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Bees (Hymenoptera, Apoidea) in an Ecotonal Cerrado-Amazon Region in Brazil

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Abstract

Little is known about the composition of the bee community in the Cerrado-Amazon transition area. Herein, we present the results of a bee survey done within the municipality of Conceição do Araguaia, in the state of Pará. Six fragments were sampled twice (once in the dry season and once in the rainy season) using three methods of collecting: arboreal pitfalls with urine, scent traps, and pan traps. We recorded 67 bee species, distributed in 28 genera and eight tribes. Except for *Partamona chapadicola*, which is endemic to the Cerrado biome, the remaining species we sampled occur in the Amazonian Forest. Of those, 15 species are considered endemic to the Amazonian biome (four Euglossini, eight Meliponini, one *Paratetrapedia*, one *Xylocopa* and one Augochlorini), while 27 occur in forest and areas of Cerrado (seven Euglossini, fifteen Meliponini, two *Paratetrapedia*, one *Xylocopa* and two Augochlorini). Among 53 species sampled (disregarding the Euglossini species which were sampled almost exclusively with scent), 41 were captured with arboreal pitfall traps. Of those, 20 species were from the Meliponini tribe.

Introduction

An ecotone is a transition area between two biomes, characterized by the presence of faunal and floral components from both biomes. Therefore, faunal inventories performed in an ecotonal area may reveal important findings related to the limits of distribution of species that are endemic to either one of the biomes considered in this transitional area. In the sourthern border of the Brazilian Amazon, there is an extensive ecotonal region (also known as ´Zone of Ecological Tension'), approximately 4,500 km long, between the two largest South American biomes, the Cerrado savanna and the Amazon forest (Marimon et al., 2006). Bees from this region, which comprise the most important pollinator group (Klein et al., 2007; Ollerton et al., 2011), are poorly known in this transitional area. Previous to the present study, this group has been studied in only two localities, the Bico-do-Papagaio region, at the northern portion of the state of Tocantins (Santos et al., 2004), and the municipality of Ribeirão Cascalheira, in the northeastern of the state of Mato Grosso (Oliveira-Junior et al., 2015). In the first region, the sampling consisted of monthly, systematic sampling of flower visitors during the course of one year. The sampling in the other study area consisted of a rapid survey of orchid bees using baited traps and chemical baits with hand nets.

The standard sampling method for bee inventory consists of capturing the bees visiting flowers using entomological nets (Sakagami et al., 1967). However, net sampling demands a huge sampling effort, mainly in forested area with high canopy height. Other sampling methods that are often used to capture bees consist of using passive traps to sample these organisms. One example, the pan/bowl trap, (Cane et al.,

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2000; Roulston et al., 2007; Wilson et al., 2008; Joshi et al., 2015) consists of plastic plates painted with colors attractive to bees (usually blue, yellow, and white) and filled with water and soap droplets to decrease the water's surface tension and avoid the specimens' escape. Another passive method, specifically designed for sampling orchid bees, uses scent/baited traps made with PET bottles (Nemésio, 2012; Nemésio & Vasconcelos, 2014). These insects are easily attracted to synthetic compounds that mimic floral fragrances, making field studies easy to conduct. Although such traps are widely used, their effectiveness has been questioned recently (see Nemésio & Vasconcelos, 2014), after it was shown that scent baits allowed researchers to sample a different composition of species than active sampling. Nonetheless, given the resource limitations and logistic difficulties in conducting field research, passive sampling of orchid bees with scent traps are still widely used. Here, we also employed for the first time the use of an unusual passive sampling method for bees that is already commonly used to sample ants: urine traps. Urine contains nitrogen and salts (Kaspari et al., 2009), which make it very attractive to insects. The use of urine in arboreal pitfall traps is common in ant inventories (see more at Maravalhas & Vasconcelos, 2014). Here we employed it to sample bees in multiple ecotonal transects simultaneously, along with other sampling methods usually used in bee inventories. Therefore, since our goal was to perform rapid bee samplings in an ecotonal area between the Amazon forest and the Brazilian Cerrado savanna, here we used the different passive sampling methods we described before to sample bees in multiple ecotonal areas of the Amazon forest with the Cerrado.

The current study describes the composition of the bee community in the Amazonia-Cerrado ecotone in southeast Pará. Here, we discuss the distribution of each sampled species and also evaluate whether the ecotone is the limit of the species' geographic distribution. Although our sampling was selective to some degree, it contributes to the knowledge of the bee fauna of this region where knowledge on this group is scarce and that it also undergoing through rapid deforestation. Since insect data is usually compromised by knowledge gaps, especially the Wallacean shortfall (e.g. lack of knowledge on the biogeographic distribution of species; Diniz-Filho et al., 2010; Cardoso et al., 2011), additional sampling is always welcomed to fight other biological data shortfalls (Hortal et al., 2015).

Materials and methods

Study site

We performed this study in the municipality of Conceição do Araguaia, in the southeastern portion of Pará state (Figure 1). Six native vegetation fragments, varying in distance from 4 to 27 Km, were sampled (Site 1, 8°10'41.32"S 49°21'52.60"W; Site 2, 7°55'35.21"S 49°24'10.49"W; Site 3, 7°59'30.39"S 49°24'25.13"W; Site 4, 8°00'01.25"S 49°22'12.49"W; Site 5, 8°03'43.69"S 49°20'54.07"W; Site 6, 8°02'33.44"S 49°27'34.66"W). The area sampled had high environmental complexity, due to its location in an ecotonal region between the Cerrado savanna and the Amazon forest, formed by Seasonal Forest/Ombrophilous Forest (Haidar et al., 2013). The mean altitude of this region is 240 m, and the climate has two well-defined seasons, with the dry season extending from May to September and the wet season spanning October to April. The mean temperature is around 28ºC and the mean annual precipitation is 1,200 mm, according Brazilian National Institute of Meteorology (INMET).

Bee sampling

We sampled each fragment twice, once in the dry season (June 6-14 of 2017), and once in the wet season (November 6-14 of 2017). In each sampled area, we set an 80 m transect, at least 20 m from the fragment's border to minimize the border effect (Fisher, 1999). We sampled at five locations along each transect, each 20 m apart. In each sampling location, we set a group of traps (arboreal pitfalls with urine, a scent trap, and several pan traps) as described below.

Arboreal pitfalls with urine

We installed four arboreal pitfall traps in tree canopies at locations between 1.5 and 3 m in height. The pitfall traps were consisted of 100 ml plastic cups, fixed to tree branches with wires. Each trap was filled with a mixture of water (70%), human urine (30%), and soap droplets. The sampled bees were a by-product of this sampling protocol intended to sample ants. The pitfall traps remained in trees for a total of 48h in each of the six sampling locations.

Scent traps

We used scent traps made of PET bottles with two openings (adapted from Campos et al., 1989; Sofia & Suzuki, 2004). The traps were placed 1.7 m from the ground and fixed to tree branches with wire. We used five scents, one per sampling location in each one of the six areas. The scents used (benzyl acetate, methyl cinnamate, cineol, eugenol, and vanillin) were selected because they are commonly used to sample Euglossini bees in field surveys due to their similarity to plant chemicals, or as attractants of male specimens (Silva & De Marco, 2014). Scent traps were left out for seven days, revisited every 48 h to remove specimens from traps and replenish scents.

Pan traps

We used colored pan traps filled with water and soap, commonly used to sample bees (Krug & Alves-dos-Santos, 2008; Hall, 2016; Silva et al., 2017). We placed four (yellow, blue, orange, and green) 22 cm traps in each sampling location to increase the diversity of sampled insects. Traps were placed on the ground spaced 20 cm apart from each other, forming a square. These traps were left at each location for 48 h.

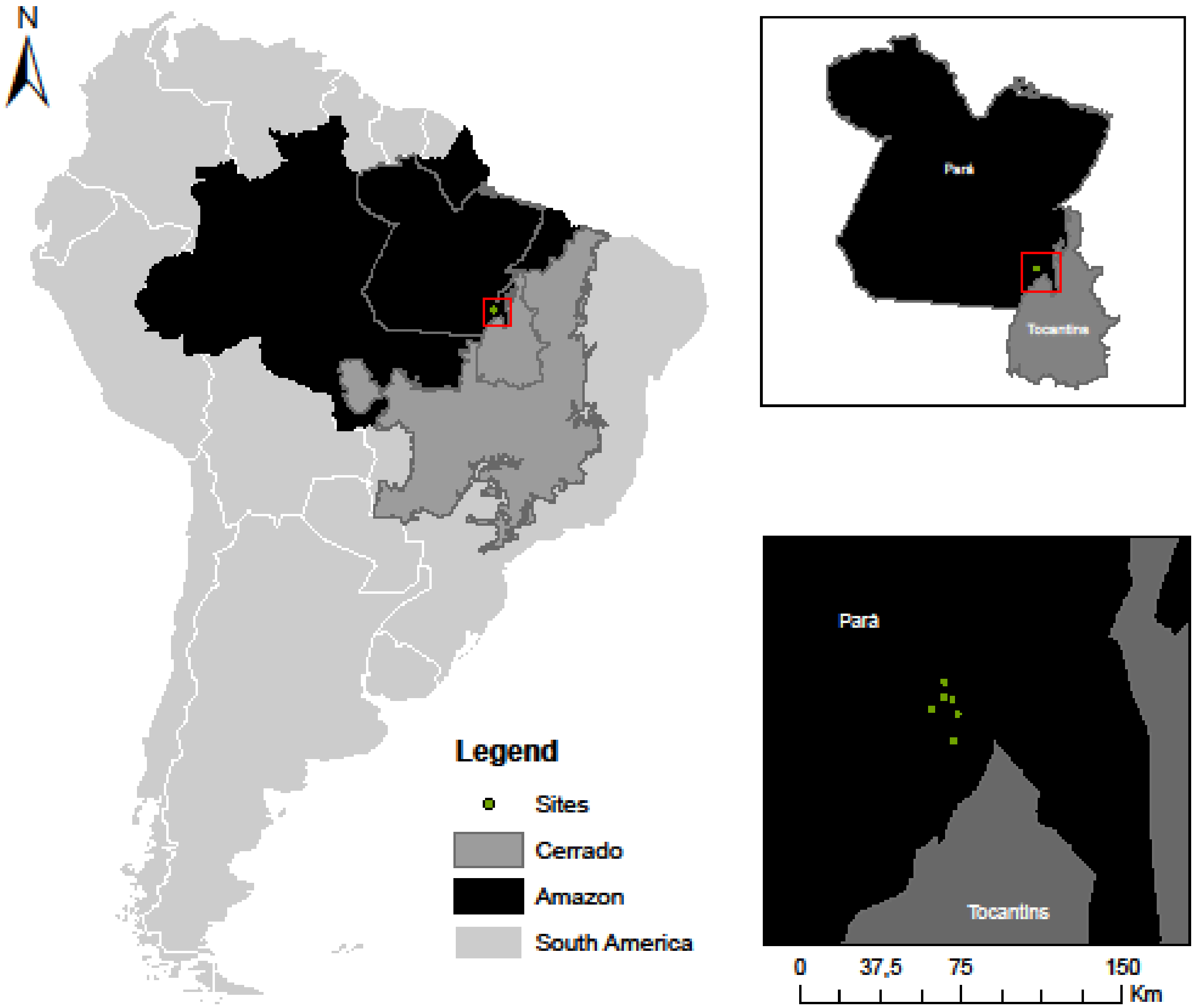

Fig 1. Location of the six bee collecting areas in a Cerrado and Amazon Forest ecotone in the municipality of Conceição do Araguaia, southeast of Pará, Brazil.

Sampled specimens pinning and identification

Bees were removed from the tubes, pinned, and labeled. Species were identified using identification keys found in the supplemental material (Supplementary Material) and compared by BWTC with the identified specimens already deposited in the Entomological Collection from Museu Paraense Emílio Goeldi (MPEG). The sampled specimens received the collection numbers MPEG 03032032–03032076, and MPEG 03032797–03033191 and were deposited in the Entomological Collection of MPEG. The sampling license was granted to us by the Secreataria de Meio Ambiente (SEMAS) from the state of Pará: Capture, Sampling, and Transportation of Wildlife (AU Nº3459/2017, process number 2016/39794).

Results

In this study, we sampled 1,411 specimens belonging to 67 species, 28 genera, and 2 bee families (Apidae and Halictidae). In Table 1, the species we sampled are listed, along with their abundance in each different sampling method we tested: arboreal urine pitfalls, scent traps, and pan traps. Only one species, *Stilbochlora eickworti* (Engel, Brooks & Yanega, 1997), had not been previously reported for Pará (Moure et al., 2012).

A total of 882 male orchid bees from 14 different species representing four of the euglossine genera were sampled: *Euglossa* with eight species, *Eulaema* with four, *Eufriesea*, and *Exaerete* represented by a single species. The most abundant species were *Eulaema nigrita* Lepeletier, 1841 (54.1% of the total amount of orchid bees sampled), *El. cingulata* (Fabricius, 1804) (33.7 %) and *Euglossa ignita* Smith, 1874 (8.4 %). The remaining 11 species made up just 3.8 % of the total bees sampled.

Stingless bees were the second most abundant group sampled, with 481 specimens from 29 species, and 14 genera. The most common species was *Trigona* aff. *fuscipennis* Friese, 1900, with 285 specimens (59.3% of the total amount of stingless bees sampled), followed by *Tetragona clavipes* (Fabricius, 1804) (40 specimens; 8.3%) and *Trigona guiane* Cockerell, 1910 (37; 7.7%). The remaining species made up 24.3 % of the total of stingless bees sampled.

The remaining species of Apidae sampled in our inventory are distributed among the genera *Apis* (1), *Paratetrapedia* (4 species), *Ceratina* (3), *Xylocopa* (3), and *Tetrapedia* (2). The three types of traps sampled only 24 specimens of Halictidae, representing 11 species and morphospecies from five genera: *Augochlora* (2), *Augochloropsis* (5), *Megalopta* (2), *Megaloptidia* (1) and *Stilbochlora* (1).

The highest species richness was observed for the arboreal urine pitfalls, with which we sampled a total of 43 species, being twenty of Meliponini, representing 11 genera. *Euglossa intersecta* Dressler, 1982 was the only orchid bee only sampled with the urine pitfalls. The scent traps showed the second highest richness, with 28 species sampled. The lowest species richness was recorded by the pan traps, with which only 15 species were captured.

Table 1. List of bee species sampled in six sites and using three different traps (arboreal pitfalls with urine, scent trap and pan traps) in a Cerrado and Amazon Forest ecotone in the municipality of Conceição do Araguaia, southeast of Pará, Brazil. (N = Abundance of bees).

Taxon	Scent trap		Pan trap		Pitfall	
	N	Site	N	Site	N	Site
APIDAE						
Apini						
Apis mellifera Linnaeus, 1758	1	2	1	2	1	6
Ceratinini						
Ceratina sp.1	0	-	1	2	1	6
Ceratina sp.2	0	-	0	-	1	6
Ceratina sp.3	0	-	0	-	3	6
Euglossini						
Eufriesea concava (Friese, 1899)	1	1	0	-	0	-
Euglossa avicula Dressler, 1982	2	5;6	0	-	0	-
Euglossa decorata Smith, 1874	1	6	0	-	0	-
Euglossa ignita Smith, 1874	74	1;2;3;4;5;6	0	-	0	-
Euglossa intersecta Latreille, 1817	0	-	0	-	2	5;6
Euglossa liopoda Dressler, 1982	1	6	1	4	0	-
Euglossa orellana Roubik, 2004	2	5;6	0	-	0	-
Euglossa piliventris Guérin, 1844	1	6	0	-	0	-
Euglossa townsendi Cockerell, 1904	1	5	0	-	0	-
Eulaema cingulata (Fabricius, 1804)	297	1;2;3;4;5;6	0	-	0	-
Eulaema meriana (Olivier, 1789)	9	1;3;4;5	0	-	0	-
Eulaema mocsaryi (Friese, 1899)	1	4	0	-	0	-
Eulaema nigrita Lepeletier, 1841	476	1;2;3;4;5;6	0	-	1	6
Exaerete smaragdina (Guérin, 1844)	12	2;4;5;6	0	-	0	-
Meliponini						
Aparatrigona impunctata (Ducke, 1916)	1	4	0	-	0	-
Celetrigona longicornis (Friese, 1903)	0	-	0	-	2	2
Cephalotrigona capitata (Smith, 1854)	0	-	1	6	0	-
Frieseomelitta longipes (Smith, 1854)	0	-	0	-	1	2
Frieseomelitta sp.1	1	1	0	-	0	-
Melipona seminigra Friese, 1903	0	-	0	-	2	4
Melipona flavolineata Friese, 1900	0	-	4	4;6	8	4
Nannotrigona punctata (Smith, 1854)	0	-	0	-	2	6
Nannotrigona schultzei (Friese, 1901)	0	-	0	-	3	6
Oxytrigona sp.1	0	-	0	-	1	4
Partamona chapadicola Pedro & Camargo, 2003	1	2	2	6	15	3;4;6
Plebeia alvarengai Moure, 1994	0	-	5	6	2	5
Plebeia minima (Gribodo, 1893)	0	-	0	-	1	6
Plebeia sp.2	0	-	0	-	4	3;4
Scaptotrigona postica (Latreille, 1807)	11	1;6	1	5	0	-
Scaptotrigona tubiba (Smith, 1863)	4	2;3	0	-	0	-
Scaptotrigona sp.1	1	1	0	-	0	-

Table 1. List of bee species sampled in six sites and using three different traps (arboreal pitfalls with urine, scent trap and pan traps) in a Cerrado and Amazon Forest ecotone in the municipality of Conceição do Araguaia, southeast of Pará, Brazil. (N = Abundance of bees). (Continuation)

Taxon	Scent trap		Pan trap		Pitfall	
	N	Site	N	Site	N	Site
Meliponini						
Scaura latitarsis (Friese, 1900)	0	-	0	-	2	6
Tetragona beebei (Schwarz, 1938)	1	5	0	-	19	4;5;6
Tetragona clavipes (Fabricius, 1804)	0	-	0	-	40	2;3;4;6
Tetragona truncata Moure, 1971	0	-	0	-	1	4
Tetragonisca angustula (Latreille, 1811)	0	-	0	-	1	6
Trigona branneri Cockerell, 1912	0	-	0	-	1	6
Trigona chanchamayoensis Schwarz, 1948	0	-	1	5	7	6
Trigona dallatorreana Friese, 1900	1	5	1	2	0	-
Trigona guianae Cockerell, 1910	0	-	5	4;6	32	2;4;6
Trigona hypogea Silvestri, 1902	3	2	0	-	0	-
Trigona pallens (Fabricius, 1798)	1	4	0	-	0	-
Trigona aff. *fuscipennis* Friese*,* 1900	233	1;2;3;4;5;6	7	2;6	52	2;4;6
Tapinotaspidini						
Paratetrapedia flaveola Aguiar & Melo, 2011	0	-	0	-	1	6
Paratetrapedia lugubris (Cresson, 1878)	0	-	0	-	1	4
Paratetrapedia testacea (Smith, 1854)	0	-	0	-	1	4
Paratetrapedia sp.01	0	-	0	-	1	4
Tetrapediini						
Tetrapedia sp.1	0	-	0	-	1	6
Tetrapedia sp.2	0	-	0	-	2	2
Xylocopini						
Xylocopa aurulenta (Fabricius, 1804)	0	-	0	-	6	2;3;5
Xylocopa nigrocincta Smith, 1854	0	-	0	-	1	2
Xylocopa suspecta Moure & Camargo, 1988	0	-	0	-	1	6
HALICTIDAE						
Augochlorini						
Augochlora sp.1	0	-	0	-	2	1;3
Augochlora sp.2	0	-	0	-	1	3
Augochloropsis sp.1	0	-	0	-	2	4;6
Augochloropsis sp.2	1	2	1	4	1	4
Augochloropsis sp.3	1	3	0	-	0	-
Augochloropsis sp.4	0	-	1	4	2	6
Augochloropsis sp.5	0	-	0	-	1	6
Megalopta amoena (Spinola, 1853)	3	5	0	-	0	-
Megalopta sodalis (Vachal, 1904)	0	-	0	-	4	4;6
Megaloptidia sp.1	0	-	0	-	2	3
Stilbochlora eickworti (Engel, Brooks & Yanega, 1997)	0	-	2	4;6	0	-
Richness	28		15		43	
Exclusive species	19		2		31	
Abundance	1142		34		235	

Discussion

The number of Euglossini species we found (14 species) is similar to the number sampled by Oliveira-Junior et al. (2015) in a transitional forest at Ribeirão Cascalheira, in northeastern Mato Grosso state (16 species). Five of the species we sampled were also sampled in the study by Oliveira-Junior et al. (2015): *El. nigrita*, *El. cingulata* (Fabricius, 1804), *El. mocsary* (Friese, 1899), *Eg. ignita* and *Exaerete smaragdina* (Guérin, 1844). The first and second most abundant species, *El. nigrita* and *El. cingulata*, respectively, were the same in both inventories.

All orchid bee species sampled here, in addition to those listed by Oliveira-Junior et al., (2015), were recorded for Brazilian Amazon. Among the 23 species (*Euglossa* gr. *purpura* was not included), six (26.1% of the total of species) are endemic to the Amazonian biome (Nemésio & Silveira, 2007): *Euglossa bidentata* Dressler, 1982, *Eg. chalybeata* Friese, 1925, *Eg. intersecta, Eg. orellana* Roubik, 2004, *Eg. piliventris* Guérin, 1844 and *El. mocsaryi*; and two species, *Eufriesea concava* (Friese, 1899) and *Euglossa bursigera* Moure, 1970 are found in the Amazonian Basin and Central America (but see Moure et al., 2012 for a discussion regarding the distribution of *Ef. concava*). Thus, the Cerrado-Amazon ecotone is expected to be the southern limit of their distributions. Six species, among the 23 listed, occur also in Atlantic Forest domain (Nemésio & Silveira, 2007; Sydney et al., 2010): *Eufriesea surinamensis* (Linnaeus, 1758), *Euglossa cordata* (Linnaeus, 1758), *Eg. liopoda* Dressler, 1982, *Eg. pleosticta* Dressler, 1982, *Eg. securigera* Dressler, 1982 and *Eg. avicula* Dressler, 1982.

Among the 23 species of orchid bees sampled in the Amazonia-Cerrado ecotone, nine were recorded from Cerrado in the state of Minas Gerais: *Eg. cordata*, *Eg. decorata* Smith, 1874, *Eg. imperialis*, *Eg. securigera*, *Eg. pleosticta*, *Eg. townsendi*, *El. cingulata*, *El. nigrita,* and *Ex. smaragdina*. Additionally, the species *El. bombiformis* (Packard, 1869), *El. cingulata*, *El. meriana* (Olivier, 1789), *El. nigrita* and *Euglossa ignita* were recorded in the inventory carried out by Vital et al. (2016) within the Cerrado biome in the state of Tocantins. Therefore, 52.2% of the euglossine species sampled in the ecotonal region also occur in Cerrado.

Except for *P. chapadicola* Pedro and Camargo, 2003, which occurs from the southeastern region of Pará to up to the state of Piauí in both the Cerrado and Caatinga biome (Pedro & Camargo, 2003), the remaining 24 species of stingless bees sampled in our study are present in the Amazonian Forest (Rebêlo et al., 2003; Moure et al., 2012; Pedro, 2014). Among these 24 species, six (25.0% of the total of species) are endemic to the Amazonian biome: *Nannotrigona punctata* (Smith, 1854), *N. schultzei* (Friese, 1901), *Tetragona beebei* (Schwarz, 1938), *Plebeia alvarengai* Moure, 1994, *P. minima* (Gribodo, 1893) and *Friesiomellita longipes* (Smith, 1854). Thus, the Cerrado-Amazon ecotone is the southern limit of the distributions of these endemic species, and to *Aparatrigona impunctata* (Ducke, 1916)*,* which occurs in Central America and the Amazonian Basin. This region is also likely the distribution limit of *Melipona seminigra* Friese, 1903 and *M. flavolineata* Friese, 1900*,* because these species require large cavities in large trees for nesting (Pioker-Hara, 2011). In the state of Tocantins, these species are present in the Cerrado only because they are reared by humans (Costa-Neto et al., 2016).

Among the 24 species of Meliponini bees sampled in the Amazonia-Cerrado ecotone we inventoried, five species were recorded in Cerrado from state of Goiás (Santiago et al., 2009; Moure et al., 2012): *Trigona chanchamayoensis* Schwarz, 1948, *Celetrigona longicornis* (Friese, 1903), *Trigona pallens* (Fabricius, 1798), *T. branneri* Cockerell, 1912 and *Tetragona truncata* Moure, 1971. The species *Trigona guianae* Cockerell, 1910 is found in the states of Tocantins, Ceará, and Paraiba (Moure et al., 2012); and *T. dalatorreana* Friese, 1900 is found in the ecotone area in the state of Tocantins (Santos et al., 2004). Furthermore, eight species are widely distributed in Brazil (Moure et al., 2012), inhabiting both forest and Cerrado (Andena et al., 2005; Santiago et al., 2009; Imperatriz-Fonseca et al., 2011; Pioker-Hara, 2011): *Cephalotrigona capitata* (Smith, 1854), *S. postica* (Latreille, 1807), *S. tubiba* (Smith, 1863), *Scaura latitarsis* (Friese, 1900), *Tetragonisca angustula* (Latreille, 1811), *T. clavipes, T. hypogea* Silvestri, 1902 and *T.* aff. *fuscipennis*. Therefore, about 62.5% of Meliponini species sampled in this ecotone region occur in Cerrado.

The bees from the *Paratetrapedia* genus are especially diverse in the Amazon Forest (Aguiar & Melo, 2011). Among the three species of this genus we sampled and identified, only *P. testacea* (Smith, 1854) is endemic to the Amazon basin, occurring mainly in the eastern Amazon (Aguiar & Melo, 2011). The species *P. lugubris* (Cresson, 1878) has a pan-neotropical distribution, while *P. flaveola* Aguiar and Melo, 2011 is a widespread species distributed throughout Brazil. We identified three species of Xylocopa: X. nigrocincta Smith, 1854, X. suspecta Moure and Camargo, 1988 with widely distribution (Moure et al., 2012), and X. aurulenta (Fabricius, 1804), which is restricted to the Amazonian domain.

We also recorded three species of sweat bees. Two of them are widely distributed: *Megalopta amoena* (Spinola, 1853) occurs from Guatemala to the state of São Paulo in Brazil, while *M. sodalis* (Vachal, 1904) occurs from Venezuela to the Brazilian state of Santa Catarina. However, *Stilbochlora eickworti* (Engel, Brooks & Yanega, 1997) is strictly an Amazonian species. Only five species sampled in this study were among those listed by Santos et al. (2004): *El. nigrita*, *M. seminigra*, *T. dalatorreana*, *T. pallens*, and *P. testacea*. This small proportion of overlap in sampled species is likely due to differences in the methodologies used in both the surveys. In total, Santos et al. (2004) captured 83 species from 38 genera and five families.

In this inventory, we expected to sample specimens from at least three different families of bees: Apidae, Halictidae, and Andrenidae. The lack of Andrenidae species is probably due to the poor sampling efficiency of the pan traps. The efficiency of pan traps is not well studied, but may be dependent on the local vegetation type, water availability, and both type and placement of traps (Gonçalves et al., 2012). Previous studies have reached different conclusions about the performance of this sampling method. Krug and Alves-Dos-Santos (2008), Gonçalves and Oliveira (2013), Ayala (2014), Perillo et al. (2017) for instance, reported capture efficiency. However, Gonçalves et al. (2012) reported very poor performance of these traps in Atlantic Forest.

Out of the 23 genera of stingless bees reported for Pará (Pedro, 2014), 48.8% were captured with arboreal urine pitfall. Based on our results, we encourage the use of this trap as complementary sampling method for bee inventories, especially in northern Brazil, where there is high species richness of stingless bees (Oliveira et al., 1995). We suggest this sampling method may help overcome the difficulty in sampling them passively in forested areas, especially with pan traps. The arboreal urine pitfall traps also seem to be efficient in sampling specimens of *Paratetrapedia*, *Tetrapedia*, *Xilocopa*, *Ceratina*, and Halictidae bees.

In summary, the bee community in the transitional Cerrado-Amazon area we sampled contains fifteen endemic species from the Amazonia region, one species endemic to the Cerrado as well as 27 species which occur in forest and areas of Cerrado. We suggest that future studies employing arboreal urine pitfalls are needed to properly evaluate the sampling efficiency of urine pitfall traps, especially for sampling Meliponini bees.

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Author contributions

RPSA collected the specimens and wrote the text; FVA collected the specimens and wrote the text; DPS wrote the text; e BWTC identified the specimens and wrote the text.

References

Aguiar, A.J.C. & Melo, G.A.R. (2011). Revision and phylogeny of the bee genus Paratetrapedia Moure, with description of a new genus from the Andean Cordillera (Hymenoptera, Apidae, Tapinotaspidini). Zoological Journal of the Linnean Society, 162(2): 351–442. doi: 10.1111/j.1096-3642.2010.00678.x

Alvarenga, P.E.F., Freitas, R.F. & Augusto, S.C. (2007). Diversidade de Euglossini (Hymenoptera: Apidae) em Áreas de Cerrado do Triângulo Mineiro, MG. Bioscience Journal, 23: 30–37

Andena, S., Rolandi, L. & Mechi, M.R. (2005). A Comunidade de abelhas (Hymenoptera, Apoidea) de uma área de cerrado (Corumbataí, SP) e suas visitas às flores. Revista Brasilera Zoociencias Juiz de Fora., 7(1): 55–91. doi: 10.1590/S0085-56262005000400017

Antonini, Y., Silveira, R.A., Oliveira, M.L., Martins, C. & Oliveira, R. (2016). Orchid bee fauna responds to habitat complexity on a savanna area (Cerrado) in Brazil. Sociobiology, 63(2): 819–825. doi: 10.13102/sociobiology.v63i2.1038

Campos, L.A.O., Silveira, F.A., Oliveira, M.L. de, Abrantes, C.V.M., Morato, E.F., & Melo, G.A.R. (1989). Utilização de armadilhas para a captura de machos de Euglossini (Hymenoptera, Apoidea). Revista Brasileira de Zoologia, 6(4): 621–626. doi: 10.1590/S0101-81751989000400008

Cane, J.H., Minckley, R.L. & Kervin, L.J. (2000). Sampling Bees (Hymenoptera: Apiformes) for Pollinator Community Studies: Pitfalls of Pan-Trapping. Journal of the Kansas Entomological Society, 73(4): 225–231. doi: 10.2307/25085973

Cardoso, P., Erwin, T.L., Borges, P.A.V. & New, T.R. (2011). The seven impediments in invertebrate conservation and how to overcome them. Biological Conservation, 144(11): 2647–2655. doi: 10.1016/j.biocon.2011.07.024

Costa-Neto, D.J., Valadares, M.S., Silva-Costa, E.S. & Souto, J.N. (2016). Levantamento da fauna de abelhas sem ferrão no estado do Tocantins. Acta Biológica Catarinense, 2(3): 138–48

Diniz-Filho, J.A.F., de Marco, P. & Hawkins, B.A. (2010). Defying the curse of ignorance: Perspectives in insect macroecology and conservation biogeography. Insect Conservation and Diversity, 3(3): 172–179. doi: 10.1111/j.1752-4598.2010.00091.x

Faria, L.R.R. & Silveira, F.A. (2011). The orchid bee fauna (Hymenoptera, Apidae) of a core area of the Cerrado, Brazil: The role of riparian forests as corridors for forest-associated bees. Biota Neotropica, 11(4): 87–94. doi: 10.1590/s1676-06032011000400009

Fisher, B.L. (1999). Improving Inventory Efficiency: A case study of leaf-litter ant diversity in Madagascar. Ecological Applications, 9(2): 714–731.

Gonçalves, R.B. & Oliveira, P.S. (2013). Preliminary results of bowl trapping bees (Hymenoptera, Apoidea) in a southern Brazil forest fragment. Journal of Insect Biodiversity, 1(2): 1–9. doi: 10.12976/jib/2013.1.2

Gonçalves, R.B., Santos, E.F., & Scott-Santos, C.F. (2012). Bees (Hymenoptera: Apoidea: Apidae s.l.) captured with Malaise and pan traps along an altitudinal gradient in the Parque Estadual da Serra do Mar, Ubatuba, São Paulo, Brazil. Chek List, 8(1): 53–56.

Haidar, R.F., Fagg, J.M.F., Pinto, J.R.R., Dias, R.R., Damasco, G., Silva, L.C.R. & Fagg, C.W. (2013). Florestas estacionais e áreas de ecótono no estado do Tocantins, Brasil: parâmetros estruturais, classificação das fitofisionomias florestais e subsídios para conservação. Acta Amazonica, 43(3): 261–290. doi: 10.1590/S0044-59672013000300003

Hall, H.G. (2016). Color Preferences of Bees Captured in Pan Traps. Journal of the Kansas Entomological Society, 89(3): 273–276. doi:10.2317/JKESD1600022.1

Hortal, J., Bello, F., Diniz-Filho, J.A.F., Lewinsohn, T.M., Lobo, J.M. & Ladle, R.J. (2015). Seven Shortfalls that Beset Large-Scale Knowledge of Biodiversity. Annual Review of Ecology, Evolution, and Systematics, 46(1): 523–549. doi: 10.1146/annurev-ecolsys-112414-054400

Imperatriz-Fonseca, V.L., Alves-dos-Santos, I., Santos-Filho, P.D.S., Engels, W., Ramalho, M., Wilms, W., Aguilar, J.B.V., Pinheiro-Machado, C.A., Alves, D.A. & Kleinert, A.D.M.P. (2011). Checklist das abelhas e plantas melitófilas no Estado de São Paulo, Brasil. Biota Neotropica, 11: 631–655. doi: 10.1590/S1676-06032011000500029

Joshi, N.K., Leslie, T., Rajotte, E.G., Kammerer, M.A., Otieno, M. & Biddinger, D.J. (2015). Comparative trapping efficiency to characterize bee abundance, diversity, and community composition in apple orchards. Annals of the Entomological Society of America, 108(5): 785–799. doi: 10.1093/aesa/sav057

Kaspari, M., Yanoviak, S.P., Dudley, R., Yuan, M. & Clay, N.A. (2009). Sodium shortage as a constraint on the carbon cycle in an inland tropical rainforest. Proceedings of the National Academy of Sciences, 106(46): 19405–19409. doi: 10.1073/pnas.0906448106

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences, 274(1608): 303–313. doi: 10.1098/rspb.2006.3721

Krug, C. & Alves-dos-Santos, I. (2008). O Uso de Diferentes Métodos para Amostragem da Fauna de Abelhas (Hymenoptera: Apoidea), um Estudo em Floresta Ombrófila Mista em Santa Catarina. Neotropical Entomology, 37(June): 265–278. doi: 10.1590/S1519-566X2008000300005

Maravalhas, J. & Vasconcelos, H.L. (2014). Revisiting the pyrodiversity-biodiversity hypothesis: Long-term fire regimes and the structure of ant communities in a Neotropical savanna hotspot. Journal of Applied Ecology, 51(6): 1661–1668. doi: 10.1111/1365-2664.12338

Marimon, B.S., Lima, E.S., Duarte, T.G., Chieregatto, L.C. & Ratter, J.A. (2006). Observations on the vegetation of northeastern Mato Grosso, Brazil. IV. An analysis of the Cerrado-Amazonian forest ecotone. Edinburgh Journal of Botany, 63(2–3): 323-341. doi: 10.1017/S0960428606000576

Moure, J.S., Melo, G.A.R. & Faria, Jr L.R.R. (2012). Euglossini Latreille, 1802. In: Moure, J.S.; Urban, D.; Melo, G.A.R. (Org.). Catalogue of Bees (Hymenoptera, Apoidea) in the Neotropical Region - online version.

Nemésio, A. & Silveira, F.A. (2007). Diversity and distribution of orchid bees (Hymenoptera: Apidae) with a revised checklist of species. Neotropical Entomology, 36(6): 874–888. doi: 10.1590/S1519-566X2007000600008

Nemésio, A. & Vasconcelos, H.L. (2014). Effectiveness of two sampling protocols to survey orchid bees (Hymenoptera: Apidae) in the Neotropics. Journal of Insect Conservation, 18(2): 197–202. doi:10.1007/s10841-014-9629-5

Nemésio, A. (2012). Methodological Concerns and Challenges in Ecological Studies With Orchid Bees (Hymenoptera: Apidae: Euglossina). Bioscience Journal, 28(1): 118–135.

Nemésio, A., & Faria-Junior, L.R.R. (2004). First assessment of the orchid-bee fauna (Hymenoptera: Apidae) at Parque Estadual do Rio Preto, a cerrado area in southeastern Brazil. Lundiana, 5(2): 113–117

Oliveira, M.L., Morato, E.F. & Garcia, M.V.B. (1995). Diversidade de espécies e densidade de ninhos de abelhas sociais sem ferrão (Hymenoptera, Apidae, Meliponinae) em floresta de terra firme na Amazônia central. Revista Brasileira de Zoologia, 12(1): 13–24. doi: 10.1590/S0101-81751995000100004

Oliveira-Junior, J.M.B., Almeida, S.M., Rodrigues, L., Silvério-Júnior, A.J. & Anjos-Silva, E.J. (2015). Orchid bees (Apidae: Euglossini) in a forest fragment in the ecotone Cerrado-Amazonian forest, Brazil. Acta Biologica Colombiana, 20(3): 67–78. doi: 10.15446/abc.v20n3.41122

Ollerton, J., Winfree, R. & Tarrant, S. (2011). How many flowering plants are pollinated by animals? Oikos, 120(3): 321–326. doi:10.1111/j.1600-0706.2010.18644.x

Pedro, S.R.M. & Camargo, J.M.F. (2003). Meliponini neotropicais: o gênero Partamona Schwarz, 1939 (Hymenoptera, Apidae). Revista Brasileira de Entomologia, 47: 1–117. doi: 10.1590/S0085-56262003000500001

Pedro, S.R.M. (2014). The stingless bee fauna in Brazil (Hymenoptera: Apidae). Sociobiology, 61(4): 348–354. doi: 10.13102/sociobiology.v61i4.348-354

Perillo, L.N., Neves, F.D.S., Antonini, Y. & Martins, R.P. (2017). Compositional changes in bee and wasp communities along Neotropical mountain altitudinal gradient. PLoS ONE, 12(7): 1–14. doi: 10.1371/journal.pone.0182054

Pioker-Hara, F.C. (2011). Determinantes da densidade e distribuição de ninhos e diversidade de espécies de meliponíneos (Apidae, Meliponini) em áreas de cerrado de Itirapina, SP. Tese de doutorado, 231.

Ramírez Freire, L., Alanís Flores, G., Ayala Barajas, R., Velazco Macías, C. & Favela Lara, S. (2014). Using pan traps and netting to collect native bees in Nuevo León state, Mexico El uso de platos trampa y red entomológica en la captura de abejas nativas en el estado de Nuevo León, México TT - Using pan traps and netting to collect native bees in Nuevo. Acta zoológica mexicana, 30(3): 508–538. doi: 10.21829/azm.2014.30375

Rebêlo, J.M.M., Rêgo, M.M.C. & Albuquerque, P.M.C. (2003). Abelhas (Hymenoptera, Apoidea) da região setentrional do Estado do Maranhão, Brasil. Apoidea Neotropica: Homenagem aos 90 Anos de Jesus Santiago Moure,. In: Melo, G.A.R., Alves-dos-Santos, I. (orgs) Apoidea Neotropica: Homenagem aos 90 Anos de Jesus Santiago Moure, UNESC. Criciúma, p 265–278.

Roulston, T.H., Smith, S.A. & Brewster, A.L. (2007). A Comparison of Pan Trap and Intensive Net Sampling Techniques for Documenting a Bee (Hymenoptera: Apiformes) Fauna. Journal of the Kansas Entomological Society, 80(2): 179–181.

Sakagami, S.F., Laroca, S. & Moure, J.S. (1967). Wild Bee Biocoenotics in São Jose dos Pinhais (PR), South Brazil. Journal of the Faculty of Science Hokkaido University, 16(2): 253–291.

Santiago, L.R., Brito, R.M., Muniz, T.M.V.L., Oliveira, F.F. & Francisco, F.D.O. (2009). A fauna apícola do Parque Municipal da Cachoeirinha (Iporá, GO). Biota Neotropica, 9(3): 393–397. doi: 10.1590/S1676-06032009000300034

Santos, F.M., Carvalho C.A.L. & Silva, R.F. (2004). Diversidade de abelhas (Hymenoptera: Apoidea) em uma área de transição Cerrado-Amazônia. Acta Amazonica, 34(2): 319–328. doi: 10.1590/S0044-59672004000200018

Silva, D.P. & De Marco, P. (2014). No evidence of habitat loss affecting the orchid Bees *Eulaema nigrita* Lepeletier and *Eufriesea auriceps* friese (Apidae: Euglossini) in the Brazilian Cerrado Savanna. Neotropical Entomology, 43(6): 509–518. doi: 10.1007/s13744-014-0244-7

Silva, D.P., Nogueira, D.S. & De Marco, P. (2017). Contrasting Patterns in Solitary and Eusocial Bees While Responding to Landscape Features in the Brazilian Cerrado: a Multiscaled Perspective. Neotropical Entomology, 46(3): 264–274. doi: 10.1007/s13744-016-0461-3

Sofia, S.H. & Suzuki, K.M. (2004). Comunidades de machos de abelhas Euglossina (Hymenoptera: Apidae) em fragmentos florestais no Sul do Brasil. Neotropical Entomology, 33(6): 693–702. doi: 10.1590/S1519-566X2004000600006

Sydney, N.V., Gonçalves, R.B. & Faria, L.R.R. (2010). Padrões espaciais na distribuição de abelhas Euglossina (Hymenoptera, Apidae) da região neotropical. Papéis Avulsos de Zoologia, 50(43): 667–679. doi: 10.1590/S0031-10492010004300001

Vital, S.L., Souza-Leão, M.V.P., Campêlo, P.H. & Previero, C.A. (2016). Levantamento de abelhas Euglossini (Hymenoptera: Apidae) como possíveis bioindicadoras da qualidade ambiental no reassentamento rural Mariana,. XVI Jornada de Iniciação Científica do CEULP/ULBRA RESUMO, (December): 1–7.

Wilson, J.S., Griswold, T. & Messinger, J.O. (2008). Sampling Bee Communities (Hymenoptera: Apiformes) in a Desert Landscape: Are Pan Traps Sufficient? Journal of the Kansas Entomological Society, 81(3): 288–300.

Supplementary Material

Aguiar, A.J.C. & Melo, G.A.R. (2011). Revision and phylogeny of the bee genus Paratetrapedia Moure, with description of a new genus from the Andean Cordillera (Hymenoptera, Apidae, Tapinotaspidini). Zoological Journal of the Linnean Society, 162(2): 351–442. doi: 10.1111/j.1096-3642.2010.00678.x

Dressler, R.L. (1982). New species of Euglossa IV. The cordata and purpurea species groups (Hymenoptera: Apidae). Revista de Biologia Tropical, 30(2): 141–150.

Engel, M.S. (2000). Classification of the Bee Tribe Augochlorini (Hymenoptera: Halictidae). Bulletin of the American Museum of Natural History, 250(1): 90. doi: 10.1206/0003-0090(2000)250<0001:COTBTA>2.0.CO;2

Kimsey, S.L. (1982). Systematics of bees of the genus Eufriesea Hymenoptera: Apidae). University of California Publications in Entomology

Moure, J.S. (1950). Notas sobre alguns Meliponinae Bolivianos (Hymenoptera, Apoidea). Dusenia, 1(1): 70–80.

Moure, J.S. (1950). Contribuição para o conhecimento das espécies brasileiras de Hypotrigona Cockerell (Hym. Apoidea). Dusenia, 1(4): 241–260.

Oliveira, M.L. (2006). Três novas espécies de abelhas da Amazônia pertencentes ao gênero Eulaema (Hymenoptera: Apidae: Euglossini). Acta Amazonica, 36(1): 121–127. doi: 10.1590/S0044-59672006000100015

Pedro, S.R.M. & Camargo, J.M.F. (2003). Meliponini neotropicais: o gênero *Partamona* Schwarz, 1939 (Hymenoptera, Apidae). Revista Brasileira de Entomologia, 47: 1–117. doi: 10.1590/S0085-56262003000500001

Rasmussen, C. & Gonzalez, V.H. (2017). The neotropical stingless bee genus *Nannotrigona* Cockerell (Hymenoptera: Apidae: Meliponini): An illustrated key, notes on the types, and designation of lectotypes. Zootaxa, 4299(2): 191–220. doi:10.11646/zootaxa.4299.2.2

Santos, L.M. & Melo, G.A.R. (2015). Updating the taxonomy of the bee genus *Megalopta* (Hymenoptera: Apidae, Augochlorini) including revision of the Brazilian species. Journal of Natural History, 49(11–12): 575–674. doi: 10.1080/00222933.2014.946106

Schrottky, C. (1902). Ensaio sobre as abelhas solitarias do Brazil. Revista do Museu Paulista, 5: 330–613.

Schwarz, H.F. (1932). The genero Melipona. Bulletin of the American Museum of Natural Historty, 63: 231–460.

Schwarz, H.F. (1938). The Stingless Bees (Meliponidae) of British Guina and Some Related Forms. Bulletin of the American Museum of Natural Historty, 74: 437–508

Schwarz, H.F. (1948). Stingless Bees (Meliponidae) of the Western Hemisphere. Bulletin of the American Museum of Natural Historty, 90: 1–546.