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Species Richness and Diversity in Bee Assemblages in a Fragment of Savanna (Cerrado) at Northeastern Brazil

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Abstract

The conservation of the fauna of bees inhabiting the Brazilian savanna is threatened due to changes in land use in the last decades. We investigated the composition, species richness and abundance of a bee assemblage in the vicinity of the Chapada Diamantina National Park. In addition, we compiled data on composition and diversity from another bee assemblage located in the same portion of the Cerrado, which was previously investigated by one of us almost 30 years ago, in order to produce a more complete panorama on beta diversity of bees in this region. We used a non-metric multidimensional scaling ordination analysis (NMDS) to compare composition of bee assemblages from different types of open vegetation. We recorded 77 bee species ($H' = 2.95$; $J = 0.68$), 42% of them were singletons. We collected slightly more than half of the species and 60% of the genera recorded in the bee assemblage studied three decades ago. H' was significantly lower in our area than in the previous study ($t = 8.588$, $p < 0.001$), but equitability (J) was very similar. Several factors may contribute to these differences, including local differences in bee assemblage composition, differences in the probability of capturing the different species (many rare species), factors affecting the sampling itself, and perhaps species loss over the three decades separating the two studies. The magnitude of species loss is difficult to assess because the two studies were not carried out exactly in the same area and there were differences in sampling time and sampling effort.

Introduction

Bees stand out as the dominant taxonomic group of pollinators in most geographic regions (Williams et al., 2001). These bee populations depend on plant resources related to adult maintenance and offspring production, which include supplies of nectar and pollen (Roubik, 1989; Michener, 2007). Some species require additional resources such as floral oils, floral fragrances or resins, as well as adequate nesting sites (Roubik, 1989). The persistence of different populations of bees can be strongly affected by habitat quality, which can be evaluated, among other parameters, by the abundance

of available floral resources (Rosa & Ramalho, 2011). Declines in species richness and abundance, as well as some substitution in the dominant species over the last decades have been reported in Brazil (Martins et al., 2013; Cardoso & Gonçalves, 2018).

The Brazilian savanna (Cerrado) is a biodiversity hotspot (Myers et al., 2000; Silva & Bates, 2002). In spite of its importance for the conservation of biodiversity, anthropic pressures on the Cerrado have increased in recent decades, mainly due to the expansion of pasturelands and croplands, including the mechanized production of grains, soybean and maize (Klink & Machado, 2005; Sano et al., 2010). The



replacement of native vegetation promotes habitat loss and fragmentation, reduction of the local floristic diversity and in the abundance of floral resources available to the bees, as well as the reduction of cavities (e.g. tree hollows) available for nest construction. Impacts on soil, such as those resulting from ploughing the soil (Freitas et al., 2009), increase in pavement and changes in soil permeability (Fortel et al., 2014) are also relevant, especially for the brood, since most bees nest under the soil surface (Roubik, 1989). Carvalho et al. (2009) pointed out the urgent need to understand how the land use in mosaics influences the persistence of animal and plant populations, as well as the maintenance of ecological processes.

Although the bee fauna of the southernmost part of the Cerrado (19° to 24° S) is well sampled (Silveira & Campos, 1995; Carvalho & Bego, 1996; Andena et al., 2005; 2012; and unpublished studies cited in Faria & Gonçalves, 2013), there are significant sampling gaps in the northern and middle portions of the Cerrado domain. In this study we present new data on the bee assemblage of a fragment located in the middle portion of the Cerrado, in the Chapada Diamantina, an area where there is a mosaic of phytophysiognomies (cerrado, caatinga, campos rupestres and forests) at short distances (Harley, 1995). In addition, we compiled data on the composition and species richness from another bee assemblage located in the same portion of the Cerrado at Chapada Diamantina region (12° 34' 0" S; 41° 22' 60" W, Cerrado with elements of Campos rupestres), which was previously investigated by one of us (Martins, 1994), to yield a more complete panorama on beta diversity of bees in this region. These sites are located in the vicinity of a biodiversity protection area, the Chapada Diamantina National Park (12° 20' - 12° 25' S; 41° 35' - 41° 15' W), and knowledge of local species richness can help in the establishment of land use policies and conservation strategies for the surrounding areas of the Park.

Methods

Study area

The study area is located in the municipality of Palmeiras (altitude: 727 m), State of Bahia, Brazil. It is covered by Cerrado (Brazilian savanna vegetation). Nearby there are other types of vegetation, mainly Caatinga (seasonally dry forest) and Campos Rupestres (sandstone outcrop vegetation), which surround with this Cerrado fragment. Additionally, close to the Cerrado there are different types of forests, forming a vegetation mosaic typical of the Chapada Diamantina region (Harley, 1995). The climate is tropical humid, with rainy season from December to April in general, while the driest period is from August to November (Jesus et al., 1983; Nimer, 1989). The average rainfall ranges from 600 to 1000 mm/year, and the average temperature is 22° C (CEI, 1994).

The sampled area was divided into three sampling sites, I: Teto Verde (12° 26' 03" S, 41° 29' 22" W), II: Barranco (12° 26' 19" S, 41° 30' 11" W), and III: Coités (12° 25' 50" S; 41° 30' 20" W), ranging from 900 m to 1,700 m apart.

In each site, three transects were chosen to sample the bees, totaling nine transects (see Supplementary Material 1 for geographic coordinates), each one measuring approximately 1,500 m in length and 6 m in width. The Cerrado vegetation sampled was composed of herbaceous-shrub fields and sparse small trees (sites I and III). Trees were small to medium size on site II. *Byrsonima sericea* and *Byrsonima cydoniifolia* (Malpighiaceae) trees were very common in all three sites. Signs of anthropic activities include the presence of nearby highways (BR 242 and BA 480), some dirt roads, and small-scale clay extraction (site II). This area suffers from burnings on native vegetation, as occurred in December 2015, and affected site I, near Morro do Pai Inácio.

Data sampling

We performed 17 samplings between 2013 and 2016 (Table 1). In each sample, the bees were collected during two consecutive days, from 8:00 am to 4:00 pm, by two collectors, totaling 34 days and 408 h of sampling effort per collector. At each sampling, three transects were sampled, one at each site (I, II, III). The transect to be sampled in each subarea was randomly chosen, in order to distribute the collection effort among the nine transects. Bees flying or visiting flowers were captured with entomological nets, according to Sakagami et al. (1967). In each flowering plant, floral visitors were captured for 5 to 10 minutes. The bees were dry mounted and identified by one of us (F. Vivallo) and other bee specialists employing the multi-family classification system used in Michener (2007) and genus- and species-level classification of Moure et al. (2007).

Data analysis

We used the Shannon index ($H' = -\sum p_i \times \ln p_i$) to evaluate the diversity and the Pielou index ($J' = H' / \log_2 S$) to evaluate the uniformity of abundance distribution (Magurran, 2011). We used a one-sample t-test proposed by Hutcheson (Zar, 1999) to investigate whether H' value found in our area differed from that calculated for the area studied by Martins (1994).

Species dominance was calculated using the Kato index. This index considers as dominant the species whose value of the lower limit (LI) of relative abundance is above the limit of dominance (LD). LD is obtained by the inverse of the total number of species captured multiplied by 100 (Sakagami & Matsumura, 1967). To evaluate whether the sample effort was sufficient to sample the species richness of the bee assemblage, we used Chao and Jackknife richness estimators (Magurran, 2011).

We used a non-metric multidimensional scaling ordination analysis (NMDS) based on Bray-Curtis similarity index, to compare the similarity in the composition of bee assemblages from different types of open vegetation: Cerrado (CEBA1: Lençóis, Bahia (Martins, 1994); CEBA2: Palmeiras, Bahia (este estudo); CEGO1: Iporá, Goiás (Santiago et al.,

2009); CEMA1: Barreirinhas, Maranhão (Rêgo & Albuquerque, 2012); CEMA2: Chapadinha, Maranhão (Rêgo & Albuquerque, 2012); CEMG1: Uberlândia, Minas Gerais (Carvalho & Bego, 1996); CEMG2: Paraopeba, Minas Gerais (Silveira & Campos, 1995), CESP1: Corumbataí, São Paulo (Silveira & Campos, 1995), CESP2: Corumbataí, São Paulo (Andena et al., 2005), CESP3: Santa Rita do Passa Quatro, São Paulo (Andena et al., 2012); CETO1: Esperantina, Tocantins (Santos et al., 2004)), Campos rupestres (CRBA1: Palmeiras, Bahia (Silva-Pereira & Santos, 2006); CRMG1: Ouro Branco, Minas Gerais (Araújo et al., 2006); CRMG2: Lavras Novas, Minas Gerais (Faria-Mucci et al., 2003)), Caatinga (CABA1: Casa Nova, Bahia (Martins, 1994); CABA2: Castro Alves, Bahia (Santos et al., 2013); CABA3: Itatim, Bahia (Aguiar & Zanella, 2005); CAPB1 (São João do Cariri, Paraíba (Aguiar & Martins, 1997); CAPE1: Chã Grande, Pernambuco (Milet-Pinheiro & Schlindwein, 2008); CARN1: Serra Negra do Norte, Rio Grande do Norte (Zanella, 2003)); and Canga (CGMG1: Ouro Preto, Minas Gerais (Araújo et al., 2006)). We constructed a matrix containing the number of species per bee genera in each of these 21 sites. We made

this analysis using the package vegan version 2.4-3 (Oksanen et al., 2017), and to plot the figure we used the ggplot2 package (Wickham, 2009), both in the R software version 3.0.3 (R Development Core Team, 2016).

Results

The bee assemblage of this Cerrado fragment was composed of 77 species, distributed in 42 genera (Table 1). The number of species at each sampling point was 40 (site I), 43 (site II) and 48 (site III), and 43 species were recorded at a single sampling point (Table 1). Apidae had a significant contribution to the richness of species (74% of all species), especially Centridini ($S = 18$) and Meliponini ($S = 10$). The species diversity was $H' = 2.95$ and the equability $J = 0.68$. The Chao 1 and Jackknife 2 estimators indicated that the expected richness for this area (130 and 138 species, respectively) is higher than the observed richness. The species richness curve showed an increasing slope, indicating that there are species not yet sampled in the assemblage (Figs 1A, 1B).

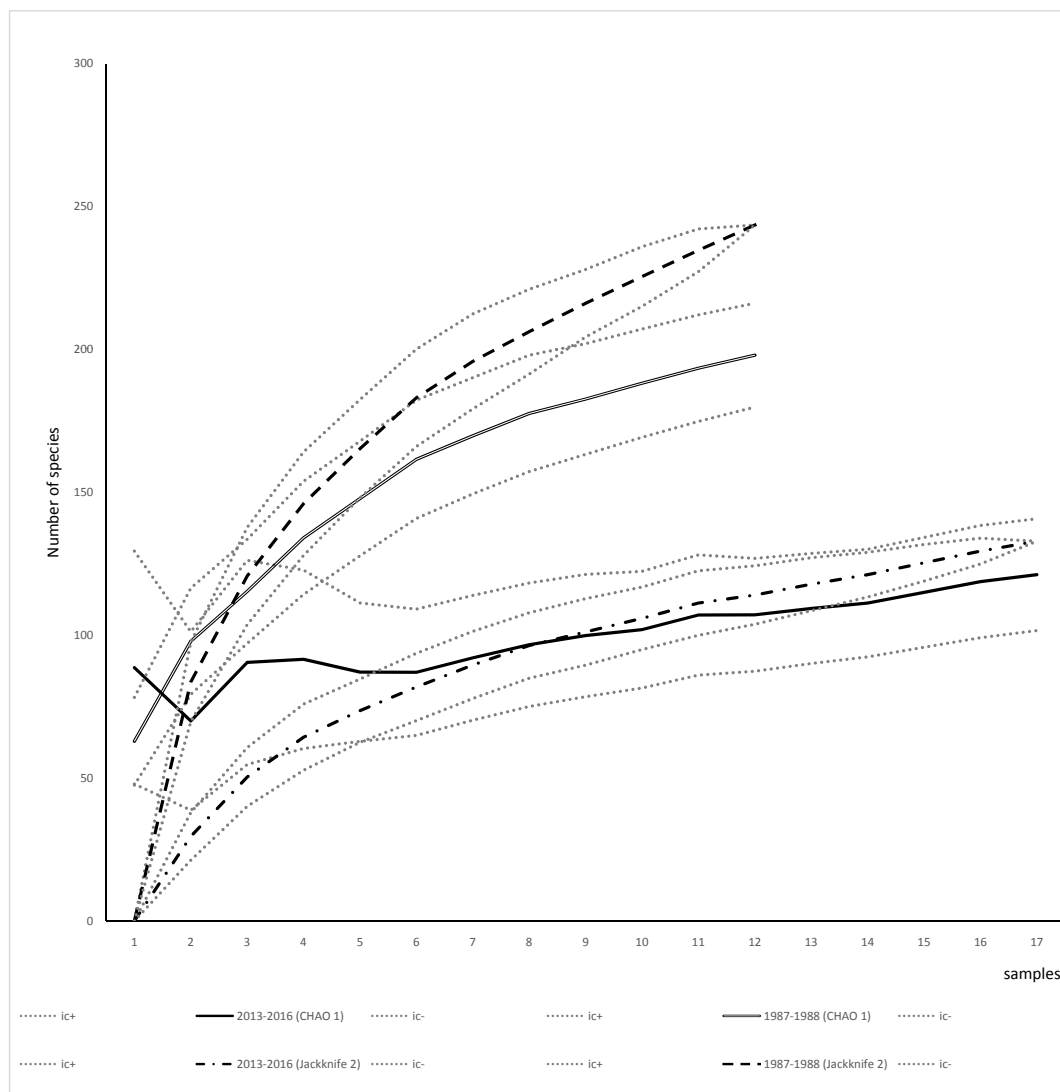


Fig 1A. Species richness curves (estimators abundance data based, Jackknife 2 and Chao 1) in bee assemblages in a Neotropical savanna (Cerrado), Brazil.

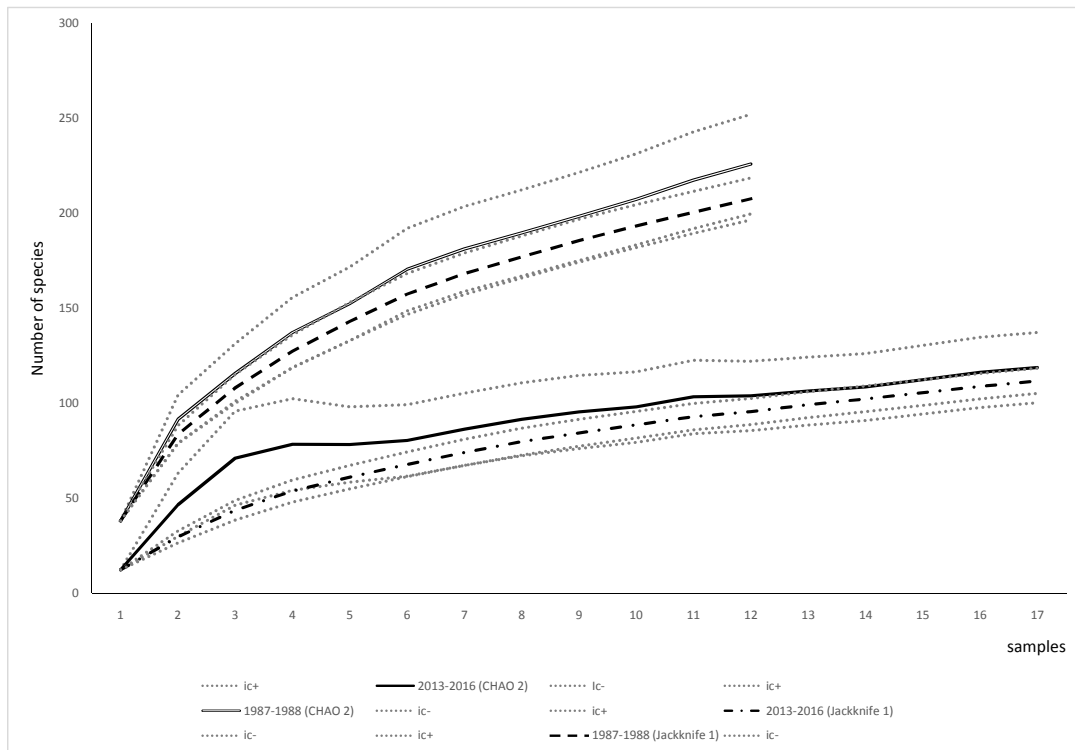


Fig 1B. Species richness curves (estimators incidence data based, Jackknife 1 and Chao 2) in bee assemblages in a Neotropical savanna (Cerrado), Brazil.

The distribution of abundances was quite uneven among species. The vast majority of species were infrequent, 42% of them were singletons and 12% doubletons. Few species were dominant: the introduced Africanized honeybee *Apis mellifera* Linnaeus (20.5%), *Centris aenea* Lepeletier (14.5%), *Trigona spinipes* (Fabricius) (13.2%), *Scaptotrigona aff. postica* (Latreille) (11.5%), *Epicharis bicolor* Smith (4%), *Trigona hyalinata* (Lepeletier) (3.8%), *Epicharis analis* Lepeletier (3.2%), *Centris perforator* Smith (2.5%), and *Centris caxienseis* Ducke (2.1%). Apidae showed the highest relative abundance (94% of individuals), while other bee families were poorly represented. The species *A. mellifera*, *C. aenea*, *C. perforator* and *T. spinipes* occurred in more than 50% of the samples, while most species (67 species) occurred in less than 25% of the samples (Table 1).

Regarding the composition of the analyzed bee assemblages, the non-metric ordination analysis (NMDS; $S = 0.177$) allowed to recognize two distinct groups (Fig 2). The first grouping the bee assemblages from Caatinga (CA), and a second one mixing bee assemblages from Cerrado (CE), Campos rupestres (CR) and Canga (CG), which were not differentiated by type of vegetation, although this group differed from that of bee assemblages of the Caatinga.

Discussion

Even with sampling extending for several years, we obtained a species richness curve that did not stabilize, which should be influenced by the occurrence of many rare species (Williams et al., 2001), a similar finding of most surveys of

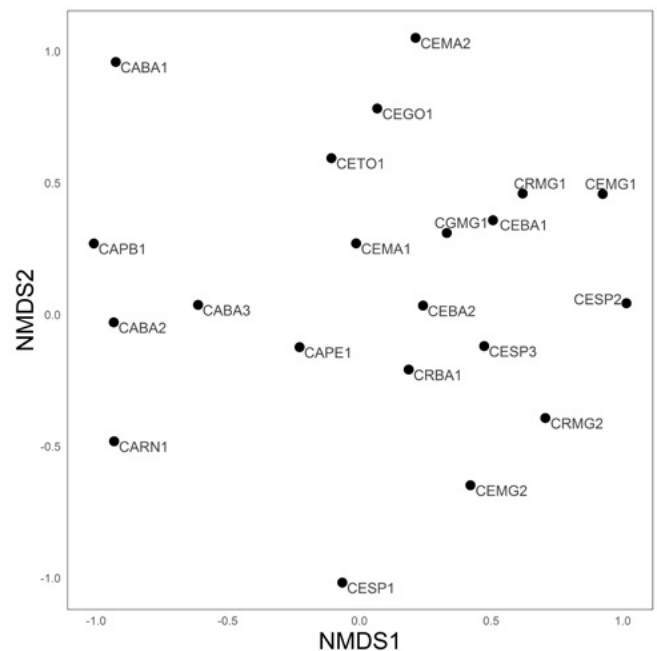


Fig 2. Non-metric multidimensional scaling (NMDS) ordination plot. $S = 0.177$. Types of vegetation: Caatinga (CABA1; CABA2; CABA3; CAPB1; CAPE1; CARN1), Campos rupestres (CRBA1; CRMG1; CRMG2), Canga (CGMG1), Cerrado (CEBA1; CEBA2; CEGO1; CEMA1; CEMA2; CEMG1; CEMG2; CESP1; CESP2; CESP3; CETO1).

bee assemblages. Many species (53%) were represented in only one of the three sampling points, indicating that sampling in a single site is quite biased to represent the local richness of species in bee assemblages, as pointed out by others

(Zanella, 2003; Gonçalves et al., 2009). Many species in bee assemblages are rare (singletons or doubletons), so the probability of capture them is small, even when there is a large sampling effort (Williams et al., 2001). The comparison of the composition of this bee assemblage with that one located 19 km away previously investigated by one of us (Martins, 1994) showed that each of them presents several exclusive elements (Supplementary Material 1). Fifteen genera and 29 species were added to previous knowledge on the bee species richness of this portion of the Cerrado. Thus, the total number of bee species recorded for this Cerrado at Chapada Diamantina, is at least 177 species (Supplementary Material 1). The analysis of beta diversity at genus level, which presents little taxonomic impediment, resulted in a total of 60 genera. Most genera were represented by one or two species, but *Megachile*, *Centris*, *Augochloropsis* and *Augochlora* contributed with more than 10 species to the species richness (Supplementary Material 1). The assemblage recently sampled by us presented slightly more than half of the species and 60% of the genera recorded in the bee assemblage studied three decades ago ($S = 147$, $H' = 3.53$, $J = 0.71$) (Martins, 1994; Supplementary Material 1), despite the sampling effort in our study (34 days over the course of four years) was higher than that of Martins (1994) (24 days in one year). The two bee assemblages here compared showed different diversity, H' was significantly lower in our area ($t = 8.588$, $p < 0.001$). On the other hand, the level of equitability (J) was very similar, indicating that differences in H' values were mainly influenced by differences in species richness, as the abundance distribution was similar. It is noteworthy that some groups as the orchid bees (Euglossini), Anthidiini, *Megachile* and its cleptoparasites (*Coelioxys*) were much richer in the former study. On the other hand, oil collecting bees (Centridini) were richer in our study site than in Martins (1994), which may be related to the large local supply of floral oil by species of *Byrsonima* (Malpighiaceae) (Aguiar et al., 2017).

Several factors may have contributed to these observed differences, including local differences in bee assemblage composition, even if they are close (see also Williams et al., 2001; Zanella, 2003; Gonçalves et al., 2009), differences in the probability of capturing the different species, factors affecting the sampling itself, and perhaps species loss over the three decades separating the two studies. Small populations, which are the majority of the components of both bee assemblages, are less likely to be sampled; although they may be resident species, they may not have been recorded. Thus, the absence of many of the rare species collected by Martins (1994; Supplementary Material 1) in current sampling may be a consequence to their rarity, as pointed out by Martins et al. (2013) when they compared changes in the bee fauna over 40 years. In our case, the magnitude of species loss is difficult to assess because the two studies were not carried out exactly in the same area and there were differences in sampling time and sampling effort.

There are large variations in the observed species richness among bee assemblages in the Cerrado, as previously discussed by Gonçalves et al. (2009), and Faria and Gonçalves (2013). Bee assemblages composed of around 40 species were recorded in the northernmost portion (2° to 3° S) (Rebêlo et al., 2003; Rêgo & Albuquerque, 2012), but Santos et al. (2004) recorded 83 species in an area (5°20' S) with a strong influence of livestock activity. On the other hand, in the southern portion of the Cerrado (19° to 24° S), bee assemblages are generally composed of more than one hundred to almost two hundred species (Carvalho & Bego, 1996; Menezes-Pedro & Camargo, 1991; Silveira & Campos, 1995; and unpublished studies cited in Faria & Gonçalves, 2013), although there are also some areas where species richness is lower (67-70 spp.) in this southernmost portion (Andena et al., 2005; 2012). Faria and Gonçalves (2013) found that diversity and composition in Brazilian bee assemblages were explained by different sets of abiotic variables. Diversity (H') and species richness were highest at places with higher temperature annual range. They also pointed out that the generic composition of bee assemblages varied in response to annual mean temperature and temperature seasonality, as well as to temperature annual range and annual precipitation.

Our results of the ordination analysis (NMDS) reflected the differences in the composition of the bee faunas of Cerrado and Caatinga. Zanella (2000, 2003) pointed out that the bee fauna of the Caatinga presents several endemic elements, which differentiates this group of bee assemblages from those of other vegetations. The lack of differentiation among the bee assemblages of Cerrado and Campos rupestres is probably related to the proximity of these types of vegetation, since in some geographic regions, such as the Chapada Diamantina and other areas in the Espinhaço mountain chain, Campos rupestres occur in altitudes above of 900 m (Giulietti & Pirani, 1988), surrounded by lower areas covered by Cerrado vegetation. Thus, populations of many bee species can colonize neighboring areas in this mosaic of habitats. The sampling hiatus of bee assemblages in the northern and middle portions of the Cerrado still do not allow a realistic picture of bee species diversity in this ecosystem. Current knowledge suggests that there is an increase in the species richness of bees in the north-south direction of the Cerrado. Greater sampling effort should be undertaken in the non-sampled regions to increase knowledge on species richness and distribution, structure of assemblages, as well as to support bee conservation strategies in the face of the increasing degradation of the Cerrado, due in particular to the expansion areas for agricultural crops and pastures.

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Table 1. Species composition and bee abundance in an assemblage in a Neotropical savanna (Cerrado), Brazil. n: number of individuals; sample **1**: Oct 2013/**2**: Nov 2013/**3**: Dec 2013/**4**: Jan 2014/**5**: Feb 2014/**6**: Mar 2014/**7**: Sep 2014/**8**: Nov 2014/**9**: Feb 2015/**10**: Mar 2015/**11**: Apr 2015/**12**: Aug 2015/**13**: Oct 2015/**14**: Jan 2016/**15**: Mar 2016/**16**: May 2016/**17**: Jul 2016. * Species recorded in the area, in odor baits. (Continuation)

Taxa	n	Sites			Samples																
		I	II	III	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Eucerini																					
<i>Florilegus</i> sp. 1	1			1																	1
Euglossini																					
<i>Euglossa cordata</i> (Linnaeus)	2	*	1	1											1					1	
<i>Euglossa melanotricha</i> Moure	*	*	*	*																	
<i>Euglossa securigera</i> Dressler	*	*	*	*																	
<i>Eulaema cingulata</i> (Fabricius)	*	*	*	*																	
<i>Eulaema nigrita</i> Lepeletier	5	3	1	1	1	1	1		1												1
Exomalopsini																					
<i>Exomalopsis</i> (<i>Phanomalopsis</i>) sp. 1	1			1												1					
<i>Exomalopsis</i> (<i>Exomalopsis</i>) sp. 2	1			1												1					
Meliponini																					
<i>Frieseomelitta francoi</i> (Moure)	1	1																			1
<i>Geotrigona mombuca</i> (Smith)	3	1	1	1			1						1		1						
<i>Melipona quadrifasciata</i> Lepeletier	2	1		1			1														1
<i>Nannotrigona testaceicornis</i> (Lepeletier)	4	1		3								1			2			1			
<i>Paratrigona incerta</i> Camargo & Moure	7	1	4	2			4								2				1		
<i>Partamona combinata</i> Pedro & Camargo	2			2											1						1
<i>Scaptotrigona</i> aff. <i>postica</i> (Latreille)	97	10	18	69	7		1					59		1	23	3	2				1
<i>Tetragonisca</i> sp. 1	1		1				1														
<i>Trigona hyalinata</i> (Lepeletier)	32			32				23			8			1							
<i>Trigona spinipes</i> (Fabricius)	111	25	44	42	7		28	1			6	3		12	6	7					13 28
Protepeolini																					
<i>Leiopodus abnormis</i> (Jørgensen)	1		1												1						
Tapinotaspidini																					
<i>Lophopedia nigrispinis</i> (Vachal)	2		1	1			1					1									
<i>Monoeca</i> aff. <i>mourei</i> Aguiar	1	1						1													
<i>Tapinotaspoides</i> sp. 1	2	1	1												1						1
<i>Tropidopedia nigrocarinata</i> Aguiar & Melo	9		8	1			8	1													
<i>Urbanapis diamantina</i> Aguiar & Melo	9		9				1	7		1											
<i>Xanthopedia</i> sp. 1	5		4	1			1		4												
Tetrapediini																					
<i>Tetrapedia amplatarsis</i> Friese	3		3					3													
<i>Tetrapedia diversipes</i> Klug	4			4	3										1						
Xylocopini																					

Table 1. Species composition and bee abundance in an assemblage in a Neotropical savanna (Cerrado), Brazil. n: number of individuals; sample 1: Oct 2013/2: Nov 2013/3: Dec 2013/4: Jan 2014/5: Feb 2014/6: Mar 2014/7: Sep 2014/ 8: Nov 2014/ 9: Feb 2015/ 10: Mar 2015/ 11: Apr 2015/ 12: Aug 2015/ 13: Oct 2015/ 14: Jan 2016/ 15: Mar 2016/ 16: May 2016/ 17: Jul 2016. * Species recorded in the area, in odor baits. (Continuation)

Taxa	n	Sites			Samples																
		I	II	III	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Ceratina (Crewella)</i> sp. 1	10	6	2	2	1		1		1								1	5			1
<i>Ceratina (Crewella)</i> sp. 2	1	1																			1
<i>Ceratina (Crewella)</i> sp. 3	1			1													1				
<i>Xylocopa cearensis</i> Ducke	4	4			2		2														
<i>Xylocopa frontalis</i> (Olivier)	1			1							1										
<i>Xylocopa subcyanea</i> Pérez	1	1			1																
<i>Xylocopa</i> sp. 2	1	1					1														
Colletidae																					
<i>Colletes</i> sp. 1	5		5				5														
Halictidae																					
Augochlorini																					
<i>Augochlora</i> (<i>Oxystoglossella</i>) sp. 3	5	2	2	1	1	2								1	1						
<i>Augochlora</i> (<i>Oxystoglossella</i>) sp. 2	1		1			1															
<i>Augochlora</i> (<i>Augochlora</i>) sp. 5	1			1							1										
<i>Augochloropsis</i> sp. 3	1			1																	1
<i>Augochloropsis</i> sp. 4	1			1												1					
<i>Augochloropsis</i> sp. 5	7		5	2					1					1	4						1
<i>Augochloropsis</i> sp. 6	1	1																			1
<i>Augochloropsis</i> sp. 7	6	1	4	1	1	2	1	1	1												
<i>Augochloropsis</i> sp. 8	2	1	1			1					1										
<i>Pseudaugochlora pandora</i> (Smith)	1		1			1															
<i>Pseudaugochlora</i> sp1	1	1																			1
<i>Temnosoma</i> cf. <i>metallicum</i> Smith	1		1												1						
Halictini																					
<i>Dialictus opacus</i> (Moure)	5	3	2			1	1									2					1
Megachilidae																					
Anthidiini																					
<i>Dicranthidium</i> sp. 1	1	1													1						
Megachilini																					
<i>Coelioxys</i> (<i>Acrocoelioxys</i>) sp. 1	1		1																		1
<i>Megachile</i> (<i>Pseudocentron</i>) sp. 3	1	1														1					
<i>Megachile</i> (<i>Sayapis</i>) sp. 1	1	1														1					
<i>Megachile</i> sp. 8	1		1			1															

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