



RESEARCH ARTICLE - BEES

Large Trees in Tropical Dry Forest Facilitate the Presence of Stingless Bee Nests (Apidae: Meliponini): The Case of *Ficus crocata*

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Abstract

Stingless bees are a crucial pollinator group for the functioning of tropical ecosystems. While most species nest in tree cavities, the importance of different tree species for nesting bees remains poorly understood. In this study, we evaluated *Ficus crocata* as a nesting site for stingless bees in a tropical dry forest within the Guanacaste Conservation Area, Costa Rica. Additionally, we recorded the presence of nests in other tree species around *F. crocata*. We examined correlations between tree size (diameter at breast height, DBH) and the presence of nests, the number of nests, and the richness of stingless bee species. Our results indicate that *F. crocata* is an important nesting resource, with 85.7% of stingless bee nests found in trees of this species. Regardless of the tree species, DBH was positively correlated with nest presence, nest abundance, and the richness of stingless bee species. Of the eight stingless bee species identified, *Tetragonisca angustula* was the most frequent. Up to three stingless bee species were observed nesting in a single tree, with a maximum of seven nests in an individual *F. crocata*. Other tree species: *Gliricidia sepium*, *Guazuma ulmifolia*, and *Simarouba glauca* also harbored unique stingless bee species, although less frequently. These results highlight the ecological importance of large trees – particularly *F. crocata* – in providing critical nesting sites for stingless bees in tropical dry forests. Therefore, conserving large trees is essential for maintaining nesting resources and supporting stingless bee diversity in these ecosystems.

Introduction

Stingless bees (Apidae: Meliponini) are distributed in tropical and subtropical areas, with higher abundance and species richness in the Neotropical region (Aguilar et al., 2013; Grüter, 2020). According to Grüter (2020), approximately 80% of the global diversity of stingless bees

— more than 400 species — is concentrated in the Neotropics (Camargo et al., 2013). Stingless bees are eusocial insects that form perennial colonies composed of thousands to tens of thousands of workers (Hubbell & Johnson, 1977; Grüter, 2020), which depend on plant communities to complete various stages of their life cycle (Aguilar et al., 2013; Grüter, 2020). Most stingless bee species visit flowers to collect



nectar for nourishment and pollen to provision their brood (Grüter, 2020; Bueno et al., 2023). Due to their abundance and ecological interactions with plants, stingless bees are considered a crucial group for the functioning of tropical ecosystems (Bawa, 1990; Tornyie & Kwapong, 2015; Bueno et al., 2023).

In addition to floral resources, most stingless bees require suitable nesting sites, often in tree cavities or at the base of tree trunks (Wille & Michener, 1973; Moreno & Cardozo, 1997; Roubik, 2006, 2023). Among their nesting habits, cavity-nesting within trees is the most common strategy, accounting for approximately 65.5% of species, followed by ground-nesting species (11.7%) and those that nest in termite mounds (9%) (Wille & Michener, 1973; Grüter, 2020). Since stingless bees establish long-lived, perennial colonies, selecting an appropriate nesting site is crucial for colony survival. Suitable nesting locations provide access to essential resources, reduce predation risks, and enhance the colony's ability to withstand environmental fluctuations (Grüter, 2020; Jiménez et al., 2021).

Although the nest architecture of stingless bees has been well-documented since the work of Wille and Michener (1973), fewer studies have focused on identifying the specific tree species and tree-level characteristics that influence nesting site selection by stingless bees (Antonini & Martins, 2003; Martins et al., 2004; Aguilar et al., 2013; Barquero-Elizondo et al., 2019). Available evidence indicates that stingless bees predominantly nest in living trees (Vergara et al., 1986; Kerr et al., 1999; Roubik, 2006), often showing a preference for hardwood species (Roubik, 1983). In some cases, individual bee species establish their colonies using only a limited number of tree species (Van Veen, 1999; Antonini & Martins, 2003; Martins et al., 2004; Ravelo Pimentel et al., 2014). For example, *Melipona beecheii* has been reported to nest in seven tree species but shows a marked preference for *Gliricidia sepium* (Fabaceae) (Moreno & Cardozo, 1997; Van Veen, 1999; Fonte et al., 2009).

Tree-nesting insects are influenced by both plant species diversity and tree growth and ontogeny (Basset et al., 1992; Ribas et al., 2003; Campos et al., 2006). As trees develop, they change their microclimatic conditions and resource availability (Lawton, 1983; Basset et al., 1992; Basset, 2001). These changes enhance the availability of food resources, nesting sites, refuges from predators, and oviposition sites for a variety of organisms (Lawton, 1983; Fonseca & Benson, 2003; Basset et al., 2003; Djieto-Lordon et al., 2004). Consequently, tree size is expected to have a significant influence on stingless bee richness and the number of colonies present in a given area.

A study conducted in the dry forest of Costa Rica reported the presence of nests belonging to nine species of stingless bees within tree trunks. The highest proportion of nests was found in large trees belonging to genera such as *Quercus* (Fagaceae) and *Ficus* (Moraceae), with *Ficus* trees

showing the largest stem diameters (>2 meters) (Barquero-Elizondo et al., 2019). Moreover, trees with a greater number of cavities have been identified as the primary nesting sites for bees of the genus *Melipona* (Kerr et al., 1999; Brown & Albrecht, 2001).

In this study, we evaluated *Ficus crocata* as a nesting site for stingless bees in a tropical dry forest within the Guanacaste Conservation Area, Costa Rica. Additionally, we recorded the presence of nests in other tree species around *F. crocata*. We tested whether larger trees support a higher number of nests and a greater diversity of stingless bee species.

Materials and Methods

Field site and study species

This study was conducted over one week in December 2022, during the dry season, with daily observations carried out from 09:00 to 17:00. The research took place in the lowland areas (280–290 m a.s.l.) of the Guanacaste Conservation Area (GCA), specifically within the Santa Rosa sector, which is characterized as a tropical dry forest habitat. The rainy season occurs from May to November, with an average temperature of 38°C and an average accumulated precipitation of 1,585 mm. The dry season extends from December to April, with temperatures ranging from 20 °C to 31 °C and an average accumulated precipitation of 106 mm (Cooley et al., 2019). The GCA comprises areas representing different successional stages of tropical dry forest regeneration, including patches of mature forest. This protected area is considered one of the most significant remnants of tropical dry forest in Central America (Sánchez-Azofeifa et al., 2013; Área de Conservación Guanacaste Fuente de Vida y Desarrollo, 2022). Floristic surveys conducted across various successional stages of the site have recorded 159 tree species from 55 families. Notably, species from the genus *Ficus* are not listed among the most common trees (i.e., species representing <2% of the total number of individuals) (Kalacska et al., 2004).

Ficus crocata (Miq.) Mart. ex Miq. (Moraceae) is typically a hemiepiphytic tree, although it can occasionally grow as a rupicolous species. It reaches heights of 4 to 30 m (González-Castañeda et al., 2010). The species is widely distributed, ranging from Mexico to the Antilles, Bolivia, and Brazil. It commonly occurs in tropical dry forests and gallery forests, spanning an altitudinal range of 300 to 2100 m above sea level. Common names for this species include matapalo, amate negro, amate prieto, higuera prieta, and higuera, among others (González-Castañeda et al., 2010).

Stingless bees: Approximately 60 species of stingless bees (Apidae: Meliponini) have been reported in Costa Rica (Aguilar et al., 2013; Figueroa-Mata et al., 2016; Hanson et al., 2021). In the provinces of Guanacaste, Puntarenas, San José, Cartago, and Heredia, around 20 species of wild and semi-domesticated stingless bees have been recorded (De Jong, 1999; Herrera & Aguilar, 2011; Aguilar et al., 2013). Among

these are *Melipona beecheii*, *Nannotrigona perilampoides*, *Plebeia tica*, and *Trigona fulviventris* (Aguilar et al., 2013). However, in recent years, populations of some species, such as *M. beecheii*, have declined due to increasing demand for honey and anthropogenic disturbances, including forest fragmentation (Villanueva-Gutiérrez et al., 2005; Aguilar et al., 2013).

Presence of stingless bee nests in Ficus crocata trees

Stingless bee nests were identified on the trunks of *F. crocata* trees through observations conducted up to a height of 5 m. To assess nest presence in trees neighboring *F. crocata* individuals, a 10 m radius plot was established around each focal tree. Within these plots, all neighboring trees were examined for the presence of nests. For each tree sampled, we recorded the condition of the trunk (presence or absence of cavities), whether the tree was alive or dead, and whether it hosted stingless bee nests.

To assess whether nest occurrence differed among tree species, a chi-square (χ^2) test of independence was performed to evaluate the association between tree species and nest presence. In this analysis, tree species were treated as the categorical predictor variable, and the number of nests was the response variable. All statistical analyses were conducted in R version 4.2.2 (R Core Team, 2022).

Tree size and diversity of stingless bees

The diameter at breast height (DBH; measured at 1.3 m above ground level) was recorded for all *F. crocata* individuals and neighboring trees containing nests. For each tree with nests present, the number of stingless bee nests was recorded, photographs were taken of nest entrances, and bee specimens were collected with entomological nets to identify species richness per tree. Additionally, the height above ground level at which each nest was located was recorded. To evaluate whether DBH was related to nest presence, nest abundance, and stingless bee species richness in *F. crocata*, correlation analyses were performed in R version 4.2.2 (R Core Team, 2022).

A bipartite interaction matrix was constructed to represent the network of associations between tree species and stingless bee species. In this matrix, bee species were treated as one level and tree species as the other, with the number of nests per bee species in each tree species serving as the interaction strength to assess network attributes. The species strength (*SS*) was calculated using the *Bipartite* R package (Dormann et al., 2009). The *SS* index quantifies the structural and functional importance of each species by measuring its relevance at one trophic level in relation to species at another level (Bascompte et al., 2006; Poisot et al., 2012; Salazar-Rivera et al., 2020). All network analyses were conducted in R version 4.2.2 (R Core Team, 2022).

Stingless bee nest density

We recorded the total number of stingless bee nests and their density across the sampling area, including nests found in both *F. crocata* and other tree species. The sampling area was delineated by mapping the spatial distribution of *F. crocata* trees and neighboring trees within a 10 m radius of each focal *F. crocata* individual. For spatial mapping, polar coordinates (angle in degrees and distance in meters from the focal tree) were recorded for each tree. These polar coordinates were converted to Cartesian coordinates (x, y), and the resulting data were used to calculate the total sampling area, which consisted of 11 plots of varying sizes.

Results

Presence of stingless bee nests in Ficus crocata trees

Of the total *F. crocata* trees sampled ($n = 74$), 12 individuals (16%) contained stingless bee nests. In contrast, among neighboring trees, only three out of 258 individuals (<1%) presented nests, resulting in a total of 332 trees examined. The neighboring trees with nests belonged to three species: *Gliricidia sepium*, *Guazuma ulmifolia* (Malvaceae), and *Simarouba glauca* (Simaroubaceae). Regarding cavity presence, 43% of all sampled trees had cavities in their trunks, while only four individuals were recorded as dead trees. As expected, all trees hosting stingless bee nests had cavities in the stem. Additionally, only one dead individual of *F. crocata* contained a stingless bee nest. A chi-square test ($\chi^2 = 30.42$, $df = 1$, $p < 0.01$) revealed a significant difference in nest presence between *F. crocata* and other tree species, with nest frequency being significantly higher in *F. crocata*.

Tree size and diversity of stingless bees

There was a significant positive correlation between tree diameter at breast height (DBH) and nest presence ($r = 0.6914$, $t = 8.0657$, $p < 0.05$). Based on this relationship, we fitted a Generalized Linear Mixed Model (GLMM) using the *glmer* function from the *lme4* (Bates et al., 2015) package in R (version 4.4.2) (R Core Team, 2022), assuming a *Poisson* error distribution. The number of nests was modeled as the response variable, DBH as a fixed effect, and tree species as a random intercept to account for interspecific variation. The model showed no evidence of overdispersion (residual deviance/ $df = 0.82$). A significant positive effect of DBH was detected (Estimate \pm SE = 0.547 ± 0.086 , $z = 6.397$, $p < 0.001$), indicating that larger trees tend to support more nests. The variance of the random intercept for tree species was 0.572 (SD = 0.756), suggesting moderate variation among species. Overall, these results support the hypothesis that nest abundance increases with tree diameter, regardless of species identity (Fig 1).

Eight stingless bee species were identified. However, no specimens were collected from one nest due to its difficult accessibility, leaving its species identity undetermined.

The identified species included *Tetragonisca angustula*, *Tetragona* sp., *Plebeia* sp., *Partamona orizabaensis*, *Nannotrigona* sp. 1, *Nannotrigona* sp. 2, *Geotrigona* sp., and *Cephalotrigona zexmeniae* (Fig 2). A single nest represented most species; however, *T. angustula* accounted for 13 nests (Table 1).

It is noteworthy that *Nannotrigona* spp. and *Geotrigona* sp. were not found nesting in *F. crocata*. *Nannotrigona* sp. 2 and *Geotrigona* sp. were recorded on *G. sepium*. At the same time, *Nannotrigona* sp. 1 was found on *G. ulmifolia* (Fig 3). There was a significant positive correlation between DBH and the number of stingless bee species per tree ($r = 0.6007$, $t = 6.3314$, $p < 0.05$). Nest entrance heights ranged from 0.21 m for *T. angustula* to 4.9 m for *Nannotrigona* sp. (Table 1).

A total of 28 stingless bee nests were recorded, with 85.7% found in *F. crocata* trees and 14.3% in other tree species. Among *F. crocata* trees with nests, 50% hosted a single nest, 25% hosted two nests, 16.6% hosted three nests, and one tree hosted the maximum of seven nests (8.4%). Both *G. ulmifolia* and *S. glauca* had one nest each, while *G. sepium* hosted two nests. The tree with seven nests was an individual *F. crocata* with DBH > 1 m. Three stingless bee species (*T. angustula*, *P. orizabaensis*, and *Plebeia* sp.) nested on this tree, which also had the highest number of bee species observed in a single tree, all belonging to *F. crocata* with DBH > 1 m.

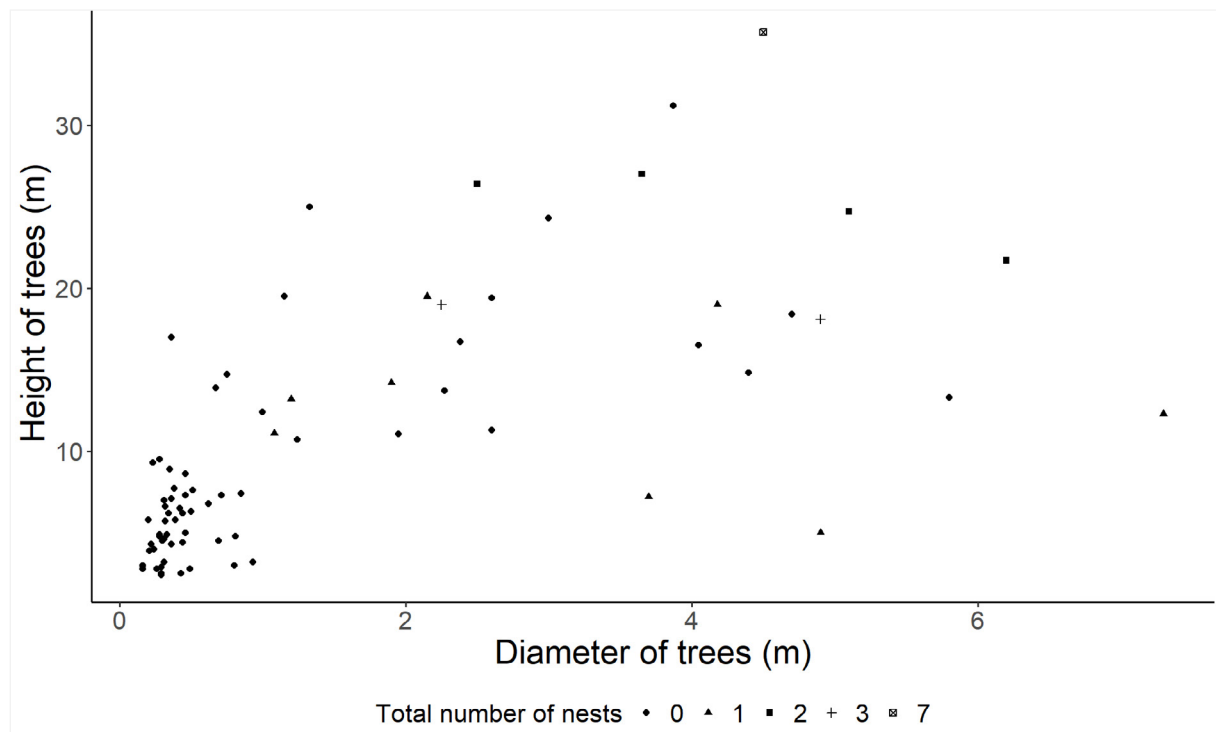


Fig 1. Size (diameter at breast height [DBH] and height) of *Ficus crocata* individuals ($n = 74$). The number of stingless bee nests recorded in each tree is indicated. Study conducted in the Santa Rosa sector, Guanacaste Conservation Area, Costa Rica.

Table 1. Number of nests and nest height (minimum, maximum, and average) recorded in the Guanacaste Conservation Area, Santa Rosa sector, Costa Rica. Heights are given in meters. Missing values are indicated with a dash (-).

| Bee species | Tree species | Number of nests | Average height | Minimum height | Maximum height |
|---------------------------------|--------------------------|-----------------|----------------|----------------|----------------|
| <i>Tetragonisca angustula</i> | <i>Ficus crocata</i> | 12 | 1.6 | 0.57 | 4.4 |
| <i>Plebeia</i> sp. | <i>Ficus crocata</i> | 4 | 1.4 | 0.8 | 1.9 |
| <i>Partamona orizabaensis</i> | <i>Ficus crocata</i> | 4 | 2.2 | 1.9 | 2.6 |
| <i>Cephalotrigona zexmeniae</i> | <i>Ficus crocata</i> | 1 | 2.4 | - | - |
| Unknown | <i>Ficus crocata</i> | 1 | 4.3 | - | - |
| <i>Geotrigona</i> sp. | <i>Gliricidia sepium</i> | 1 | 1.3 | - | - |
| <i>Nannotrigona</i> sp. 1 | <i>Guazuma ulmifolia</i> | 1 | 1.3 | - | - |
| <i>Nannotrigona</i> sp. 2, | <i>Gliricidia sepium</i> | 1 | 4.9 | - | - |
| <i>Tetragonisca angustula</i> | Dead tree | 1 | 1.30 | - | - |
| <i>Tetragonisca angustula</i> | <i>Simarouba glauca</i> | 1 | 0.2 | - | - |
| <i>Tetragona</i> sp. | <i>Ficus crocata</i> | 1 | 0.3 | - | - |

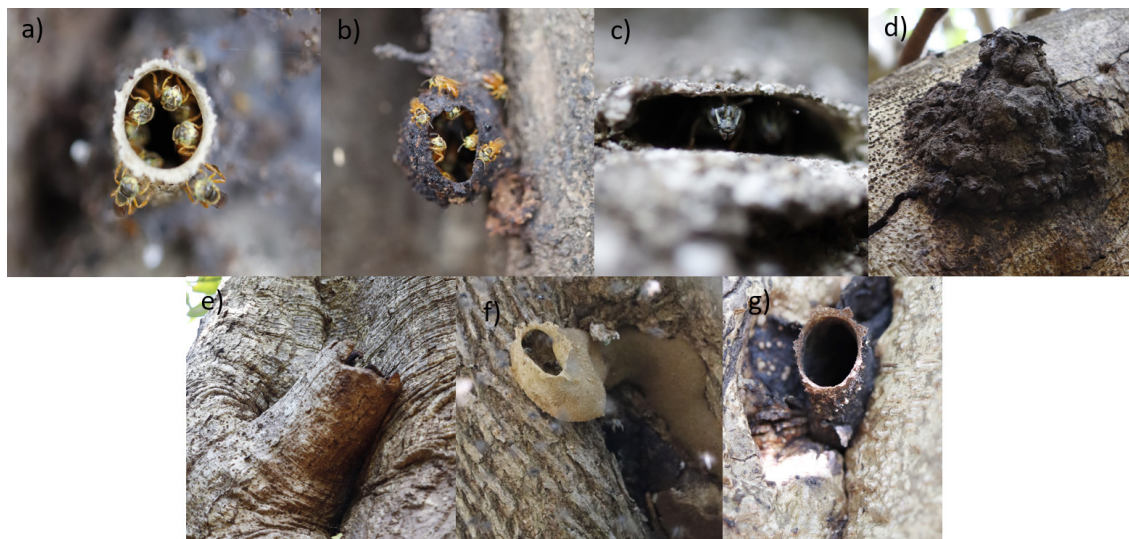


Fig 2. Nests of stingless bee species (Apidae: Meliponini) found in the Santa Rosa sector of the Guanacaste Conservation Area, Costa Rica. a) *Tetragonisca angustula*, b) *Tetragona* sp., c) *Plebeia* sp., d) *Partamona orizabaensis*, e) *Cephalotrigona zexmeniae*, f) *Nannotrigona* sp. 2, g) *Nannotrigona* sp. 1. Photos: Gerardo Manzanarez-Villasana and Isabel Briseño Sánchez.

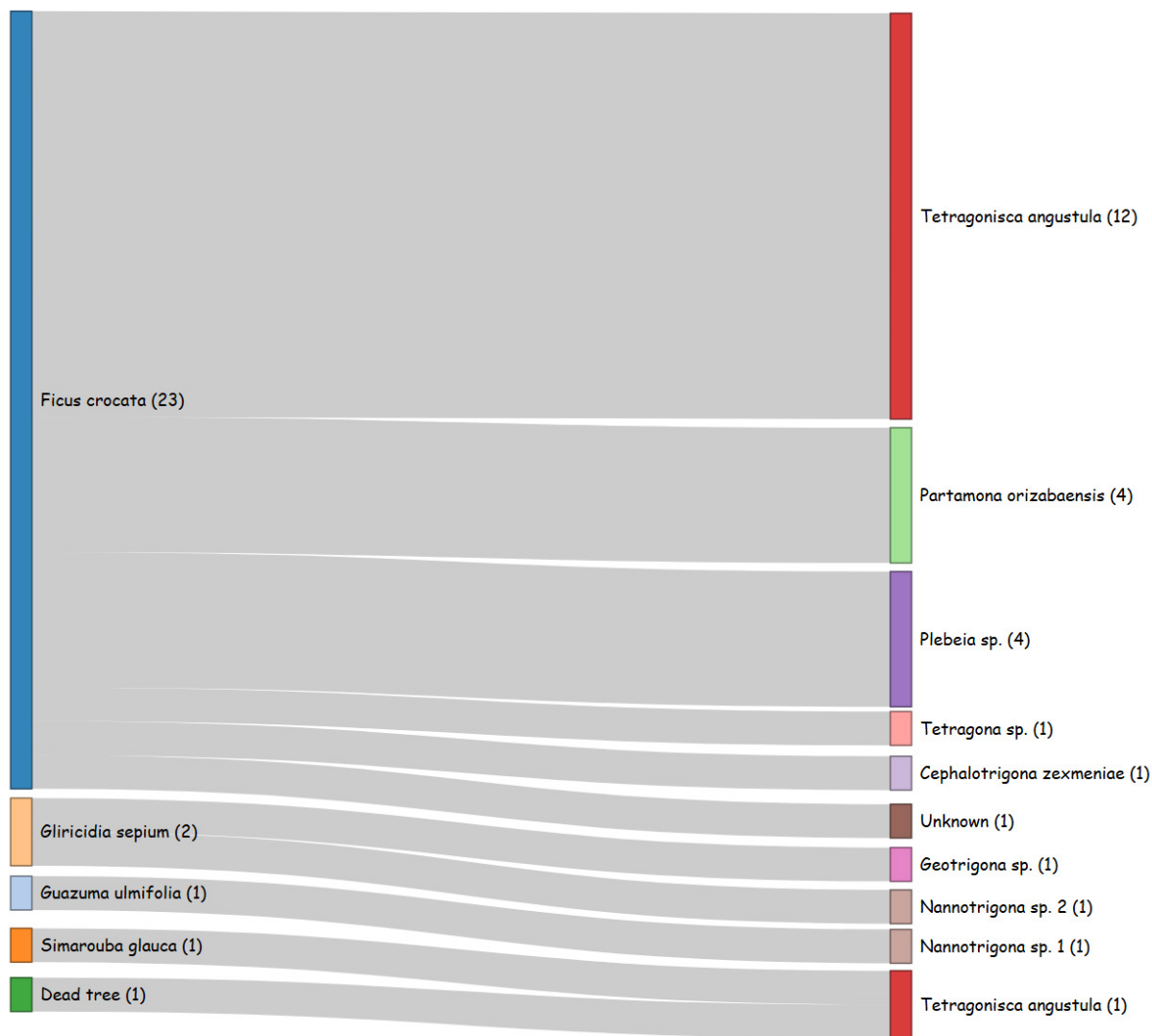


Fig 3. Bipartite network illustrating interactions between stingless bee species (Apidae: Meliponini) and tree species recorded in the Santa Rosa sector of the Guanacaste Conservation Area, Costa Rica. Links represent the number of observed interactions. The number of nests recorded for each tree species and bee species is indicated in parentheses.

The bipartite interaction network revealed differences in species strength (*SS*), reflecting the ecological importance of tree species for the stingless bee assemblage in this dry forest. *Ficus crocata* had the highest *SS* value (5.85), indicating the greatest number of interactions and the presence of stingless bee species. *G. sepium* followed with an *SS* of 2.0. In contrast, *G. ulmifolia* and *S. glauca* had lower *SS* values of 1.0 and 0.071, respectively.

Among stingless bee species, *T. angustula* had the highest *SS* value (2.52), reflecting its nesting in two of the four tree species. *Nannotrigona* sp. 1 followed with an *SS* of 1.0, while *Nannotrigona* sp. 2 and *Geotrigona* sp. each had *SS* values of 0.5. Both *P. orizabaensis* and *Plebeia* sp. had *SS* values of 0.17. In contrast, *Tetragona* sp. and *C. zexmeniae* had the lowest *SS* values (0.043), each recorded in a single nest on *F. crocata* (Fig 3).

Stingless bee nest density

The sampled individuals of *F. crocata* and other tree species were distributed across eleven plots of varying sizes (minimum = 10 m × 10 m; maximum = 50 m × 45 m), covering a total area of 0.87 ha. A total of 28 nests were recorded in this area, resulting in a nest density of 32.1 nests per hectare. The minimum distance between trees hosting nests was 5 m, while the maximum distance was 45.6 m.

Discussion

Ficus trees are recognized as key resources in tropical forests, supporting a wide range of plant-animal interactions (Janzen, 1979; Shanahan et al., 2001). In this study, we found that 16% of *Ficus crocata* individuals harbored at least one stingless bee nest, whereas less than 1% of neighboring trees from other species contained nests. The presence and richness of stingless bee species have been associated with tree species diversity, a pattern observed in other insect groups as well (Lawton, 1983; Aguilar et al., 2013; Grüter, 2020; Li et al., 2022). However, despite the availability of other tree species with cavities suitable for nesting at the study site (e.g., *Simarouba glauca*, *Guazuma ulmifolia*, *Gliricidia sepium*), nest occurrence was significantly higher in *F. crocata*.

All trees with stingless bee nests contained stem cavities. Although we did not quantify the number of cavities per tree, previous studies have demonstrated that tree diameter at breast height (DBH) is positively correlated with attributes such as tree height, crown volume, and the number of cavities and bifurcations in the trunk (Campos et al., 2006; Powell et al., 2011). It is likely that as the DBH of trees increases, the architectural complexity and availability of cavities also increase, enhancing their suitability as a nesting resource for stingless bees (Eltz et al., 2003). Supporting this hypothesis, we observed no nests in *F. crocata* individuals nor the other tree species with a DBH less than 1 m, highlighting the role of tree maturity in cavity formation and subsequent colonization by stingless bee swarms.

Barquero-Elizondo et al. (2019) reported the presence of stingless bee nesting in several tree species in the Guanacaste province of Costa Rica, across two sites: an intervened primary forest (El Hacha) and a secondary forest (Pocosol). Our study was conducted in a secondary forest at Santa Rosa. Comparing species composition across these studies, *Tetragonisca angustula* was recorded in all three sites. Additionally, *Partamona orizabaensis*, and species of the genera *Plebeia*, *Nannotrigona*, and *Tetragona* were consistently documented. However, *Trigona fulviventris* and *Scaptotrigona pectoralis* were not recorded at Santa Rosa, while *Geotrigona* sp. and *Cephalotrigona* sp. were not found at El Hacha and Pocosol. The abundance of *S. pectoralis* in El Hacha, absent from both Santa Rosa and Pocosol, suggests notable variation in species composition, potentially driven by forest successional stages. El Hacha represents a logged primary forest, in contrast to the secondary forests at Santa Rosa and Pocosol.

Among the nine stingless bee species recorded by Barquero-Elizondo et al. (2019), only *P. orizabaensis* was associated with *Ficus* species. Our findings expand the list of stingless bee species nesting in *Ficus* in the Guanacaste region, adding *T. angustula*, *Tetragona* sp., *Plebeia* sp., and *C. zexmeniae* to *P. orizabaensis*. Nest heights observed in this study, ranging from 0.21 m (*T. angustula*) to 4.9 m (*Nannotrigona* sp.), are consistent with previously reported ranges for stingless bees (Vergara et al., 1986). Notably, although *Geotrigona* species are typically described as ground-nesters (Camargo & Moure, 1996), we documented an atypical arboreal nest of *Geotrigona* sp. in *G. sepium* at a height of 1.3 m. Further research is necessary to assess the frequency and ecological significance of such nesting behaviors in *Geotrigona* species.

The presence of bee nests on specific tree species may reflect their relative abundance rather than active preference (Batista et al., 2003; Silva & Ramalho, 2014; Tornyie & Kwapong, 2015). In this study, *F. crocata* supported the majority of stingless bee nests recorded, despite not being among the most abundant trees in our study area (Kalacska et al., 2004). However, it was not the only uncommon species with nest presence, so we cannot confirm an active preference by stingless bees for any particular tree species. Network analysis highlighted the ecological importance of the trees, revealing high species strength (*SS*) values for *F. crocata*, indicating its central role in the stingless bee nesting network in the studied dry forest. Comprehensive data on cavity availability and tree species composition, including individuals with and without nests, are required to determine whether stingless bees exhibit true nesting preferences for *F. crocata*, as has been demonstrated in other systems (e.g., *Melipona quadrifasciata* and *Caryocar brasiliense*; Antonini & Martins, 2003). The observed importance of *F. crocata* suggests that its decline could have a negative impact on the local stingless bee community, as predicted by studies modeling

species loss in plant-animal interaction networks (Bascompte et al., 2006; Rumeu et al., 2007; Salazar-Rivera et al., 2020).

Regarding to nest density, we documented 32.1 nests per hectare within a total sampling area of 0.87 ha. This is comparable to the density reported by Barquero-Elizondo et al. (2019) in Guanacaste's dry forest (26.9 nests/ha over 1.32 ha), but significantly higher than early reports from similar vegetation types, such as 5 nests/ha in a 36.7-ha plot (Hubbell & Johnson, 1977). Nest densities in other vegetation types also vary, though differences in sampling design limit comparisons. For example, Ravelo Pimentel et al. (2014) reported 1.75 nests/ha in xerophytic scrub, 1.24 nests/ha in semi-deciduous forests, and fewer than 1 nest/ha in pine, oak, and gallery forests. In rainforests, nest densities have ranged from 6 nests/ha (Roubik, 1983) to 16.2 nests/ha in dipterocarp forests adjacent to mangroves (Eltz et al., 2002), with much lower densities (0.5–0.7 nests/ha) in continuous forests. In West Africa, Tornyie and Kwapong (2015) found densities ranging from 1.7 to 2.4 nests/ha in fragmented forests. These findings suggest that certain tropical dry forests can support unusually high populations of stingless bees, likely due to the availability of floral resources and suitable nesting sites (Eltz et al., 2002; Batista et al., 2003; Ribas et al., 2003; Powell et al., 2011).

Most nests recorded in our study were located at heights below 5 m, consistent with observations that stingless bee nests are often concentrated in the lower strata of forests (Aguilar et al., 2013). Nevertheless, our data exclude potential nests in higher canopy strata, termite mounds, and subterranean sites, which may have led to an underestimation of actual nest density.

Our results support the notion that habitat loss and forest degradation have a negative impact on stingless bee communities (Kerr, 1999; Liow et al., 2001). Large trees, which provide critical nesting sites, are generally more abundant in mature forests and underrepresented in secondary or fragmented forests (Laurance et al., 2000; Samejima et al., 2004). In our study, most of the *F. crocata* individuals were small trees (DBH<1m), while large trees were underrepresented. Given the ongoing loss of large trees (Laurance et al., 2000), the persistence of stingless bee populations may be at risk. In general, greater vegetation heterogeneity is associated with higher insect species richness (Lawton, 1983; Basset et al., 1992; Campos et al., 2006; Li et al., 2022). The structural complexity provided by large trees may therefore play a key role in maintaining stingless bee populations in tropical dry forests.

Conclusion

Large trees provide critical nesting sites for stingless bees in dry tropical forests. Tree size, measured as diameter at breast height (DBH), was positively associated with the presence of nests, the number of nests per tree, and the richness of stingless bee species. Although *F. crocata* is not among the most abundant tree species in the study area, it

serves as a critical resource for nesting, with the majority of stingless bee nests recorded in this species. Other tree species: *Gliricidia sepium*, *Guazuma ulmifolia*, and *Simarouba glauca*, also harbored unique stingless bee species, although less frequently. All tree hosting nests had DBH values greater than 1 meter and featured cavities in their trunks. Up to three different stingless bee species were observed nesting within a single tree, with a maximum of seven nests documented per individual.

The complex architecture of larger trees may facilitate interspecific interactions and enhance nesting opportunities, thereby influencing the composition and stability of the stingless bee community. These findings highlight the importance of conserving large trees, as their loss could have detrimental effects on stingless bee populations in tropical dry forests. The preservation of these trees is therefore essential to maintaining habitat heterogeneity and supporting pollinator diversity in these ecosystems.

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Authors' Contributions

G.M-V.: Conceptualization, methodology, formal analysis, investigation, data curation, writing-original draft, writing-review & editing, visualization, supervision, and project administration.

M.I.B-S.: Conceptualization, methodology, formal analysis, investigation, data curation, writing-original draft, writing-review & editing, visualization, supervision, and project administration.

J.L.: Conceptualization, methodology, resources, writing-review & editing, project administration, and funding acquisition.

M.Q.: Contributed to conceptualization, resources, writing-review & editing, project administration, and funding acquisition.

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Data availability statement

The datasets generated and/or analyzed during the current study are publicly available on Zenodo at <https://doi.org/10.5281/zenodo.12786379>

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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