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Article

The bee fauna (Hymenoptera, Apoidea) in Cerrado and Cerrado-Amazon Rainforest transition sites in Tocantins state, Northern Region of Brazil

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Abstract: Two sites located in Tocantins State, Brazil, were selected for the bee's community survey. One of them was mostly covered by Cerrado vegetation and the other one is located in the Cerrado-Amazon Rainforest ecotone. Five expeditions were performed in each site throughout a 12-month period, between 2019 and 2020. The total of 771 bee specimens were collected and distributed into four families. Apidae presented the greatest species abundance and richness, it was followed by Halictidae, Megachilidae and Andrenidae, respectively. *Trigona pallens* (Fabricius) (Apidae) was the species presenting the greatest abundance in both sites, it totaled 118 specimens, which corresponded to 26.9% of the total abundance of individuals belonging to tribe Meliponini. In general, the community presented several species with few individuals and few species with many individuals. Bee collections were performed by using three different methodologies, among them one finds sampling based on the entomological net method, which allowed collecting the largest number of both individuals and species in comparison to the other used methods. Based on the frequency and abundance classes, only few species were classified as very frequent (VF) and very abundant (VA) in both sites based on the frequency and abundance classes. Most species were constant (W) in both regions, and there was a small number of dominant species (D); moreover, more than 70% of the sampled species were considered accidental (Z). According to the present study, either Cerrado or Cerrado-Amazon Rainforest studied sites presented higher species richness than other sites in these biomes sampled in Brazil.
Keywords: *Apidae; Anthophila; biodiversity; faunal indices; species richness.*

A fauna de abelhas (Hymenoptera, Apoidea) em áreas de Cerrado e de transição Cerrado-Floresta Amazônica no estado do Tocantins, Região Norte do Brasil

Resumo: Duas áreas localizadas no Estado do Tocantins, Brasil foram selecionadas para o levantamento da comunidade de abelhas, uma área com vegetação predominante de Cerrado e outra em ecótono Cerrado-Amazônia. Durante cinco expedições em cada área em um período de 12 meses, entre os anos de 2019 e 2020 foram coletados 771 espécimes de abelhas, distribuídas em quatro famílias: Apidae, com a maior abundância e riqueza de espécies, seguida de Halictidae, Megachilidae e Andrenidae. *Trigona pallens* (Fabricius) (Apidae) foi a espécie com maior abundância em ambas as áreas, totalizando 118 espécimes, o que correspondeu a 26,9% da abundância total de indivíduos da tribo Meliponini. De um modo geral, a comunidade apresentou muitas espécies com poucos indivíduos e poucas espécies com muitos indivíduos. A metodologia de coleta com uso de rede entomológica permitiu a coleta do maior número de indivíduos e de espécies em relação a outros três métodos utilizados. Em ambas as áreas, poucas espécies foram classificadas como muito frequentes (MF) e muito abundantes (MA), de acordo com as classes de frequência e de abundância. Também para ambas as áreas, grande parte das espécies foram constantes (W) e um baixo número de espécies dominantes (D), com mais de 70% delas consideradas acidentais (Z). O presente estudo revelou que tanto o Cerrado como a área de transição Cerrado-Floresta Amazônica apresentou alta riqueza de espécies em comparação com outras áreas destes biomas amostradas no Brasil.
Palavras-chave: *Apidae; Anthophila; biodiversidade; índices faunísticos; riqueza de espécies.*

Introduction

Bees (Hymenoptera, Anthophila) are among the most important pollinator insect groups worldwide, mainly in temperate and tropical regions. This taxonomic group is considered to be of great diversity, and the last census showed an apifauna of approximately 20,600 valid species distributed around the globe (Orr et al. 2021). However, estimates shows that there are many other species yet to be described, mainly in the Neotropical region. When it comes to the national apifauna, about 2,000 species were recently recognized as valid for Brazil (Ascher & Pickering 2020, ITIS 2021), distributed into the following families: Andrenidae, Apidae, Colletidae, Halictidae and Megachilidae (Michener 2007, Moure et al. 2012). However, other estimate predicted a bee fauna of approximately 3,000 bee species in Brazil (Silveira et al. 2002).

A good example representing the incredible biodiversity of bees in Brazil is the stingless bees (tribe Meliponini, corbiculate Apidae), one of the best-known tribes due to the interest in their beekeeping (meliponiculture) once they are eusocial and can be managed for honey production (and other products) and crops pollination. For this tribe, 244 species were recognized as valid in 2014, these distributed into 29 genera, and also computed approximately 90 "morphospecies" already recognized by different authors (assumingly they are new species) (Pedro 2014). Among the Meliponini species registered for the Brazilian fauna, approximately 90 species are endemic and correspond to 20% of the estimate for Neotropical stingless bee species (Pedro 2014). It is also important to point out that, after 2014, various authors have described several other species of Meliponini of different genera for Brazil, as for example, for the genera, *Trichotrigona* (Pedro & Cordeiro 2015), *Scaura* (Nogueira et al. 2019), *Paratrigona* (Oliveira et al. 2020), *Scaptotrigona* (Nogueira et al. 2022b; Engel 2022a,b,c) and *Tetragona* (Nogueira et al. 2021, 2022a), however, few report only a few species occurring in Tocantins (Nogueira et al. 2019, 2021, 2022a).

Another tribe worth mentioning is Euglossini tribe (corbiculate Apidae), popularly known as orchid bees, once, besides being essential pollinators for the Orchidaceae family, the males of this tribe collect aromatic substances from orchid flowers for females' attraction (Dodson 1962, Dressler 1967, 1968a, 1968b, Williams 1982, Williams & Whitten 1983, Whitten et al. 1989, 1993, Rebêlo & Garófalo 1997, Eltz et al. 1999, 2003, Roubik 2004); the males stored the aromatic substances in the tibial organ of the hind legs (which contains a spongy tissue), which makes the hind tibiae of these insects quite broad. Euglossini are mostly Neotropical, represented by about 250 species, 128 of which are registered in Brazil (Ascher & Pickering 2022). These bees are well known for their beauty, which includes the metallic luster of many species, and the males are easily collected with the use of aromatic substances (Campos et al. 1989, Nemésio & Morato 2006).

Still regarding to the bee's families with great diversity, the Halictidae family, one of the most diversified in Brazil, whose species attract attention by its beautiful colors green, blue, reddish, or even black metallic luster, like the bees of the Euglossini tribe, little is known about the fauna of the Tocantins State. Bees from this family have different levels of sociability, ranging from solitary to subsocial. The Augochlorini tribe is one of the most diverse in the family, and well represented in tropical forest areas, with its most remarkable diversity in southern Brazil and Argentina. Recently, from this tribe, the genus *Augochlora* Smith, 1853 was revised for species from Northeast and South Brazil (Lepeco & Gonçalves 2020a, 2020b), with remaining gaps in knowledge about the fauna of Tocantins.

The main ecological relevance of bees is related to the ecosystem service they provide, which is expressed by their role in pollinating angiosperms, which is a biological phenomenon vital in natural sites and also in several cultivation sites (Garibaldi et al. 2016). Pollination is one of the most important mechanisms to maintain plant genetic variability and to conserve biodiversity and general life on the planet (Thakur et al. 2012). However, floral rewards provided by plants during pollination are not the only requirement by bees to occupy and persist in the environment. They also need nesting substrates and favorable climatic conditions, among other essential factors, either in natural environments or in cultivated sites (Giannini et al. 2017, Ollerton 2017).

From the ecological point of view, knowing of taxonomic and functional diversity of bees is essential for better understand ecosystems' functioning in order to ensure biodiversity conservation, as well as food security and human subsistence (Borges et al. 2020, Campbell et al. 2022). Studies focused on conserving bees require taxonomic and biological knowledge to determine these pollinators' important species in native forests in different regions (Thakur et al. 2012).

Apifauna surveys can be considered the main sources of bees' records on their host plants (the ones providing records of food and other used resources), since they allow observation and data collection in the field, as well as broadening the knowledge of species taxonomy, interactions, and geographic distribution. Furthermore, they are important tools to evaluate pollinators' local abundance and richness, as well as enable better understanding these insects' geographic and temporal variations by taking into account important for the proposition of new conservation actions (Oliveira et al. 2020).

Cerrado is the second biggest biome in Brazil, and this is the place where bees stand out as the main pollinators (Gottsberger & Silberbauer-Gottsberger 2006). Previous studies suggest that Cerrado's apifauna presents greater species richness and higher abundance than other biomes. Species composition in Cerrado areas can present high variation due to the floristic composition (Silveira & Campos 1995). Furthermore, bee species' richness can be even higher in ecotone regions between Cerrado areas and the Amazon Rainforest, and important concerning the limits distribution in any of the biomes taken into account in the transition site. A good example of it is the study carried out in this transition area type, which reported that the bees' community held 15 species endemics to the Amazonian region, one species endemic to Cerrado, and 27 species common to both the Amazon Rainforest and Cerrado (Almeida et al. 2019).

The apifauna in a Cerrado-Amazon Rainforest ecotone site and in a Cerrado area were surveyed in order to allow to understand the bee's community in Tocantins State (Brazil). Tocantins' territory is featured by 92% Cerrado cover and 8% Amazon Rainforest, the states' central region is featured by vegetation cover presenting Cerrado Seasonal Forest phytoecological environments (Haidar et al. 2013), whereas there is an ecotone zone (Ecological Tension Zone) to the West of the state, between the Cerrado and Amazon rainforest biomes (Marimon et al. 2006).

Knowing the apifuana of a given region is the main tool to get to know local pollinators and to define suitable strategies to explore and conserve biological resources in plant and animal communities (Matheson et al. 1996, Proctor et al. 1996). Besides, knowing the apifauna is a way to get significant information about bees' diversity and population density patterns, seasonal and geographic variations, as well as the period of more significant foraging activity (Oliveira & Campos 1995). Knowing the apifauna of a site in a certain area helps broadening the existing knowledge about it, because such a knowledge produces data on bees' diversity and geographic distribution (Silveira & Godínez 1996).

There are several studies about bee communities in Cerrado showing a relatively large number of species in this Brazilian biome (Faria & Silveira 2011, Pires et al. 2013, Lima & Silvestre 2017, Roel et al. 2019). Nevertheless, with respect to Cerrado in Tocantins State, we only find the register of one study about bees' diversity in the state. It was carried out in a Cerrado-Amazon Rainforest transition site in North Tocantins state: it recorded 83 species distributed into 38 genera (Santos et al. 2004).

Therefore, there is a huge gap in knowledge about bee fauna in this Brazilian region. According to Santos et al. (2004), the bee community in this region is little diversified in comparison to the expectations, since they have assessed an area located in a zone of great environmental and biological diversity. However, the collection method adopted by them was based on collecting bees on flowers with entomological net, based on the methodology described by Sakagami et al. (1967). Although this technique is more often used and recommended for bee surveys given the great sample diversity provide by it, mainly when the records of visited flowers are also surveyed, its performance fully depends on the collectors' skills. Thus, previous studies pointed out better results for the number of sampled species when multiple methods are used as collection methodology to complete the method based on using entomological nets (Moreira et al. 2016, Sircom, et al. 2018).

Passive traps, such as Colored Water Traps (ARCAs or Pantraps), stand out among such multiple sampling methods often used to collect bees. These traps consist of colored plastic plates (often blue, yellow and white) that reflect ultra-violet (UV) rays simulating flowers for bee attraction (Campbell & Hanula 2007). Another passive method, which was specifically developed for bee tribe Euglossini, consists in odor-baited traps, since male bees belonging to this tribe are easily attracted by synthetic composites that mimic flower essences (Nemésio 2012, Nemésio & Vasconcelos 2014). Malaise traps work by intercepting insects (in general) at flight, mainly Diptera and Hymenoptera; they are also efficient in collecting bees (Cruz et al. 2009).

Only few standardized surveys applied to Apoidea were carried out in the Cerrado biome and in Cerrado-Amazon Rainforest transition sites. Most of the publish studies only take into account the diversity of specific tribes, such as Meliponini or Euglossini (Roel et al. 2019, Oliveira-Junior et al. 2015). Besides, most surveys only use one collection method (Santiago et al. 2009, Roel et al. 2019, Santos et al. 2004), and only few of them use more than one collection method (Almeida et al. 2019, Ferreira et al. 2019).

If one takes into consideration that there are only few studies carried out in the Cerrado area in the Midwestern Brazilian region and in the Cerrado-Amazon Rainforest transition sites, the aims of the present study were to be pioneer in describing the bee community composition, its richness and abundance in Cerrado sites, in Tocantins State, as well as to broaden the knowledge on the bee fauna in Cerrado-Amazon Rainforest transition site in the assessed state, in order to contribute the knowledge on Brazilian bees biogeography.

Materials and Methods

1. *Study sites*

The present study was carried out in two natural sites in Tocantins State (Brazil): (i) an area in the Private Natural Patrimony Reserve, at Canguçu Research Center (Canguçu RPPN), which is located in Pium County, Western Tocantins State, 135 km away from Palmas City (Figures 1A and 2); and (ii) an area in Lajeado State Park, also known as PEL, which is located in the state's Center-South region, 32 km away from Palmas City (Figures 1B and 3). Canguçu RPPN has total area of 60.10 ha (9°58'45.31''S, 50°2'12.44''W) and is located between two Conservation Units – Araguaia National Park and Cantão State Park (Brasil 2004). The area housing PEL covers 9,931 ha, it is evenly set on the square between parallels 10°00'and 10°11' South, between meridians 48°10' and 48°19' West. PEL area is surrounded by Serra do Lajeado Environmental Protection Area (EPA) (Naturatins, 2005).

Climate in both regions is classified as Aw, of the tropical type, with dry Winter, based on Köppen's classification (1948). They present rainy season in Summer, from November to April, and dry season in Winter, from May to October. Mean annual temperature is close to 26.7 °C and annual rainfall is higher than 750 mm – it can reach 1,800mm.

Canguçu RPPN is located in the Cerrado-Amazon Rainforest ecotone macro-region (Haidar et al. 2013). It is mainly covered by Cerrado vegetation, with flower formations (Riparian Forest) and Seasonal Semideciduous Forests (*Torrão* Forest) (Naturatins 2005). There are two trails in this reserve's area, they were used by the research team; each one of them was 1,000m long, approximately, in a straight line: one trail on vegetation typical to Seasonal Semideciduous Forest, with large-sized trees; the other trail was covered by vegetation typical to Cerrado and it was located on Javaés River riverbanks (Figures 1A and 2). There was a 1,000m pre-existing trial in PEL (its line was little sinuous); it was also herein used (Figures 1B and 3). This trial is inserted in Cerrado vegetation cover and crosses four Phytophysiognomies: Semideciduous Dry Forest, *Cerradão*, Typical Cerrado and Thin Cerrado. The study was authorized by State and Federal Environmental Inspection organs in both regions: Process n. 4306-2018-B and requirement n. 5883-2018 in Naturatins and register n. 62583-1 in the Biodiversity Authorization and Information System (SISBIO).

2. *Bee sampling*

Five expeditions were performed to collect bees in each of the two study sites. Three expeditions were conducted in Canguçu RPPN in the dry season (May, September and October 2019) and two ones were performed in the rainy season (March 2019 and February 2020), whereas two expeditions were carried out in PEL in the dry season (August and October 2019) and three in the rainy season (April and November 2019, and January 2020). Six (6) sampling points were established along 1000 m in each trail, in both areas distance between the sampling points in each trail changed, depending on the presence of glades where traps of the three passive sampling methods could be installed. Traps of one of the three passive sampling methods were installed at each sampling point of the trail: Pantraps, Odor-baited traps and Malaise Trap (Figure 4). The three sampling methods in the three points of each trail were randomly distributed between expeditions (Figure 4). The entomological net was used as the fourth bee sampling method (active). The four methods are described below.

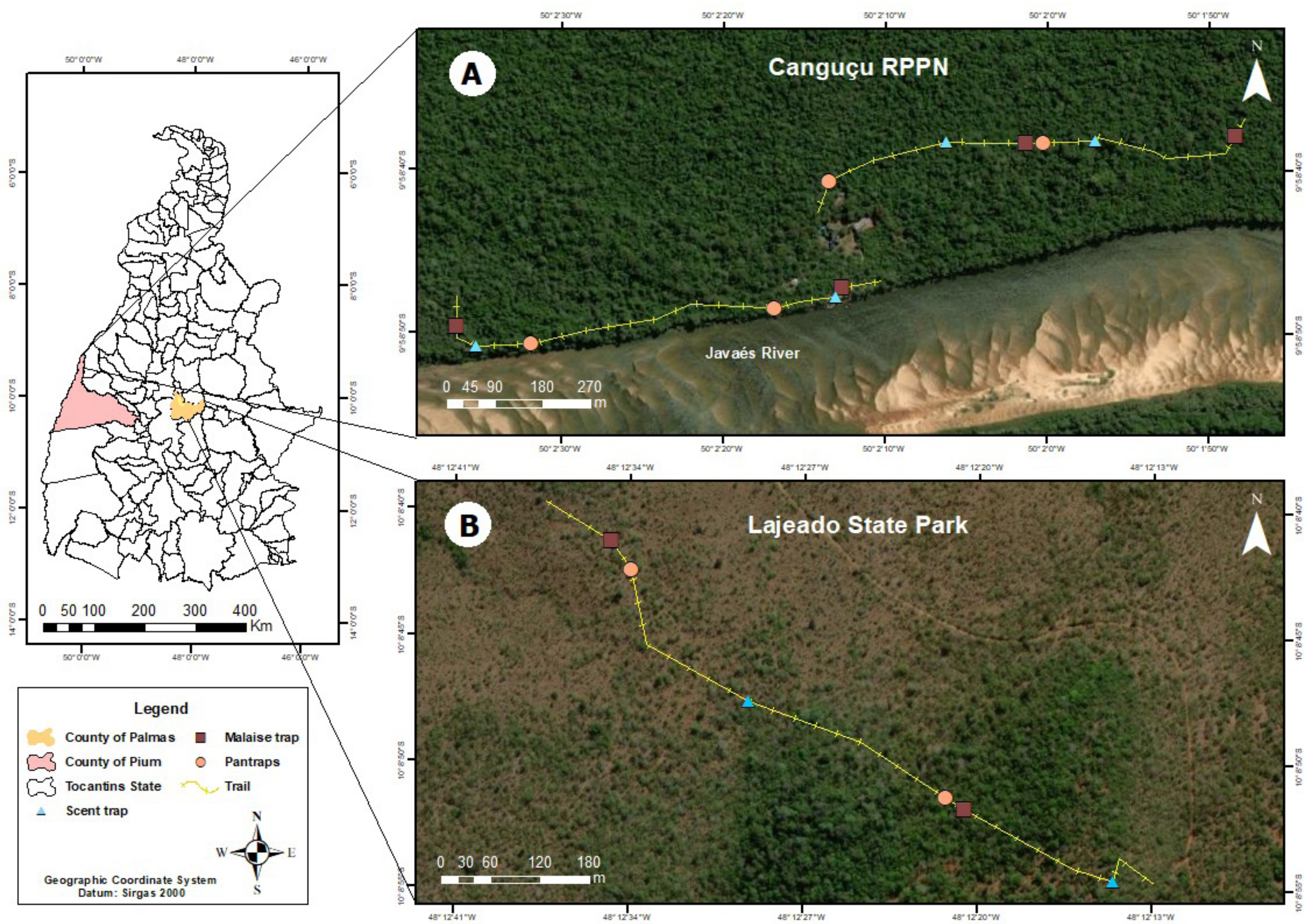

Figure 1. Location of both Canguçu Research Center (Canguçu Private Natural Heritage Reserve - RPPN) (A) and Lajeado State Park (PEL) (B), where the bee survey was performed.

Colored water traps (ARCAs or Pantraps): two sets of plates-traps were installed per trail, each set had three plates, one of each color (blue, yellow and white; plates were10cm in diameter and 4.5 cm in height), without UV. Plates were installed close to the vegetation, suspended 1m from the ground, distant 5m from each other; they were filled with approximately 150 ml of water and 4-5 drops of detergent. The two sets of plates remained in the field between 06:30 am and 04:30 pm, for two consecutive days – they were removed at the end of each day (Figures 4A and 4B).

Odor-baited traps: 2-liter plastic bottles were used for bee collection in this method, each one of them had two opposite openings in the upper half of them - necks of the same bottle type - painted in yellow and red - were fixed right on the entrance left for the bees (Figures 4C, 4D and 4E). A cotton swab with few drops of one of three different essences (eucalyptol, eugenol or vanillin) used to attract male Euglossini bees was introduced in the bottles. Two sets of three bottles, each one with one of the three essences, were installed in each of the two sampling points in the trails. Each bottle, of each set, was tied to the vegetation, approximately 1.5 from the ground, 5m from each other. The odor-baited traps were kept active between 06:30 am and 04:30 pm, for two consecutive days.

Malaise trap: Two trap of this kind was installed in each trail. Traps remained in the sampling points for 36 hours, and the points chosen for malaise installation were the glades presenting the largest number of flowering plants nearby (Figure 4F). The trap's collector flask was oriented towards greater luminosity sides, based on recommendations by Cruz et al. (2009).

Entomological net: this method was used to sample any bee stopped or flying over plants' flowers throughout each trail. Based on this active capture method, a pair of collectors with entomological nets crossed the assessed trails in Canguçu twice in the morning, between 06:00 and 10:00 am, and between 07:00 and 11:00 am, in PEL - the same procedure was repeated by noon, between 12:00 am and 04:00 pm, in both study sites (Figure 4G). The collected bees were immediately transferred from the net to a death chamber filled with ethyl acetate. Bee collection based on the entomological net methodology was based on Sakagami et al. (1967).

Bees captured in odor-baited traps and collected with entomological net in a daily basis were conditioned in Falcon and Eppendorf flasks, respectively – flasks were labeled with tags presenting information about collection methodology type, location and date - and stored in freezer. Bees captured by pantraps were washed in water after their collection and stored in small labeled glass flasks filled with 70% alcohol. The material stored in the Malaise-collector flasks was screened in stereomicroscope in laboratory, for specimen separation. The bees were stored in small glass flasks filled with 70% alcohol, labeled based

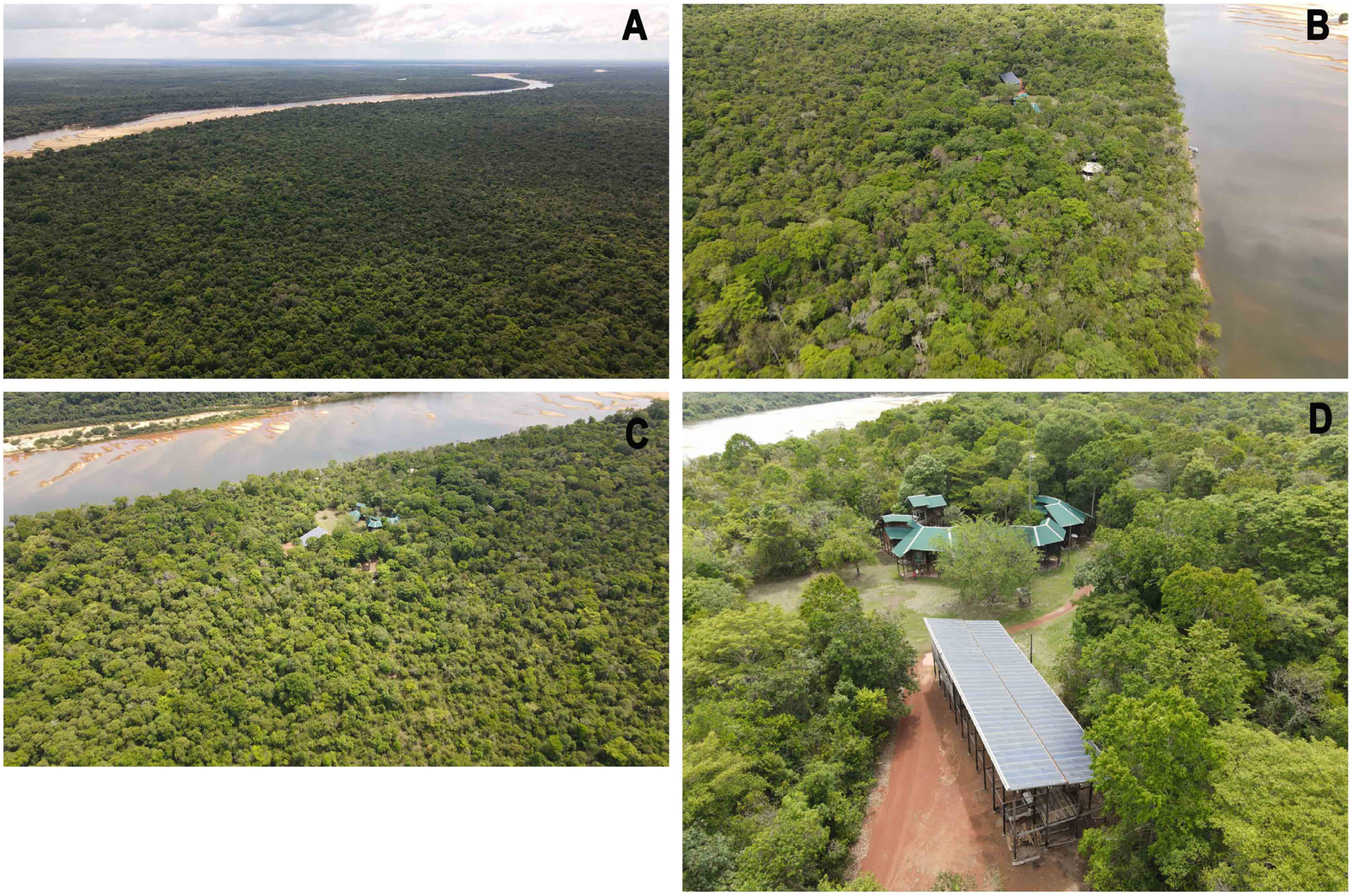

Figure 2. Perimeter of the Canguçu Research Center (Canguçu Private Natural Heritage Reserve - RPPN), where the bee survey was performed: A- general aerial view of the RPPN; B and C- aerial view of the trail near the Javaés river; D- aerial view of the trail near the Canguçu Research Center head office.

on sampling point, collecting method and sampling date. Subsequently, all bees were mounted on entomological pins, labeled and dried in drying oven at 46 °C for 72 hours. Families' and tribes' classification were based on Michener (2007), and genera on the Online Version of the Catalogue of Bees (Hymenoptera, Apoidea) in the Neotropical Region (Moure et al. 2012). Part of the collected bees' specimens was stored in the Insects Collection of the Entomology Laboratory of Federal University of Tocantins, Palmas City, Tocantins State, Brazil. Duplicates were donated to the Entomological Reference Collection of the Laboratory of Bionomy, Biogeography and Insect Systematics (BIOSIS) of the Biology Institute of Federal University of Bahia (UFBA), Ondina Campus, Salvador City, Bahia State, Brazil. The database of trustee collections is under digitization process and will soon be available in the Brazilian Biodiversity Information System (SiBBr), Reference Center for Environmental Information (CRIA) and in the Global Biodiversity Information System (GBIF).

Information on bee species' geographic distribution in the Neotropical Region was based on the online version of Moure bees' catalog (Moure et al. 2020, Camargo & Pedro 2013) and also in the recent taxonomic revision of Meliponini genera that cites the fauna from Tocantins (Nogueira et al. 2019, 2021, 2022a). And more specifically, the record of bees from Tocantins State was also based on the work by Santos et al. (2004). All species or genera recorded in the present article that are not listed in this catalog or in the publications listed above as occurring in Tocantins State were considered to be a new occurrence record in the state, and marked in table with one asterisk (Table 1).

3. *Data analysis*

Patterns presented by the bee fauna community were featured by different faunal indices: relative frequency and constancy (Silveira Neto et al. 1976), species' dominance (Kato et al. 1952), Margalef index, S abundance. Frequency classes were established for each species based on Confidence Intervals (CI) at 5% probability: little frequent (LF) = f < than the lower limit (LL) of 5% CI; frequency (F) = f within the 5%CI; very frequent (VF) = f > than the upper limit (UL) of the 5% CI. Bödenheimer classification was used for species' constancy in the collections (cited by Silveira-Neto et al. 1976) – species were considered constant (W) when their occurrence rate was equals to, or higher than50%, they were considered accessory species (Y) when their occurrence rate ranged from 25% to 50%, and they were considered accidental species (Z) when their occurrence rate was equals to or lower than, 25%. Dominance (D) of a given species was identified when the lower limit of its confidence interval (Kato et al. 1952) was higher than the reversed total number of species multiplied by 100, based on Sakagami et al. (1967).

Features were distributed into abundance classes based on the confidence interval (CI) of the number of individuals (n) at 5% and 1% significance level, based on Bicelli et al. (1989). The class limits taken

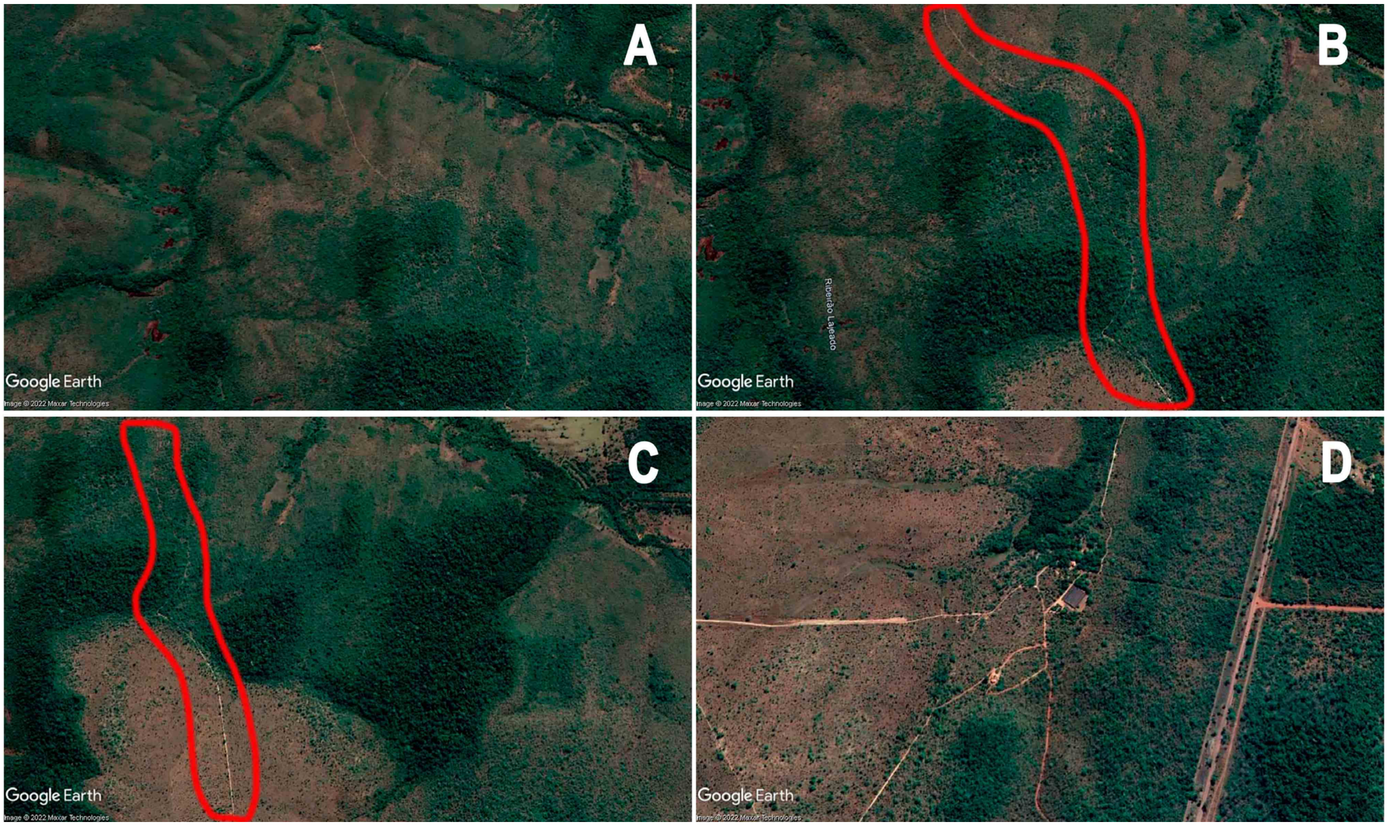

Figure 3. Perimeter of the Lajeado State Park (PEL), where the bee survey was performed. A- General view of the park and trail; B and C- Aerial view of the studied trail along the path covered; D- Aerial view of the Instituto Natureza do Tocantins (NATURATINS) administrative head office, in the Serra do Lajeado Environmental Protection Area (EPA).

into account were Rare (r) = n lower than the lower limit of the 1% CI; Disperse (d) = n between the lower limits of the 1% and 5% CIs; Common (c) = n located within the 5% CI; Abundant (a) = n located between the upper limits of 5% and 1% CIs; Very abundant (m) = n higher than the upper limit of the 1% CI. Confidence intervals for the frequency, constancy and abundancy classes, and values recorded for the F test to determine dominance were calculated in the statistic functions of Microsoft Excel, version 2013. Species that have presented the highest values in the frequency, constancy, abundance and dominance classes were considered dominant in the study sites.

Results

The total of 771 bees were sampled in both biomes. Abundance reached 400 individuals in the Cerrado-Amazon Rainforest transition site (Canguçu RPPN) and 371 specimens in Cerrado (PEL). Individuals were distributed into four families, 37 genera and 90 species. The greatest species richness was recorded in the Cerrado area (n=59), as well as the largest number of species was restricted to this area (n=40), in comparison to the Cerrado-Amazon Rainforest transition site (species richness n=50; restricted species n=32) (Table 1). Apidae was the family accounting for the largest number of genera (n= 27), species (n= 71) and individuals (n= 733) in both biomes. Meliponini formed the group presenting the highest richness and abundance (35 species; 15 genera; 434 specimens) (Table 1). *Trigona pallens* (Fabricius 1798) (Figure 5A and 5B) was the most common species in tribe Meliponini, representing 26.9% of the individuals, especially in the Canguçu area (70.9% of the collected individuals).

Although the species *Apis mellifera* Linnaeus, 1758 (Africanized polyhybrid of the Apidae family) has been observed visiting flowers in the study areas at relatively high frequency and abundance, it was not collected. As it is an introduced species (non-native), with very populous colonies, and these large numbers directly impact the dataset, the decision was taken to remove this species from the analysis for a better understanding of the native bee community.

Euglossini (orchid bees) was the second tribe with the largest number of species (n= 15) occurring in both biomes, with 252 specimens distributed into four genera, with the largest number of specimens collected in the Canguçu area (n= 168). Two species belonging to family Halictidae were sampled: *Pseudaugochlora pandora* (Smith, 1853) (Figure 6C e 6D) and *Thectochlora alaris* (Vachal, 1904) (Figure 6E e 6F), and 13 morpho-species belonging to five genera were also recorded for this family: *Augochlora* (4), *Augochloropsis* (4), *Augochlorodes* (2), *Augochlorella* (1) and *Dialictus* (2). Family Megachilidae presented the following morpho-species representatives: *Megachile* (*Pseudocentron*) sp.1, *Megachile* (*Ptilosarus*) sp.1 and *Hypanthidium* sp.1; *Megachile* (*Pseudocentron*) sp.1 was distributed in Cerrado, and *Megachile* (*Ptilosarus*) sp.1 and *Hypanthidium* sp.1were distributed in the Cerrado-Amazon Rainforest transition site. Family Andrenidae was only represented by species *Callonychium* (*Callonychium*) *brasiliense* (Ducke, 1907), which was only distributed in the transition site.

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Figure 4. Collecting methods used to bees survey in both Canguçu Research Center (Canguçu Private Natural Heritage Reserve - RPPN) and Lajeado State Park (PEL): A- Blue pantrap installed in the PEL; B- Yellow pantrap installed in the PEL; C, D and E- Odor-baited traps installed in the PEL [D- *Eulaema* (*Apeulaema*) *pseudocingulata* Oliveira, 2006 attracted to the odor-bait; E- *Eulaema* (*Apeulaema*) *nigrita* Lepeletier, 1841 attracted to the odor-bait; F- Malaise trap installed in the PEL; G- Direct collection with entomological net performed in the Canguçu RPPN.

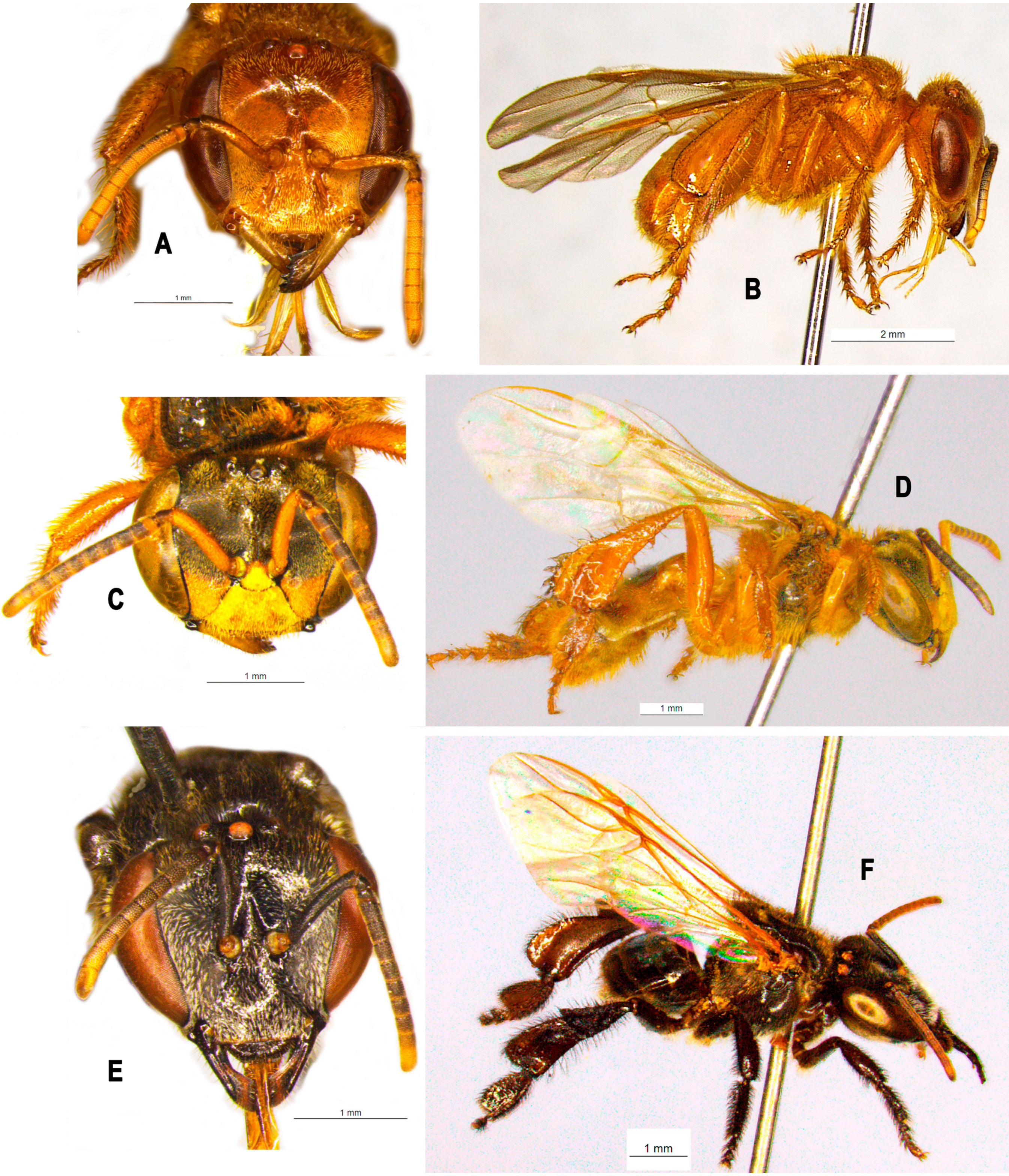

Figure 5. Meliponini (Apidae Family) species collected in the in the studied areas: A, C, E- Frontal view of face; B, D, F - Lateral profile of body. A and B- *Trigona pallens* (Fabricius 1798); C and D- *Tetragona mourei* Nogueira, 2022; E and F- *Geotrigona mombuca* (Smith, 1863).

With respect to the efficiency of the bee collection methods used, the entomological net was the method that allowed sampling the largest number of individuals and species, with approximately 57% and 67%, respectively, in comparison to the other three sampling methods (449 specimens from 60 species were sampled by this method. This method sampled 31 species, which were distributed into 10 tribes and three families in the transition site (212 specimens); 42 species were sampled in the Cerrado region, they were distributed into nine tribes and

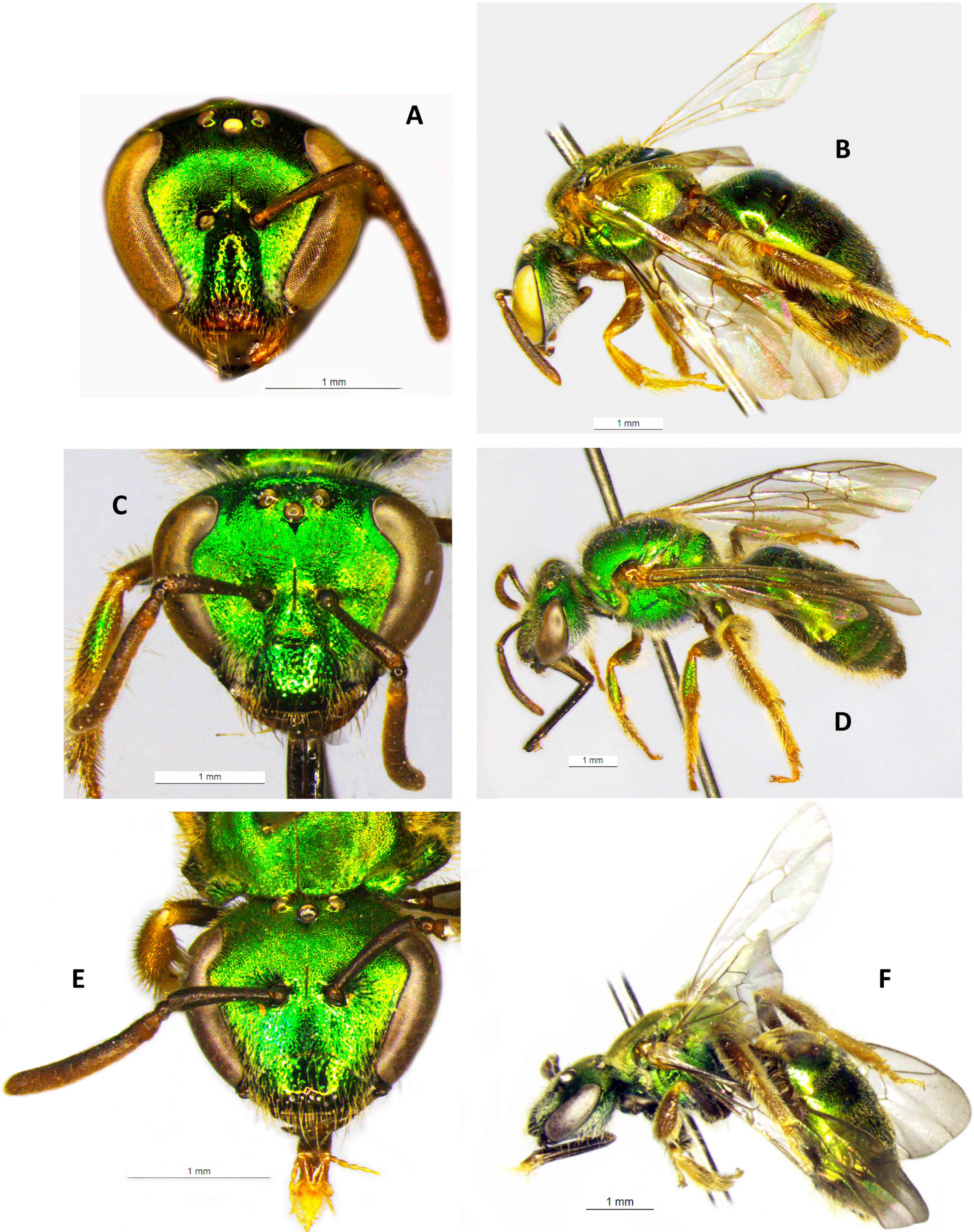

Figure 6. Augochlorini (Halictidae Family) species collected in the in the studied areas: A, C, E- Frontal view of face; B, D, F - Lateral profile of body. A and B- *Augochlorodes* sp. 2; C and D- *Pseudaugochlora pandora* (Smith, 1853); E and F- *Thectochlora alaris* (Vachal, 1904).

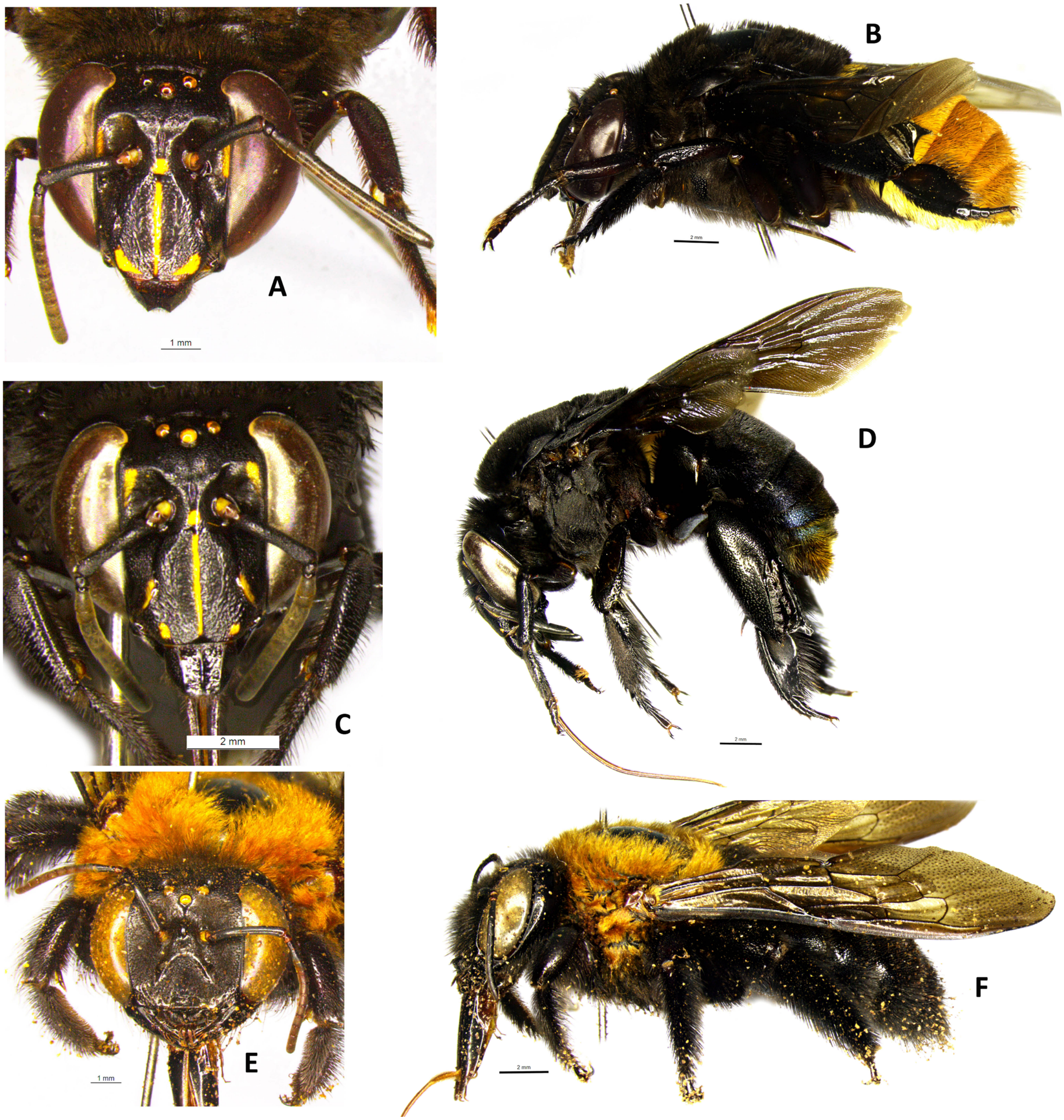

Figure 7. Euglossini and Xylocopini (Apidae Family) species collected in the in the studied areas: A, C, E- Frontal view of face; B, D, F - Lateral profile of body. A and B- *Eulaema* (*Apeulaema*) *pseudocingulata* Oliveira, 2006; C and D- *Eulaema* (*Apeulaema*) *nigrita* Lepeletier, 1841; E and F- *Xylocopa* (*Neoxylocopa*) *aurulenta* (Fabricius, 1804).

three families (226 specimens). Species belonging to tribe Meliponini in Cerrado had, at least, one of their individuals collected by the entomological net. Malaise trap was the second most efficient method in both areas (19 species were sampled by this method; 49 specimens), with 9 species represented in the transition site and 11 species in the Cerrado region (30 specimens), with emphasis on tribe Meliponini (11 species sampled; 37 specimens).

Odor-baited traps was the third most efficient method to collect bee species considering richness and the second considering abundance (19 species; n= 238 specimens collected), with 13 species in the transition site (154 specimens) and 10 species in the Cerrado area (84 specimens) (Table 2). This trap type has been signed to be specific to collect male bees belonging to tribe Euglossini, but were observed the collection of species belonging to tribe Meliponini, in both sites, and two specimens

Table 1. Number of individuals and faunal indices (FREQ=frequency, ABUN=abundance, CONS=constancy and DOMI=dominance) of bee species sampled through four methods in the Cerrado-Amazon Rainforest transition site of the Canguçu Research Center (Canguçu RPPN) and in Cerrado area of the the Lajeado State Park (PEL), Tocantins State, Brazil.

Taxon	Number of individuals- Canguçu	Number of individuals - PEL	Sampling method	Faunal indices Canguçu/PEL			
				FREQ	ABUN	CONS	DOMI
APIDAE							
Centridini							
Centris (*Xanthemisia*) aff. *bicolor* Lepeletier, 1841	-	1	Re	LF	R	Z	ND
Centris (*Centris*) *aenea* Lepeletier, 1841	-	1	Ma	LF	R	Z	ND
Centris (*Ptilotopus*) *maranhensis* Ducke, 1910*	-	1	Re	LF	R	Z	ND
Centris (*Hemisiella*) *tarsata* Smith, 1874*	-	1	Re	LF	R	Z	ND
Centris (*Heterocentris*) *analis* (Fabricius, 1804)*	1	-	Re	LF	R	Z	ND
Epicharis (*Epicharitides*) *cockerelli* Friese, 1900*	-	1	Re	LF	R	Z	ND
Ceratinini							
Ceratina (*Crewella*) sp. 1	-	1	Pa	LF	R	Z	ND
Ceratina (*Crewella*) sp. 2	2	1	Pa	LF	R	Z	ND
Ceratina (*Ceratinula*) sp. 1*	1	-	Pa	LF	R	Z	ND
Euglossini							
Eufriesea sp. 1	1	-	Is	LF	R	Z	ND
Eufriesea sp. 2	1	-	Is	LF	R	Z	ND
Eufriesea aff. *smaragdina**	1	-	Is	LF	R	Z	ND
Euglossa (*Euglossa*) *melanotricha* Moure, 1967*	-	3	Is	LF	R	Z	ND
Euglossa (*Euglossa*) aff. *modestior* Dressler, 1982*	1	-	Is	LF	R	Z	ND
Euglossa (*Euglossa*) *modestior* Dressler, 1982*	3	1	Is	LF	R	W/Z	ND
Euglossa (*Euglossa*) sp. 1*	-	1	Re	LF	R	Z	ND
Euglossa (*Glossura*) *imperialis* Cockerell, 1922*	1	-	Re	LF	R	Z	ND
Euglossa (*Euglossa*) *securigera* Dressler, 1982*	1	-	Is	LF	R	Z	ND
Eulaema (*Apeulaema*) *nigrita* Lepeletier, 1841	66	42	CAN:Is (n=64) Re= 2), PEL:(n=40), Re (n= 2)	VF	VA	W	D
Eulaema (*Apeulaema*) *pseudocingulata* Oliveira, 2006*	59	33	CAN:Is (n= 47), Re (n= 12)/ PEL: Is(n=31), Re(n=2)	VF	VA	W	D
Eulaema (*Apeulaema*) *cingulata* (Fabricius, 1804)	8	2	Is	LF	R	Z	D/ND
Eulaema (*Eulaema*) *meriana* (Olivier, 1789)*	-	1	Is	LF	R	Z	ND
Exaerete aff. *smaragdina* (Guérin,1844)*	1	-	Is	LF	R	Z	ND
Exaerete smaragdina (Guérin,1844)*	25	1	Is	VF/LF	VA/R	W/Z	D/ND
Meliponini							
Cephalotrigona femorata (Smith, 1854)*	1	-	Re	LF	R	Z	ND
Frieseomelitta varia (Lepeletier, 1836)	-	2	Re	LF	R	Z	ND
Geotrigona mombuca (Smith, 1863)*	1	7	CAN: Re (n=1) / PEL: Ma (n= 1), Pa(n= 2), Re (n= 4)	LF	R/VA	Z/W	ND/D

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Taxon	Number of individuals-Canguçu	Number of individuals - PEL	Sampling method	Faunal indices Canguçu/PEL			
				FREQ	ABUN	CONS	DOMI
Geotrigona aequinoctialis (Ducke, 1925)*	-	9	Ma (n= 1), Pa (n= 1), Re (n= 7)	LF	VA	W	D
Melipona (*Michmelia*) *flavolineata* Friese, 1900	3	-	Re	LF	R	Z	ND
Melipona (*Melikerria*) *compressipes* Fabricius, 1804*	6	-	Re	LF	R	Z	D
Melipona (*Melikerria*) *quinquefasciata* Lepeletier, 1836*	-	2	Ma (n= 1), Re (n= 1)	LF	R	Z	ND
Nannotrigona aff. *testaceicornis* (Lepeletier, 1836)*	2	-	Pa (n= 1), Re (n= 1)	LF	R	Z	ND
Oxytrigona aff. *flaveola* (Friese, 1900)*	-	1	Re	LF	R	Z	ND
Paratrigona lineata (Lepeletier, 1836)*	-	9	Re (n= 7), Pa (n= 2)	LF	R	W	D
Partamona cupira (Smith, 1863)*	-	10	Re (n= 8), Is (n= 2)	VF	VA	W	D
Partamona ailyae Camargo, 1980	-	13	Re	VF	VA	W	D
Plebeia alvarengai Moure, 1994*	-	4	Re	LF	R	Z	D
Plebeia sp.1*	8	1	CAN:Re (n= 4), Is (n= 1), Ma (n= 2), Pa(n= 1)/ PEL: Re (n= 1)	LF	R	W/Z	D/ND
Plebeia sp.2*	4	-	Re (n=2), Ma(n=2)	LF	R	Z	ND
Plebeia minima (Gribodo, 1983)*	10	1	CAN: Re (n= 6), Is (n= 2), Ma (n= 2) / PEL: Re (n= 1)	LF	R	W/Z	D/ND
Scaptotrigona sp.1	2	-	Re	LF	R	Z	ND
Scaptotrigona sp.2	3	-	Re	LF	R	Z	ND
Scaptotrigona postica (Latreille, 1907)*	-	6	Re		R		
Scaura amazonica Nogueira, Oliveira & Oliveira, 2019	1	-	Re	LF	R	Z	ND
Tetragona mourei Nogueira, 2022	11	24	CAN: Re (n=11)/PEL: Re (n=23), Pa (n=1)	LF/VF	R/VA	W	D
Tetragona quadrangula (Lepeletier, 1836)	38	2	CAN: Re (n= 36), Ma (n=2)/ PEL: Ma (n= 2)	VF/LF	VA/R	W/Z	D/ND
Tetragona truncata Moure, 1971	-	1	Re	VF	R	Z	ND
Tetragona dorsalis (Smith, 1854)	-	1	Re	LF	R	Z	ND
Tetragonisca angustula (Latreille, 1811)	-	10	Re	VF	VA	W	D
Trigona pallens (Fabricius, 1798)	84	34	CAN: Re (n= 81), Ma (n= 2), Pa (n= 1) / PEL: Re (n= 34)	VF	VA	W	D

Continued...

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Taxon	Number of individuals- Canguçu	Number of individuals - PEL	Sampling method	Faunal indices Canguçu/PEL			
				FREQ	ABUN	CONS	DOMI
Trigona spinipes (Fabricius, 1793)	1	6	CAN: Ma (n= 1) / PEL: Re (n= 5), Is (n= 1)	LF/VF	R/VA	Z	ND/D
Trigona guianae Cockerell, 1910	-	13	Re (n= 2), Ma (n= 11)	VF	VA	W	D
Trigona recursa Smith, 1863	-	32	Re	VF	VA	Z	D
Trigona aff. *fuscipennis* Friese, 1900*	-	19	Re	VF	VA	Z	D
Trigona truculenta Almeida, 1984	1	4	Re	LF/VF	R/VA	Z/W	ND/D
Trigona branneri Cockerell, 1912*	-	13	Re	VF	VA	W	D
Trigonisca aff. *extrema* Albuquerque & Camargo, 2007*	1	31	CAN: Re (n= 1) / PEL: Re (n=20), Ma (n= 10), Pa (n= 1)	LF/VF	R/VA	Z/W	ND/D
Trigonisca pediculana (Fabricius, 1804)*	-	1	Re	LF	R	Z	ND
Trigonisca vitrifrons Albuquerque & Camargo, 2007*	1	-	Re	LF	R	Z	ND
Tapinotaspidini							
Paratetrapedia sp. 1	1	-	Ma	LF	R	Z	ND
Paratetrapedia sp. 2	-	2	Re	LF	R	Z	ND
Paratetrapedia flaveola Aguiar & Melo, 2011	3	-	Re	LF	R	Z	ND
Tetrapediini							
Tetrapedia sp. 1	1	-	Ma	LF	R	Z	ND
Tetrapedia sp. 2	-	2	Pa	LF	R	Z	ND
Xylocopini							
Xylocopa (*Neoxylocopa*) sp. 1	6	-	Ma (n= 4), Pa (n= 2)	LF	R	Z	D
Xylocopa (*Neoxylocopa*) *aurulenta* (Fabricius, 1804)*	1	-	Pa	LF	R	Z	ND
Xylocopa (*Neoxylocopa*) *frontalis* (Olivier, 1789)	10	1	Re	LF	R	W/Z	D/ND
Xylocopa (*Neoxylocopa*) *grisescens* Lepeletier, 1841	-	1	Re	LF	R	Z	ND
Xylocopa (*Neoxylocopa*) *suspeita* Moure & Camargo, 1988	-	1	Is	LF	R	Z	ND
Ericrocidini							
Mesoplia sp. 1	-	1	Ma	LF	R	Z	ND
Osirini							
Osiris sp. 1	7	1	CAN:Re(n=7)/ PEL:Ma(n=1)	LF	R	Z	D/ND
ANDRENIDAE							
Calliopsini							
Callonychium (*Callonychium*) *brasiliense* (Ducke, 1907)*	1	-	Pa	LF	R	Z	ND

Continued...

...Continuation

Taxon	Number of individuals-Canguçu	Number of individuals - PEL	Sampling method	Faunal indices Canguçu/PEL			
				FREQ	ABUN	CONS	DOMI
HALICTIDAE							
Augochlorini							
Augochlora sp. 1	1	2	CAN: Pa(n=1)/ PEL:Ma(n=1)/ Pa(n=1)	LF	R	Z	ND
Augochlora sp. 2	-	1	Pa	LF	R	Z	ND
Augochlora sp. 3	-	2	Is, Pa	LF	R	Z	ND
Augochlora sp. 4	1	-	Re	LF	R	Z	ND
Augochlorodes sp. 1*	1	-	Re	LF	R	Z	ND
Augochlorodes sp. 2*	1	-	Pa	LF	R	Z	ND
Augochloropsis sp. 1	7	-	Re	LF	R	W	ND
Augochloropsis sp. 2	-	1	Re	LF	R	Z	ND
Augochloropsis sp. 4	-	1	Re	LF	R	Z	ND
Augochloropsis sp. 6	-	1	Re	LF	R	Z	ND
Augochlorella sp. 1*	1	1	Pa	LF	R	Z	ND
Thectochlora alaris (Vachal, 1904)*	-	2	Pa	LF	R	Z	ND
Pseudaugochlora pandora (Smith, 1853)*	-	1	Re	LF	R	Z	ND
Halictini							
Dialictus sp. 1*	6	-	Pa (n= 2), Re (n= 4)	LF	R	W	ND
Dialictus sp. 2*	-	1	Ma	LF	R	Z	ND
MEGACHILIDAE							
Megachilini							
Megachile (*Pseudocentron*) sp. 1*	-	1	Re	LF	R	Z	ND
Megachile (*Ptilosarus*) sp. 1	1	-	Re	LF	R	Z	ND
Anthidiini							
Hypanthidium sp. 1	2	-	Pa, Re	LF	R	Z	ND
Total of individuals:	401	370					

of *Augochlora* sp. 3 were also collected by this method. Regarding to Meliponini, *Plebeia* sp.1, *Plebeia minima* (Gribodo, 1893) and *Trigona spinipes* (Fabricius, 1793) were the species sampled in both sites, and *Partamona cupira* (Smith, 1863) was only sampled in the Cerrado region. Eucalyptol was the most attractive essence for bees (n= 112 specimens collected; 72 specimens in the transition area, and 40 in the Cerrado area), followed by Eugenol essence (n= 93 specimens collected; 58 species in the transition area, and 35 in the Cerrado area). The most abundant species in both areas were *Eulaema* (*Apeulaema*) *nigrita* Lepeletier, 1841 (104 specimens collected; 64 species in the transition area, and 40 in the Cerrado area; Figures 7C and 7D) and *Eulaema* (*Apeulaema*) *pseudocingulata* Oliveira, 2006 (76 specimens collected; 45 species in the transition area, and 31 in the Cerrado area; Figures 7A and 7B), the former more efficiently attracted by Eucalyptol (n= 83 specimens collected; 48 species in the transition area, and 35 in the Cerrado area) and Vanillin (n= 19 specimens collected; 15 species in the transition area, and 4 in the Cerrado area), and the second species most efficiently attracted to the Eugenol essence (n= 62 specimens collected; 37 species in the transition area, and 25 in the Cerrado area) (Table 2).

Although the use of pantraps did not show good efficiency accessing the abundance of the sampled species in the present study (Table 3), since they just collected a few individuals (n= 31 specimens), this method was the second most efficient regarded the richness (23 species), sampling 12 species in the transition site (n= 15 specimens) and 13 species in the Cerrado region (n= 16 specimens). However, it was possible observing that tribe Ceratinini was only collected by pantraps in both assessed sites (Table 1). The most efficient color in attracting bees on both study sites was blue pantrap (n= 16 specimens and 14 species / 9 specimens and 9 species in the Cerrado area, and 7 specimens and 6 species in the transition area), followed by white (n= 10 specimens and 9 species; 4 specimens and 4 species in the Cerrado area, and 6 specimens and 5 species in the transition area) (Table 3).

Table 2. Bees attracted by the odor-baited traps in the Cerrado-Amazon Rainforest transition site of the Canguçu Research Center (Canguçu RPPN) and in Cerrado area of the the Lajeado State Park (PEL), Tocantins State, Brazil.

Taxon	Essences					
	Eucalyptol		**Eugenol**		**Vanillin**	
APIDAE	Canguçu	PEL	Canguçu	PEL	Canguçu	PEL
Euglossini						
Eufriesea sp. 1	-	-	-	-	1	-
Eufriesea sp. 2	1	-	-	-	-	-
Euglossa (*Euglossa*) *melanotricha* Moure, 1967	-	-	-	3	-	-
Euglossa (*Euglossa*) aff. *modestior* Dressler, 1982	1	-	-	-	-	-
Euglossa (*Euglossa*) *modestior* Dressler, 1982	3	1	-	-	-	-
Euglossa (*Euglossa*) *securigera* Dressler, 1982	1	-	-	-	-	-
Eulaema (*Apeulaema*) *nigrita* Lepeletier, 1841	48	35	1	1	15	4
Eulaema (*Apeulaema*) *pseudocingulata* Oliveira, 2006	3	2	37	25	5	4
Eulaema (*Apeulaema*) *cingulata* (Fabricius, 1804)	6	-	2	2	-	-
Eulaema (*Eulaema*) *meriana* (Olivier, 1789)	-	1	-	-	-	-
Exaerete aff. *smaragdina* (Guérin,1844)	-	-	1	-	-	-
Exaerete smaragdina (Guérin,1844)	8	-	17	1	-	-
Eufriesea aff. *smaragdina*	-	-	-	-	1	-
Meliponini						
Partamona cupira (Smith, 1863)	-	-	-	1	-	1
Plebeia sp.1	-	-	-	-	1	-
Plebeia minima (Gribodo, 1983)	1	-	-	-	1	-
Trigona spinipes (Fabricius, 1793)	-	-	-	1	-	-
Xylocopini						
Xylocopa (*Neoxylocopa*) *suspecta* Moure & Camargo, 1988*	-	1	-	-	-	-
HALICTIDAE						
Augochlorini						
Augochlora sp. 3	-	-	-	1	-	-
Total of individuals:	**72**	**40**	**58**	**35**	**24**	**9**

With regards to species' distribution based on the frequency and abundance classes, in the transition site, it was possible to observe that only 5 species were classified as very frequent (VF), namely: *Eul.* (*A.*) *nigrita*; *Eul.* (*A.*) *pseudocingulata*; *Exaerete smaragdina* (Guérin, 1844); *Trigona pallens* (Figure 5A and 5B) and *Tetragona quadrangula* (Lepeletier, 1836). These same species were classified as very abundant (VA), while all other species sampled in the Canguçu area were classified as infrequent (LF), and as rare (R) (Table 1). As for constancy of species in the samples, approximately 19% of species were dominant. These species represented 94.5% of the collected individuals, all of them classified in the family Apidae, and prevalence in tribe Meliponini. In total, 73% of species in the Cerrado area were classified as infrequent (LF) and rare (R); 25% of species were classified as very frequent (VF) and very abundant (VA) (Table 1). Only 14 species in this site (23.7%) were constant (W), the other ones (76.2%) were considered accidental (Z).

Discussion

1. Richness and abundance

Species richness recorded in the current study for the Cerrado-Amazon Rainforest transition sites (n = 50) and Cerrado sites (n = 59) can be considered high if analyzed the two areas together (total = 90 species, 37 genera, 14 tribes and four families), and lower richness if we consider the data from the transition area ou Cerrado area separately, in comparison to results performed in other studies sites that have used more than one sampling method. As examples of studies carried out in transition areas with the Amazon Rainforest biome, we can mention the study performed by Ferreira et al. (2019), who assessed an western northeast Atlantic Basin-Amazon Rainforest transition site and found 70 species (1047 individuals collected, from in 35 genera, 15 tribes and three families - Apidae, Halictidae and Megachilidae), and that

Table 3. Bees attracted by the colored water traps (PANTRAPS) in the Cerrado-Amazon Rainforest transition site of the Canguçu Research Center (Canguçu RPPN-CAN) and in Cerrado area of the the Lajeado State Park (PEL), Tocantins State, Brazil.

Taxon	**Colors- PANTRAPS**					
	White		**Yellow**		**Blue**	
APIDAE	**CAN**	**PEL**	**CAN**	**PEL**	**CAN**	**PEL**
Ceratinini						
Ceratina (*Crewella*) sp. 1	-	-	-	-	-	1
Ceratina (*Crewella*) sp. 2	-	-	-	-	2	1
Ceratina (*Ceratinula*) sp. 1	-	-	-	-	1	-
Meliponini						
Geotrigona mombuca (Smith, 1863)	-	1	-	1	-	-
Geotrigona aequinoctialis (Ducke, 1925)	-	1	-	-	-	-
Nannotrigona testaceicornis (Lepeletier, 1836)	-	-	1	-	-	-
Paratrigona lineata (Lepeletier, 1836)	-	-	-	1	-	1
Plebeia sp.1	-	-	-	-	1	-
Tetragona mourei Nogueira, 2022	-	1	-	-	-	-
Trigona pallens (Fabricius, 1798)	-	-	-	-	1	-
Trigonisca aff. *extrema* Albuquerque & Camargo, 2007	-	1	-	-	-	-
Tetrapediini						
Tetrapedia sp. 2	-	-	-	-	-	1
Xylocopini						
Xylocopa (*Neoxylocopa*) sp. 1	1	-	-	-	1	-
Xylocopa (*Neoxylocopa*) *aurulenta* (Fabricius, 1804)	-	-	-	-	1	-
ANDRENIDAE						
Calliopsini						
Callonychium (*Callonychium*) *brasiliense* (Ducke, 1907)	1	-	-	-	-	-
HALICTIDAE						
Augochlorini						
Augochlora sp. 1	-	-	1	-	-	1
Augochlora sp. 2	-	-	-	-	-	1
Augochlora sp. 3	-	-	-	-	-	1
Augochlorodes sp. 2	-	-	-	-	-	1
Augochlorella sp. 1	1	-	-	-	-	-
Thectochlora alaris (Vachal, 1904)	-	-	-	1	-	1
Halictini						
Dialictus sp. 1	2	-	-	-	-	-
Anthidiini						
Hypanthidium sp. 1	1	-	-	-	-	-
Total of individuals:	6	4	2	3	7	9

performed by Almeida et al. (2019), who also studied a Cerrado-Amazon Rainforest transition site and found 67 species (1,411 specimens, distributed in 28 genera, eight tribes and only two families - Apidae and Halictidae). Faunal comparisons between different locations are important to help better understanding communities and ecosystems; however, they are hard to be properly compared, given the wide set of variables concerning them, such as differences between collectors' expertise/performance, effort procedures between sampling (Wilson et al. 2008), and the use of different collection methods (Krug & Alves-dos-Santos 2008, Gill & O'Neal 2015). Considering only the transition areas with the Amazon Rainforest biome,for example, both studies mentioned above differ from the current study in the number of areas sampled, sampling effort and types of traps used: Ferreira et al. (2019) performed a total of eight collections in one site of native vegetation fragment (two-month intervals) using entomological net and odor-baited traps (and only two essences were the same: eugenol and eucalyptol); Almeida et al. (2019) sampled six native vegetation fragments with two collection in each site (once in the dry season and once in the wet season), using arboreal pitfalls with urine, pantraps and odor-baited traps (and only two essences were the same: eugenol and vanillin); the current study sampled two sites, performing only five collecting in each site, using entomological net, malaise trap, odor-baited traps and pantraps. These differences in the collection methodology can mask the results and make comparisons difficult, and the understanding if the differences are related to the characteristics in the landscape or mistakes/lost data by the sampling method and/or collector skills.

Furthermore, data available about bee communities in Brazil have shown great variation in richness between locations and the highest values recorded range from 100 to 200 species (Pinheiro-Machado et al. 2002). Mean richness value so far recorded for the Cerrado area reached 62 species (Santiago et al. 2009), whereas for the Cerrado-Amazon Rainforest transition site this number rises to70 species (Ferreira et al. 2019). Thus, species richness values recorded for the community in the present study, in both regions, can be considered high, since higher abundance and richness values were herein recorded, despite the small sampling effort compared to that in the study by Santos et al. (2004), in transition site a Cerrado-Amazon Forest. Thus, the present study added 39 bee species to the survey carried out by Santos and collaborators (2004) in North Tocantins State, in a Cerrado-Amazon Rainforest transition – they recorded 83 species.

There was no record of bee survey carried out in Tocantins State's Cerrado biome before the present study. The pattern often observed of some bee species presenting many individuals and many species with few individuals, as here in observed, has also been observed in different sampled habitats, including transition sites (Santos et al. 2004, Almeida et al. 2019, Andena et al. 2005). According to Laroca (1972), surveys focused on diversity tend to show several species with few individuals in different habitats worldwide. This statement points out the need of further studies based on greater sampling effort and on longer periods-of-time in order to find more real richness values in bee community surveys (Ferreira et al. 2019).

The greatest representativeness of family Apidae regarding number of genera, species and individuals was also recorded by other studies performed in the Cerrado, Amazon Rainforest and in transition regions (Andena et al. 2005, Santos et al. 2004, Oliveira-Junior et al. 2015, Lima & Silvestre 2017, Almeida et al. 2019, Ferreira et al. 2019). The tribe Meliponini was the most diverse and abundant group in the herein assessed biomes, and these data corroborate results recorded in other studies performed in Cerrado and transition sites (Almeida et al. 2019, Santos et al. 2004, Santiago et al. 2009, Roel et al. 2019). The highest abundance of species belonging to genus *Trigona* recorded in the present study was also observed in Cerrado-Amazon Rainforest transition sites assessed by Santos et al. (2004), and in Cerrado areas assessed by D'avila & Marchini, (2008) and Gianinni et al. (2017). The *Trigona* species present perennial colonies with high population density, and intense and specific communication to search for food resources, and to foraging in groups. This feature leads to a large number of individuals foraging in a given site at the same time, and the presence of nests near the sampling points could explain the larger number of collected individuals and, consequently, their high abundance in the sampled areas. Euglossini was the tribe recording the second largest number of species in the transition site, and it corroborated the results in studies performed in other Cerrado-Amazon Rainforest transition sites (Oliveira-Junior 2015). This same tribe was also the third biggest one in number of collected species in other studies that have sampled Cerrado areas (Faria & Silveira 2011, Nemésio 2016), and it possibly happened due to the collection methodology based on using odor-baited traps, which attract males belonging to Euglossini species over long distances.

Euglossini bees are known for flying long distances and experiments based on bees with mid-sized to big-sized body belonging to this tribe showed that they really can fly long distances in dense forests, as demonstrated in an experiment using *Eufriesea surinamensis* (Linnaeus, 1758), whose females returned to nests located 23Km away from the point of release (Janzen 1971). Furthermore, species in this tribe have been considered to present a non-random foraging behavior (Kroodsma 1975, Ackerman et al. 1982). Among the five Euglossini genera reported in Brazil, four were sampled in the present study. The prevalence of *El. nigrita* (Figures 7C and 7D) recorded in the current study was also reported in the studies performed by Silva & De Marco Jr. (2014), Knoll (2016) and Faria & Silveira (2011). This species is considered common in Cerrado (Nemésio & Faria-Jr. 2004, Nemésio 2016), and typical of open and relatively dry landscapes in Cerrado-Amazon Rainforest transition sites (Rebêlo & Silva 1999). Besides, *E. nigrita* (Figures 7C and 7D) has been considered a bio-indicator of impacted environments, since it is abundant in disturbed areas (Carvalho-Filho 2010), probably due to its physiological plasticity - what makes these bees resistant to stressful environmental conditions (Freitas 2009).

Families Andrenidae and Colletidae are known to be poorly represented in tropical areas (Silveira & Campos 1995), and it could explain the low sampling rate of Andrenidae and the lack of species of Colletidae in the bee community assessed in the present article.

2. *Bees in the Cerrado-Amazon Rainforest transition site*

The prevalence of Apidae concerning richness and abundance in the transition site – which was followed by Halictidae and Megachilidae – was also observed by Andena et al. (2012) in Cerrado/Atlantic Rainforest transition sites. The occurrence of 10 Euglossini species recorded in the survey performed in the Cerrado-Amazon Rainforest transition site can be explained by the fact that these bees present high abundance and richness in forested areas in Neotropical regions (Roubik & Hanson 2004). The occurrence of genera *Eufriesea, Exaerete, Cephalotrigona, Geotrigona, Nannotrigona, Paratrigona, Trigonisca, Augochlorodes* (Figures 6A and 6B)*, Augochlorella, Thectochlora* (Figures 6E and 6F) and *Dialictus* recorded in the present study for the Cerrado-Amazon Rainforest transition area was added to the list of genera known in the region, based on the bee survey performed by Santos et al. (2004), and also reported by Moure et al. (2012).

Several bee genera have a large number of species, but, so far, there is no review for most of them. Therefore, the list of morpho-species is common in studies about the Brazilian fauna, which presents high diversity of bee species. If one further compares the list of morpho-species in the present study, the number of species can increase or decrease, especially when new taxonomic studies were performed. It is important highlighting that, among the cited genera, *Nannotrigona* and *Augochlorodes* (Figures 6A and 6B) had not been registered yet in the Cerrado area in Tocantins State and in any other neighbor state. Yet, by taking into consideration Moure et al. (2012) as the species register base used in the current study, it is possible stating that there was no record of occurrence for *Augochlorodes* in the Cerrado-Amazon Rainforest transition area before the current study. Species' distribution in frequency, abundance, constancy faunal indices and dominance classes followed the pattern observed in another study performed with bees, whose similar frequency data were observed in the Cerrado-Amazon Rainforest transition site in the Northern region of Tocantins State (Santos et al. 2004). The constant species (W) were *Euglossa modestior* Dressler, 1982, *E.*(*A) nigrita*, *E.* (*A*) *pseudocingulata*, *Exaerete smaragdina* (Guérin, 1844), *Plebeia* sp.1, *P. minima*, *Tetragona mourei* Nogueira, 2022 (Figures 5C and 5D), *Trigona pallens* (Figures 5A and 5B), *Tetragona quadrangula* (Lepeletier, 1836) and *Xylocopa* (*Neoxylocopa*) *frontalis* (Olivier, 1789).According to the method of Kato et al. (1952), the recorded small number of dominant (D) species recorded in the present study was similar to that observed in the only survey carried out in the state (Santos et al. 2004), which recorded low rate of dominant species (D), all of them belonged to family Apidae.

3. *Bee species from the Cerrado*

The large number of individuals, species and species restricted to the Cerrado area found in the present study may be a result from vegetation characteristics in this region. According to Oliveira (1994), plant communities in Cerrado are formed by plant species well-adapted to the region's environmental conditions, which grows and reproducing efficiently, in addition to harboring a biodiversity similar to that observed in tropical forest areas, and genetically complex populations. The analysis carried out only with woody plants from the Cerrado allowed observing that they presented a whole diversity of pollination systems comparable to those observed in forest communities, and despite the environmental changes caused by deforestation, fires (natural or not) and land use for agriculture purposes, the bees from Cerrado were little affected (Oliveira 1991). The great richness and abundance of Meliponini observed in the Cerrado area can be related to the availability of nesting substrates, as suggested by Silveira & Campos (1995). Although species in this tribe have diversified nesting habits, most species nest in pre-existing cavities in the trunks of living or dead trees in the Cerrado area. Several species in this group of bees end up building their nests very close to each other, and sometimes can be observed more than one nest of the same species in the same tree trunk (Rego & Brito 1996). As the nests are highly populated, mainly in comparison to nests of solitary species, and due to worker bees' ability to communicate with each other about the location of the most attractive sources of resources (Kerr et al. 1996), these factors help increasing the number of Meliponini in the flowers and, consequently, they help increasing the abundance of collected individuals in comparison to other groups of bees captured in the current study.

Oil collector bees belonging to the tribes Centridini, Tapinotaspidini and Tetrapediini, which were observed in the present study, are exclusively distributed in the Americas, and especially diverse in the Neotropical region, accounting approximately 20% of the melissofauna of Cerrado (Alves-dos-Santos et al. 2007). The representativeness of oil collector bees is related to the richness of Malpighiaceae species living in the Cerrado region (Alves-dos-Santos et al. 2007). As for the present study, among the twelve recorded oil collecting bee's species, seven were exclusively recorded in the Cerrado biome, namely: *Centris* (*Xanthemisia*) aff. *bicolor* Lepeletier, 1841; *Centris* (*Centris*) *aenea* Lepeletier, 1841; *Centris* (*Ptilotopus*) *maranhensis* Ducke, 1910; *Centris* (*Hemisiella*) *tarsata* Smith, 1874; *Epicharis* (*Epicharitides*) *cockerelli* Friese, 1900; *Paratetrapedia* sp. 2, *Tetrapedia* sp. 2 (Table 1). However, despite the occurrence of three tribes, the number of species (n = 11) was smaller than that recorded in other studies performed in the same biome (Andena et al. 2012).

The presence of Augochlorini species, which were recorded in low abundance (lower than that recorded for meliponids), is certainly related to non-eusocial behavior, which makes them naturally less abundant per area (more sparsely distributed in the landscape), unlike meliponids, which are naturally more abundant per area, especially when nests are located close to collection points. Although Laroca et al. (1982) observed the trend of increasing Halictidae rates in anthropized areas, which may be related to the small body size, which provides more accessible nesting sites for these bees compared to eusocial ones or those of bigger size, in addition to the relative generalist alimentary behavior visiting also large numbers of herbaceous / ruderal plants (Boff et al. 2013, Montagnana 2020), and due to the characteristics of the sampled sites studied in here (Canguçu and PEL), we can suggest that this area is less impacted by human action. However, it is essential performing additional collections in order understand whether there are frequencies higher than the recorded ones for these bees in these areas, since they are in an environmental protection region that demands further follow-up, and whether these pointed distribution patterns are perpetuated in all Cerrado areas.

Although the low diversity and abundance of orchid bees in xeric areas is a known phenomenon (Nemésio & Faria-Jr. 2004, Viotti et al. 2013), Euglossini was represented in the current study by nine species in the Cerrado region, and this number was larger than that recorded in other studies carried out in this biome (Freitas et al. 2009, Alvarenga et al. 2007). These data also highlight the richness, diversity and abundance of this bee tribe observed in the Cerrado fraction of Tocantins State. The efficiency of odor-baited traps as sampling method, which allowed collecting a large number of specimens of this bee group, is another determining factor for the great abundance of Euglossini species, and it evidences the importance of using different collection methods in bee survey studies.

4. *Efficiency of sampling methods*

The greatest species richness was surveyed by using entomological net, which emerged as the most effective sampling method in comparison to the other ones in both assessed study sites, and it also corroborates the results observed in other studies on bee communities (Pereira & Sousa 2015, Ferreira et al. 2019, Almeida et al. 2019, Prendergast et al. 2020). It was possible, because this method samples bees directly on flowers when foraging or nesting.

The high efficiency of the odor-baited trap in both study sites was also observed by Ferreira et al. (2019). Eucalyptol was the most attractive essence for Euglossini bees in both experiments, sampling 283 individuals from 22 species in the study performed by Ferreira et al. (2019), and sampling 112 individuals from 10 species and three tribes of the Apidae family in the current study (9 species in Cerrado and five species in the Cerrado-Amazon Rainforest transition sites), representing about 47% of the total number of collected individuals by the odor-baited traps (Table 2). As in the present study (attracting about 39% of total collected individuals; 93 specimens from 9 species, and four tribes of two families: Apidae and Halictidae), Eugenol was also the second most attractive substance in the experiments performed by Ferreira et al. (2019), accounted for 103 individuals from 11 species.

On the other hand, pantraps showed dissatisfactory results for accessing abundance in the current study in comparison to results recorded in other bee surveys, and this result can be explained, since we couldn't use pantraps with colors that reflect UV; therefore, we had to use pantraps without UV reflection (Prendergast et al. 2020). Besides, pantraps efficiency to capture bees also depends on the number of traps installed (Shapiro et al.2014), on the distance and distribution of traps (Droege et al. 2010) and on the habitat's structure in the area where the traps are installed (Landaverde & González et al. 2017).

Previous studies have shown greater richness and abundance of bees attracted by pantraps in open habitats than in forested habitats in tropical regions (Prado et al. 2017). However, the current results show low abundance in sampling using pantraps without UV reflection but greater diversity (n= 23 species) if compared with other collection methods (malaise and odor-baited traps, for example, that surveyed 19 species each) with a very little difference between sampling in vegetation typical to Cerrado (open fields) and Cerrado-Amazon Rainforest transition sites (16 specimens collected in Cerrado area and 15 specimens in the transition area, corresponding to 12 species in the transition site and 13 species in the Cerrado region). Despite differences in the efficiency of the used collection methods, the combination of different types of sampling methods has led to the capture of different groups of bees, and it broadened the bee records for Tocantins state. This process can be desirable, mainly in case of studies focused on exploring and featuring the bee fauna in a given region, since these methods are complementary to each other.

The herein recorded results have shown the high biodiversity of bees in Tocantins State, either in Cerrado or in Cerrado-Amazon Rainforest transition sites, where a diverse and abundant fauna belonging to four of the five bee families reported for Brazil were identified. The sampled areas only represented one fraction of Cerrado and transition sites in the state, and it suggested the presence of several environments exclusive to this region that still have to be investigated. Such a finding reinforces the hypothesis that Tocantins is rich in bee species. These faunal results suggest that most of the surveyed species were accidental and only some species were constant/abundant in the assessed environments, once only few species were classified as very abundant and very frequent, and it also explains the reason for most species to be classified as rare. Although the regions sampled in Tocantins State are still outnumbered, our results provide evidence of the considerable richness of bee species in Cerrado and in the Cerrado-Amazon Rainforest transition area. Once the present study was one of the first to assess bee fauna from Cerrado in Tocantins, further studies need to be conducted in other sites, and in other environments, since they can add new species to the herein reported ones. Additional bee monitoring, based on greater sampling effort in the same areas, and at different times of the year, are needed to complete the present study (including the use of pantraps with UV reflection), in order to access information on seasonality and on other native bee species that were not yet sampled. These new studies will evidence the real apifauna biodiversity in Tocantins State. Although the herein presented data can still be considered partial, the present study has contributed to enrich the knowledge about bees' diversity in Central Cerrado areas, and in Cerrado-Amazon Rainforest transition sites, mainly in Tocantins State, as well as to data surveys of great scientific value, due to the low number of studies in this field performed in Tocantins State. Out research will open room for further studies on apifauna diversity in the herein assessed region.

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Author Contributions

Simone Santos Oliveira Barros: Contributed equally to the concept and design of the study, manuscript preparation, data collection, data analysis, and interpretation.

Waldesse Piragé de Oliveira Júnior: Contributed equally to the concept and design of the study, manuscript preparation, data collection, data analysis, and interpretation.

Favízia Freitas de Oliveira: Contributed equally to the concept and design of the study, taxonomic identification of species, manuscript preparation, interpretation and critical revision.

Nádilla Gonçalves Andrade: Contributed equally to data collection and interpretation.

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Marcos Antônio Lima Bragança: Contributed equally to the concept and design of the study, manuscript preparation and critical revision.

Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Data availability

Supporting data are available at <https://data.scielo.org/dataset.xhtml?persistentId=doi:10.48331/scielodata.ZIPVYC&version=DRAFT>

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