Elaeocarpus tuberculatus Roxb.*	Yes	rough
Euphorbiaceae	*Givotia rottleriformis Griff.*	No	smooth
Euphorbiaceae	*Mallotus philippensis (Lam.) M. Arg.*	No	smooth
Euphorbiaceae	*Mallotus tetracoccus Kurz*	Yes	smooth
Fabaceae	*Acrocarpus fraxinifolius Wt & Arn.*	Yes	smooth
Fabaceae	*Albizia lebbeck (L.) Benth.*	Yes	smooth
Fabaceae	*Xylia xylocarpa*	No	rough
Lauraceae	*Persea macrantha (Nees) Kosterm.*	Yes	rough
Lauraceae	*Cinnamomum malabathrum Miq.*	No	rough
Lauraceae	*Litsea laevigata Gamble*	No	rough
Lythraceae	*Lagerstroemia macrocarpa Wight*	Yes	smooth
Moraceae	*Ficus microcarpa L. f.*	Yes	smooth
Moraceae	*Ficus* sp. *L.*	Yes	smooth
Myrtaceae	*Syzygium* sp.	Yes	rough
Myrtaceae	*Syzygium* sp.	No	rough
Rubiaceae	*Neolamarckia cadamba (Roxb.) J. Bosser*	Yes	rough
Rutaceae	*Euodia lunu-ankenda (Gaertn.) Merr.*	No	rough
Sabiaceae	*Meliosma pinnata Maxim.*	No	rough
Sapindaceae	*Schleichera oleosa (Lour.) Oken*	Yes	smooth
Sterculiaceae	*Pterygota alata (Roxb.) R. Br.*	Yes	smooth
Ulmaceae	*Celtis tetrandraRoxb.*	No	smooth

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Figure Legend

Figure 1. Relationship between height (m) and dbh (log cm) of trees with and without *Apis dorsata* nests in the two sites: Appankappu (all trees ≥20m tall) and Bedaguli (all trees ≥18m tall). Fitted line: solid = non-nesting trees, dashed = *Apis dorsata* nesting trees. Open circles=non-nesting trees and stars=nesting trees.

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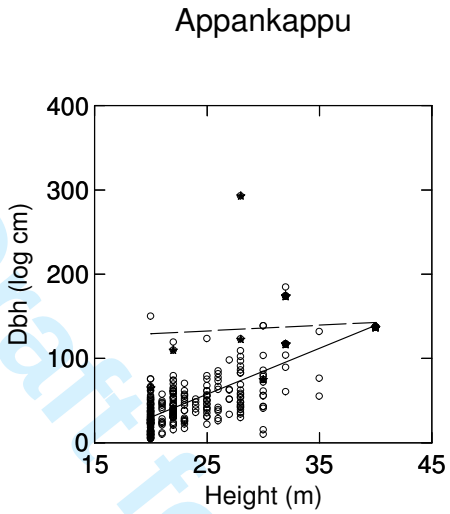

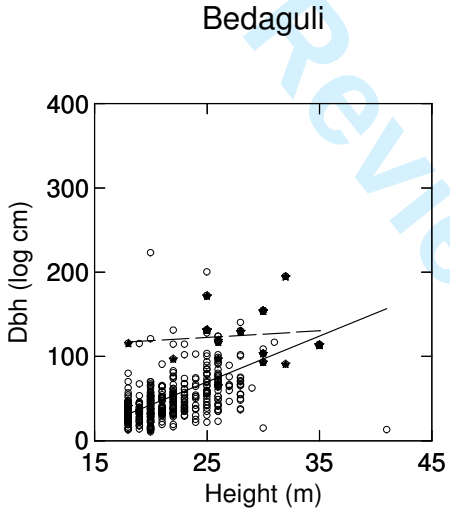

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