BIOLOGICAL SCIENCES

Stingless bee (Apidae, Meliponini) guilds occurring in the immediate edges of forest fragments of the Baturité Massif, State of Ceará, Brazil

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Abstract: This study investigated the occurrence of individuals of stingless bees attracted by the trophic resources existing in four edge areas of forest fragments located in the Baturité Massif, State of Ceará. In this sense, the study evaluated the species richness in the areas; the absolute abundance of species; the similarity of species between edges; and the affinity of bees for the same plant species. The sampling of bees compiled a total of 20 species distributed in 12 genera. Seven species stood out for abundance and two (Trigona spinipes and Trigona fulviventris) showed dominance. The results also showed that the fragments present a similar stingless bee fauna and the affinity of the bee species for the same plant species revealed the formation of five distinct bee groups in foraging preferences involving 15 (75%) out of the 20 species of bees studied.

Key words: foraging, meliponini bees, species richness, trophic resources.

INTRODUCTION

In the neotropics, researchers have faced difficulties in bee census procedures due to the degradation of natural environments (Brosi et al. 2008). This process is characterized mainly by the fragmentation of habitats caused almost always by anthropogenic actions carried out over the centuries (Viana & Pinheiro 1998, Cerqueira et al. 2003, Brown & Lomolino 2006). At the immediate edges of these fragments, the dynamics of biological interactions are altered by new established physical conditions (Bierregaard et al. 1992, Murcia 1995).

Gene flow between animal and plant populations is the factor most drastically affected in space and time. In this case, the elements that contribute most to these genetic alterations are the fragment sizes, the distances between them and the permeability of the established matrix (Viana et al. 1992, Scariot et al. 2003, Schneider et al. 2003). In the group of Meliponini and other Apoidea, this critical limit is perceived through the emergence of diploid males, due to the lack of alleles for the proper genetic combinations (Kerr & Vencovsky 1982).

Although these immediate edges of forest fragments are marked by the effects of human interference, they develop a flora, partly exotic, perfectly adapted and whose dynamics is directly related to the structural modification of the matrix (Cane 2001, López-Barrera 2004, Ewers & Didham 2006, Maciel et al. 2011). In these sites, a considerable richness of bee species, including of meliponini, has been observed using the trophic resources made available by this flora (Antonini et al. 2003, Gonçalves & Melo 2005, Gonçalves et al. 2009). However, the pattern of occurrence of meliponini bees in these environments is also characterized...
by other factors such as the conservation of the fragments, the lack, the quality and the seasonality of trophic resources and the levels of relative humidity (Heithaus 1979, Antonini et al. 2003, Brosi et al. 2008, Brosi 2009).

Bee census studies carried out in anthropic areas of different Brazilian regions have shown a relatively large variation, mainly in the richness and abundance of stingless bee species, both as a function of the region and the plant typology (Locatelli et al. 2004, Aguiar & Zanella 2005, Batalha Filho et al. 2007, Milet-Pinheiro & Schlindwein 2008, in the Northeast region; Wilms et al. 1996, Faria-Mucci et al. 2003, Anacleto & Marchini 2005, Andena et al. 2005 in the Southeast region; Krug & Alves-dos-Santos 2008, in the South region; Santos et al. 2004 in the Central-West region). Outside Brazil, similar research was also carried out in environments affected by human activities, in the vicinity of fragments of ombrophilous forests, such as those of Heithaus (1979) and Samejima et al. (2004) in Costa Rica (Central America), and Brosi et al. (2008) and Brosi (2009) in Malaysia (Southeast Asia).

In the State of Ceará, research on the Meliponini group and its trophic resources has not been carried out frequently on fragments of Atlantic forest such as those occurring in the Baturité Massif, Brazilian semi-arid. Recently, Lima-Verde et al. (2014) carried out a floristic survey in these same areas selected for this research to relate the plant species with the meliponini species.

In this sense, areas of immediate edges of forest fragments of this massif were selected to investigate the occurrence of species of these bees attracted by the trophic resources therein. In order to ecologically evaluate the behavior of this group of bees, four edges of four distinct forest fragments were used to answer the following questions: i) how is the richness of bee species represented in these areas?; ii) how is the abundance of individuals per species characterized in these environments?; (iii) how similar are the forest edges in bee species?; iv) how do bees relate to environmental variables? v) how does the sharing of floral resources occur among bees?

MATERIALS AND METHODS

Study area

Field work was conducted in areas of the municipalities of Baturité, Guaramiranga and Mulungu located on the Baturité Massif (4° to 4° 30’ S and 38° 45’ to 39° 15’ W), northeast of the State of Ceará (Gomes 1978, Souza et al. 1994, Souza 1997) (Fig. 1).

The other geoenvironmental aspects are in agreement with the literature cited in Lima-Verde et al. (2014). In this context, it is worth mentioning that the field work was carried out exclusively at the immediate edges of the forest fragments, the edges receiving the designations F1, F2, F3 and F4. F1 and F2 (municipality of Guaramiranga); F3 (municipality of Mulungu); and F4 (municipality of Baturité). In Table I, the denominations of local forest types were abbreviated to fodm (dense ombrophilous forest) and fedm (seasonal deciduous montane forest).

Bee sampling

The procedure for bee sampling was based on the standardized methodology of Sakagami et al. (1967), with modifications according to local circumstances. Bee samplings were performed once in a month during 18 months, from March 2008 to August 2009 in all four forest fragment edges. Bees were sampled from 7:00 am to 5:00 pm, with the transects inspected in two directions, twice in the morning and twice in the afternoon, totaling 40 hours per month of
collection effort in the four areas and 640 hours in the period. The collection of bees was carried out using entomological nets and occurred predominantly in herbaceous and shrubby plants and, more rarely, in arboreal specimens up to six meters high, as well as in entrances of the nests. In groups of herbaceous species and in shrub specimens, the collection time of the bees was about five minutes for each group and for each specimen. In the trees, this procedure occurred during 20 minutes, and the entomological net, in this case, was equipped with an extensible pole to reach the tree’s canopy.

The bees captured were killed in lethal vials containing ethyl acetate and then transferred to suitably labeled individual vials. In the laboratory, they were selected by morphospecies and identified according to Silveira et al. (2002) and Michener (2007), and part of the material was sent to experts for confirmation and identification. Material representative of the collections is deposited in the collection of the Bee Laboratory, Department of Animal Sciences, in the Federal University of Ceará.
An Acad Bras Cienc (2020) 92(Suppl. 2) e20181303 4 | 13

**Data analysis**

Data were organized in matrices of abundance in which the columns corresponded to the species of bees and the rows to the monthly collections. For each edge, a matrix was constructed to evaluate the parameters to be studied. The species richness in the four edges was estimated through the calculations of the species accumulation curve (collector curve), according to Gotelli & Colwell (2001). In this case, we used the Chao 2 and first order Jackknife richness estimators.

Similarity in meliponini species between edges was evaluated using the Bray-Curtis similarity coefficient and the grouping analysis (Unweighted Pair Group Method with Average - UPGMA) (Magurran 2011). These data were also used for an evaluation of the effects that the distances between edges, relief slopes, plant typologies and altitudes between edges can have in the approximation or distancing of these areas.

**Table I.** List of meliponini bees associated to the sampling sites F (Edge), to the number of species of plants visited (Nepv) and to the respective vegetation typology (Vegetation) in the Baturité Massif, State of Ceará. M01-M20 (meliponini from 01 to 20), # (collection in the nest), * (new records), fodm (dense ombrophilous forest), fedm (seasonal deciduous montane forest).

| Species | Edge | Nepv | Vegetation |
|---------|------|------|------------|
| M01. *Cephalotrigona capitata* (Smith, 1874) | F1, F4 | 3 | fodm, fodm |
| M02. *Frieseomelitta doederleini* (Friese, 1900) | F2 | 3 | fedm |
| M03. *Frieseomelitta francoi* (Moure, 1946) * | F3 | 1 | fedm |
| M04. *Frieseomelitta varia* (Lepeletier, 1836) | F1, F3 | 5 | fodm, fedm |
| M05. *Geotrigona* sp. | F4 | 1 | Fodm |
| M06. *Lestrimelitta cf. tropica* Marchi & Melo, 2006 * | F2 | # | fedm |
| M07. *Leurotrigona* sp. | F3 | 1 | fedm |
| M08. *Melipona (Mechmelia)* aff. *rufigentris* Lepeletier, 1836 | F1, F3 | 8 | fodm, fedm |
| M09. *Nannotrigona* sp. | F1, F2, F3, F4 | 9 | fodm, fedm, fedm, fodm |
| M10. *Oxytrigona tataira* Smith, 1863 * | F3, F4 | 5 | fedm, fodm |
| M11. *Partamona ailyae* Camargo, 1980 * | F1, F2, F3, F4 | 2 | fodm, fedm, fedm, fodm |
| M12. *Plebeia aff. flavocincta* (Cockerell, 1912) * | F3 | 2 | fedm |
| M13. *Plebeia* sp. | F1, F2 | 1 | fodm, fedm |
| M14. *Scaptotrigona* sp. 1 | F1, F2, F3, F4 | 15 | fodm, fedm, fedm, fodm |
| M15. *Scaptotrigona* sp. 2 * | F4 | 1 | fodm |
| M16. *Scaptotrigona* sp. 3 (sp. nov.) * | F1, F3 | 1 | fodm, fedm |
| M17. *Trigona fulviventris* Guérin,1837 | F1, F3, F4 | 39 | fodm, fedm, fodm |
| M18. *Trigona fuscipennis* Friese, 1900 | F2, F3, F4 | 3 | fedm, fedm, fodm |
| M19. *Trigona spinipes* (Fabricius, 1793) * | F1, F2, F3, F4 | 51 | fodm, fedm, fedm, fodm |
| M20. *Trigonisca pediculana* (Fabricius, 1804) | F2 | 1 | fedm |
regarding the similarity of the melipofauna. The Bray-Curtis coefficient of similarity and UPGMA were also used to investigate the sharing of floral resources among bees.

RESULTS

Bee species richness

Sampling of stingless bees collected 1,346 specimens of 20 species distributed in 12 generic taxa (Table I). The most species-rich genera were *Frieseomelitta*, *Scaptotrigona* and *Trigona*, each with three species.

Samplings per edge corresponded in F1 to 350 individuals, ten species and eight genera; in F2, to 256 individuals, nine species and eight genera; in F3, 436 individuals, 13 species and nine genera; and in F4, to 304 individuals, ten species and seven genera (Table I). The analysis of the collector curve suggests that, with the exception of the F4 edge, the other areas reached sampling sufficiency (Fig. 2). In this case, the estimation of the number of bee species of the richness estimators did not show a discrepancy between the number of species collected and the estimated number of species for F1 (Chao = 10.12, Jackknife 1 = 10.94), F2 (Chao = 8, Jackknife 1 = 8) and F3 (Chao = 13.16, Jackknife 1 = 13.94), therefore, there was sampling sufficiency for these edges. However, there was discrepancy between these data for F4 (Chao = 14.25, Jackknife 1 = 12.83).

In addition to the 12 species of meliponini bees recorded by Ducke (1908, 1911), eight new records (*Frieseomelitta francoi*, *Lestrimelitta cf. tropica*, *Oxytrigona tataira*, *Partamona ailyae*, *Plebeia aff. flavocincta*, *Scaptotrigona* sp. 2, *Scaptotrigona* sp. 3, sp. nov., *Trigona spinipes*) were made for the Baturité Massif. Among these species, as a new species, *Scaptotrigona* sp. 3 (sp. nov.) (Table I).

Figure 2. Monthly accumulation curve representing the effort of collecting meliponini bees in the edges of four forest fragments located in the Baturité Massif, State of Ceará.
Abundance of bees
In the evaluation of the absolute abundance of the stingless bees studied (Fig. 3), six species stood out: M19 (Trigona spinipes), M17 (Trigona fulviventris), M14 (Scaptotrigona sp. 1), M18 (Trigona fuscipennis), M09 (Nannotrigona sp.) and M11 (Partamona ailyae), the first two considered the dominant species.

Similarity of bees
All the areas presented similarities above 30% in the composition of bee species. The edges F3 x F4 were the most similar, with a similarity of 64.15%, also emphasizing the edges F1 x F2 with a lower limit value of 31.14% (Table II). The edge F2 (Fig. 4) was the most distinct in relation to its fauna of meliponini bees.

Sharing floral resources between bee species
The similarity analysis representing the affinity of the meliponini bee species for the same plant species (niche overlapping) revealed the formation of five distinct groups, considering a minimum similarity of 30% (Fig. 5). These groups involved 15 (75%) out of the 20 species of bees studied, where it was possible to distinguish clusters whose similarity ranged from 0 to 93.75%. The most representative affinity was between M01 and M15 (C. capitata and Scaptotrigona sp. 2), involving the latter percentage value.

DISCUSSION
The results of the collector curve showed that the collected material had a good representativeness in meliponini bee species for the conditions of the Baturité massif. Generally, in the inventories of Apoidea in Brazil the number of occurrence of species of stingless bees has been considered low in several ecosystems. In areas of savannah-steppe (caatinga of the arid region, sensu IBGE 2012), for example, this number has not exceeded 11 species (Martins 1994, Aguiar & Martins 1997, Viana 1999, Zanella 2000, 2003, Aguiar 2003, Aguiar & Zanella 2005, Batalha Filho et al. 2007). In different types of savanna (cerrado), grassy-woody steppe (clean field), semi-deciduous seasonal lowland forest (restinga) and ombrophilous forest (Atlantic forest), bee surveys recorded a maximum of only six species (Faria-Mucci et al. 2003, Locatelli et al. 2004, Gonçalves & Melo 2005, Viana & Kleinert 2006, Milet-Pinheiro & Schlindwein 2008, Siqueira et al. 2012). However, in the savanna (cerrado), Nogueira-Ferreira & Augusto (2007) recorded 18 species and, in the cerrado–Amazon transition

Figure 3. Absolute abundance of meliponini bee species registered in the Baturité Massif, State of Ceará. M01–M20 (meliponini from 01 to 20) see Table I.
area, Santos et al. (2004) recorded 20 species. Outside the Brazilian territory, in an altitude tropical forest in Costa Rica, Brosi (2009) also recorded 20 species of meliponini bees.

According to Zanella & Martins (2003), in the group Apiformes, the number of species per genus is almost always low, mainly in the caatinga, and this characteristic for the meliponini also does not escape the rule. These authors also argue that the low species richness of stingless bees found in these censuses may be associated with the local extinction of several species, as a consequence of the effects of habitat fragmentation. Some factors may contribute to this situation, among which are: reduced genetic diversity, caused by population reduction (Kerr & Vencovsky 1982); the lack of trophic resources in general, and especially those that “stimulate” the food and storage dynamics of these products by the colonies, as would be the case of plant species with mass flowering (Bawa 1980, 1990, 1994, Ramalho 1998, Monteiro & Ramalho 2010); and the lack of substrate for nesting, especially those related to arboreal cavities, where most species of meliponini bees establish their colonies (Samejima et al. 2004).

The results of absolute abundance revealed the importance, in order of magnitude, of the species *Trigona spinipes*, *Trigona fulviventris*, *Scaptotrigona* sp. 1, *Trigona fuscipennis*, *Nannotrigona* sp. and *Partamona ailyae*. The dominant group, *T. spinipes* and *T. fulviventris*, is common in the Baturité Massif. The first species has a wide geographical distribution in this mountainous area and the second one occupies only the most humid environments at altitudes generally above 600 m. Both present colonies with large numbers of individuals that are generalists in the use of local trophic resources. In generic groups, such as *Trigona* and *Scaptotrigona*, some species generally present populous colonies that stand out for their ability in food collection and storage procedures. These species therefore have a generalist behavior and are widely distributed in their nesting environments (Roubik 1982, Pacheco Filho et al. 2015).

The activity of *T. spinipes* in flowers of the various types of the Brazilian vegetation and its

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Table II. Similarities (Bray-Curtis Coefficient) of the meliponini fauna between edges (F) related to distances between edges (Distance), mountain slopes (Slope), vegetation typologies (Vegetation) and altitudes (Altitude), in the Baturité Massif, State of Ceará. Win (Windward), Lee (Leeward), fodm (dense ombrophilous forest), fedm (seasonal deciduous montane forest).

| Edge         | Similarity (%) | Distance (km) | Slope  | Vegetation | Altitude (m) |
|--------------|----------------|---------------|--------|------------|--------------|
| F1 x F2      | 31.14          | 3.23          | Win x Lee | fodm x fedm | 1015-1114 x 670-690 |
| F1 x F3      | 57.35          | 9.01          | Win x Lee | fodm x fedm | 1015-1114 x 780-790 |
| F1 x F4      | 62.81          | 3.96          | Win x Win | fedm x Fodem | 1015-1114 x 660-680 |
| F2 x F3      | 46.96          | 5.79          | Lee x Lee | fedm x fedm | 670-690 x 780-790 |
| F2 x F4      | 41.73          | 10.27         | Lee x Win | fedm x fodm | 670-690 x 660-680 |
| F3 x F4      | 64.15          | 12.36         | Lee x Win | fedm x fodm | 780-790 x 660-680 |
participation as a species of generalist preference for these resources has already been evaluated by authors such as Laroca (1970), Cortopassi-Laurino & Ramalho (1988), Wilms et al. (1996) and Pacheco Filho et al. (2015). As for the abundance, the importance of this species has been observed in bee censuses in ecosystems such as savanna, savannah-steppe, ombrophilous forest and semideciduous seasonal lowland forest (Viana et al. 1997, Lorenzon et al. 2003, Locatelli et al. 2004, Aguiar & Zanella 2005, Viana & Kleinert 2006, Milet-Pinheiro & Schlindwein 2008). Likewise, research with *T. fulviventris* also revealed its generalist habit in the use of food resources and its abundance in more humid environments (Sierra & Pardo 2008, Oliveira et al. 2009, Pacheco Filho et al. 2015).

The conditions of habitat degradation in immediate edges of fragments of various types of vegetation have particular environmental characteristics and were poorly evaluated until now, both in relation to fauna and flora. This fact has made it difficult, in particular, to investigate bees (Brogi et al. 2008). In this sense, the whole dynamics of biological interactions undergoes deep changes that mainly affect the presence of stingless bees. In particular, this group of Apoidea depends on well-preserved fragments with abundant and seasonal trophic resources, as well as environments with adequate levels of relative humidity (Heithaus 1979, Bierregaard et al. 1992, Murcia 1995, Antonini et al. 2003, Brogi et al. 2008, Brogi 2009).

The similarity between species of bees in these areas can therefore generate different interpretations due to these multiple influences. In this case, the preference that these species have for a given habitat is one of the preponderant factors, although several species have a ample spectrum of occupation in different environments, especially when these are connected by almost imperceptible continuus in the geographic space. In this context, the results suggest that the high similarity of the bee
fauna between the different fragments studied, according to the environmental parameters listed in Table II, can be a consequence of the high plasticity that these bees present in the occupation of the different local environments and where they use, as source of resources, various plant species. In fact, Meliponini bees were already registered as a group capable of using floral resources of many species of different botanical families (Pacheco Filho et al. 2015).

Several factors are associated with the sharing of floral resources by stingless bees. In this sense, one major factor for the performance of this group of bees in the foraging processes is the presence of plant species with differentiated flowering strategies, especially those species that show mass flowering (Heithaus 1979, Mantovani & Martins 1988, Ramalho 1998, 2004). A second reference directly includes the trophic habits of these bees, where the generalist feeding behavior is highlighted (Laroca 1970, Roubik 1982, Cortopassi-Laurino & Ramalho 1988, Wilms et al. 1996). Some plant species of the Baturité Massif are classified according to the flowering strategies outlined above, thus standing out for the importance in the supply of food resources to the local Meliponini species (Lima-Verde...
et al. 2014, op cit.). Among these, *Spermacoce verticillata* (Rubiaceae), *Libidibia ferrea* (Fabaceae), *Serjania lethalis* (Sapindaceae), *Vernonanthura brasiliana* (Asteraceae), *Cynophalla flexuosa* (Capparaceae), *Senna splendida* (Fabaceae) and *Wedelia scaberrima* (Asteraceae) were highlighted, some of which present the flowering strategies discussed above.

*S. verticillata*, for example, was the species that most attracted bees, 12 (60%) out of the 20 species of meliponini bees, possibly presenting a great adaptive plasticity in the four edge areas (Lima-Verde et al. 2014, op cit.). This species is arranged in concentrated patches of individuals as representing, on the whole, an individual with massive flowering. Studies such as Wilms et al. (1996), Gonçalves & Melo (2005) and Viana et al. (2006) refer to this species as one of the resources sought by several species of bees in different ecosystems in Brazil.

**CONCLUSIONS**

The record of 20 species of meliponini bees for the Baturité Massif, with some species highly abundant, evidences to some extent the existence of forest fragments and areas of temporary matrix edges with conditions to maintain this rich bee fauna, both biologically and ecologically active.

The results show that the two plant typologies are generally important for the different species of local Meliponini bees, both informing the exclusiveness of a vegetation type for a particular species and relating the use of both environments to individual species. This allows, in a way, the understanding of part of the ecology of this group of bees in this mountain range.

In the current conditions of these remaining forest fragments, their immediate edges are relevant as environments that guarantee, temporally and spatially, complementary food resources for the local meliponini fauna. However, this situation suggests that inside these fragments there is a lack of floral resources, mainly from tree species, which are characterized by attractive blooms for these bees.

Otherwise, as biological indicators, this knowledge helps in the necessary decision-making, when managing these environments as a function of these bees, as well as facilitating the most appropriate management of colonies under a rational exploitation regime by beekeepers.

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LWLV and BMF prepared the study design and performed data collection, AJSPF carried out the data analysis and the three authors wrote and reviewed the manuscript.

An Acad Bras Cienc (2020) 92(Suppl. 2) e20181303 13 | 13