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The orchid bee fauna in the Brazilian savanna: do forest formations contribute to higher species diversity?

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Abstract – The Neotropical savanna is characterized by a set of different phytophysiognomies occurring in a wide expanse of Brazilian lands. Based on the known higher diversity of orchid bees in forests rather than in savanna formations, we hypothesized that the occurrence of forest formations inside the Brazilian savanna increases the diversity of euglossine bees in that domain and that there are species more associated with these environments. To test this hypothesis, we sampled the euglossine fauna in eight forest and woody savanna remnants and analyzed their community structure. We sampled 1,010 males of 13 species of orchid bees. Bee abundance and species richness ranged from 30 to 341 individuals and from 4 to 12 species, respectively. The forest remnants showed the highest diversity indices and species richness. Our data suggest that some species of *Euglossa* are mainly associated with forest remnants. We concluded that environmental heterogeneity in the Neotropical savanna contributes to higher diversity of euglossine and that some species are more frequently found in forested habitats. Additionally, considering that some sampled species are typical of the Atlantic and Amazon forests, our data reinforce the hypothesis that forest environments inside the Brazilian savanna can be considered bio-corridors for orchid bees.

diversity / euglossinen / biogeography / neotropics / pollinators

1. INTRODUCTION

The Neotropical savanna is considered the richest, largest, and most threatened tropical savanna worldwide (Silva and Bates 2002). These characteristics make it one of the world's biodiversity hotspots (Myers et al. 2000), highlighting its ecological relevance to biodiversity conservation. It is the second largest Brazilian biome, covering approximately 2 million km² (Klink and Machado 2005). This biome, also known as Cerrado, is characterized by a set of different

phytophysiognomies including open grassland (locally called “campo limpo”), woody savanna (“cerrado sensu stricto”), gallery forest, and seasonal deciduous and semideciduous forests (Furley 1999; Ruggiero et al. 2002).

The Brazilian savanna extends as a xeric vegetation corridor between the two largest Neotropical rainforests, i.e., the Amazon and the Atlantic forests, and both influenced its flora (Mêio et al. 2003). Forest environments, such as gallery and seasonal semideciduous forests, probably acted as mesic bio-corridors for many plants and animals from the Amazon and the Atlantic forests, especially for those species that depend on higher humidity (see revision of Oliveira-Filho and Ratter 1995). Gallery forests are corridors of mesophytic forest along the rivers, occupying about 5 % of the Brazilian savanna extension and sustaining approximately one third of the plant species of this biome (Silva et al. 2008). The seasonal

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semideciduous forest is found in close contact with the typical savanna vegetation and sometimes form forest–savanna mosaics (Silva et al. 2006).

It is known that the habitat mosaics existing in the Brazilian savanna contribute to enhance the biological diversity inside its domain, since many species depend on them (Silva et al. 2006). This environmental heterogeneity promotes an increase in beta-diversity among the different phytophysionomies (Klink and Machado 2005) and, consequently, in the gamma-diversity on a wider scale. Silva and Bates (2002) suggested that species of birds and mammals could use the phytophysionomies differentially, showing distinct patterns of occurrence. These authors discussed that biodiversity depends on the assortment of vegetation types, mainly in the presence of forest environments. These characteristics entail that studies developed in this region should take into account such environmental heterogeneity in the characterization of the existing fauna within its domain.

Studies on the euglossine bee fauna, also known as orchid bees, are relatively recent in the Brazilian savanna domain (Nemésio and Faria Jr. 2004; Alvarenga et al. 2007; Justino and Augusto 2010; Faria and Silveira 2011). These bees are distributed in the Neotropical region and exhibit the greatest diversity in rainforest environments (Dressler 1982), being considered forest-dependent pollinators (Brosi 2009). There are more than 200 species (Moure et al. 2007) and a few of them, such as *Euglossa melanotricha* Moure, 1967, *Eulaema nigrita* Lepeletier, 1841, and *Eufriesea nigrohirta* (Friese, 1899), are frequently recognized in open fields (Silveira et al. 2002).

Surveys in the Brazilian savanna suggest that the richness of orchid bees resembles that obtained in several areas of the Atlantic Forest *lato sensu* (Rebêlo and Garófalo 1997; Nemésio and Silveira 2007a; Aguiar and Gaglianone 2008, 2011; Silveira et al. 2011). Furthermore, as highlighted by some authors (Silva and Bates 2002; Faria and Silveira 2011), researches on the Brazilian savanna biota are very important to obtain new information about the biogeography of different groups of organisms. An example is the occurrence of *Euglossa decorata* Smith, 1874 and *Aglae caerulea* Lepeletier and Serville,

1825, in the Brazilian savanna domain (Carvalho and Bego 1996; Silva et al. 2013), species that had been regarded as endemic to the Amazon basin for a long time.

Considering that orchid bees are more diverse in rainforest environments, it is expected that gallery forests and seasonal semideciduous forests (i.e., forested habitat) are essential for maintaining high euglossine diversity in the Brazilian savanna. Furthermore, some authors consider these forest environments as bio-corridors for euglossine bees from the Brazilian tropical rainforests (Moura and Schlindwein 2009; Silva et al. 2013).

Given the above, the aim of this study was to evaluate the diversity of orchid bees in forest and woody savanna remnants within the Brazilian savanna domain. We hypothesized that the presence of forest remnants increases the diversity of euglossine bees in the Brazilian savanna domain and that some species are mainly associated with these environments.

2. MATERIAL AND METHODS

2.1. Study sites

We conducted this study in forest (seasonal semideciduous and gallery forests) and in woody savanna remnants within the Brazilian Savanna domain, in Minas Gerais State (Figure 1). We sampled the bees in sites located in five remnants of seasonal semideciduous forest (SSF₁ to SSF₅), one of gallery forest (GF₁), and two of woody savannas, also known as cerrado *stricto sensu* (WS₁ and WS₂) (Table 1). The distances among the sampled areas ranged from 1.7 km (GF₁–WS₁) to 92.7 km (SSF₂–SSF₄) (Figure 1).

A brief description of these vegetation types is made in sequence, according to Oliveira-Filho and Ratter (2002). The seasonal semideciduous forests occur in richer soils and are characterized by woody plant communities composed of species belonging to both deciduous dry forests and rainforests (Amazon and Atlantic forests). The gallery forest is a narrow forest strip that occurs in soils with high moisture near a watercourse. The flora of this forest is characterized by evergreen woody plants, whose crowns cover the watercourse. The woody savanna is characterized by the presence of trees and shrubs whose crowns cover about 30 % of

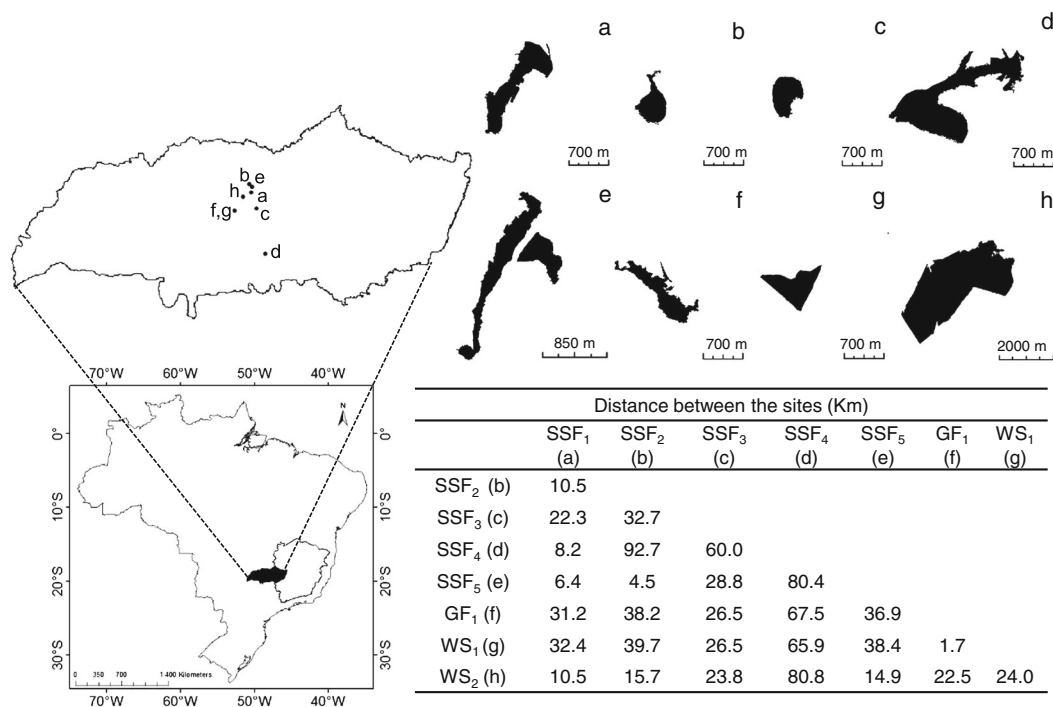


Figure 1. Location of remnants studied in the Triângulo Mineiro region, Minas Gerais State, Brazil. **a–e** seasonal semideciduous forests (SSF₁ to SSF₅), **f** gallery forest (GF₁), and **g–h** woody savannas (WS₁ and WS₂).

the soil and by herbaceous vegetation from the under-story of the forest.

The sites sampled are located in two ecological reserves, Ecological Station of Panga (sites GF₁ and WS₁) and Clube Caça e Pesca Itororó (site WS₂), one experimental farm of Federal University of Uberlândia, Gloria Experimental Farm (SSF₁), and four private properties: São José (SSF₂), Irara (SSF₃), Sucupira Cassu (SSF₄), and Marimondo (SSF₅) farms.

The Ecological Station of Panga (ESP) has 403.85 ha (Cardoso et al. 2009) and is composed of a vegetation mosaic including open grassland, woody savanna, gallery forest, and seasonal semideciduous forest (Schiavini and Araujo 1989). The savannic formations predominate in the ESP, covering 71 % of the area, while the forested habitat represents approximately 11 % (Cardoso et al. 2009). In this reserve, we sampled the bees simultaneously in two sites: a woody savanna (WS₁) and a gallery forest (GF₁) (Table 1, Figure 1). The distance between the two sites was 1.7 km.

The sampled site in the gallery forest was located near the boundary of the seasonal semideciduous forest. Both phytophysiognomies represent a

continuum of approximately 16 ha, surrounded by savanna areas.

The Clube Caça e Pesca Itororó (CCPIU) has approximately 127 ha, where woody land savanna and palm swamps (or “Vereda”) predominate. We sampled bees in WS₂ site in the same period of the samplings made in GF₁ (ESP) and WS₁ (Table 1).

The five seasonal semideciduous forest remnants (SSF₁ to SSF₅) present a neighboring gallery forest and are surrounded by pasture and crop areas (Lopes et al. 2013).

Two well-defined seasons, rainy summer and dry winter, characterize the climate of the region studied. The annual mean temperature is 22 °C and the annual rainfall is about 1,500 mm (Moreno and Schiavini 2001).

2.2. Sampling

We sampled euglossine males at each site, from 0900 to 1300 h, monthly, during 1 year, totaling 48 sampling hours per site. Seven aromatic fragrances were used to attract the males: eucalyptol, eugenol, vanillin, methyl salicylate, benzyl acetate, beta-ionone, and methyl

Table 1. Summary of principal characteristics of the studied areas inside the Brazilian savanna domain.

Sites	Phytophysognomy	Locality	Size (ha)	Study Period
SSF ₁	Seasonal semideciduous forest	Glória Experimental Farm (18° 57' 03" S/48° 12' 22" W)	30	July 2008 to June 2009
SSF ₂	Seasonal semideciduous forest	São José Farm (18° 51' 35" S/48° 13' 53" W)	20	July 2008 to June 2009
SSF ₃	Seasonal semideciduous forest	Irara Farm (19° 08' 39" S/48° 08' 46" W)	22.3	September 2010 to August 2011
SSF ₄	Seasonal semideciduous forest	Sucupira Cassu Farm (19° 40' 35" S/48° 02' 12" W)	70	September 2010 to August 2011
SSF ₅	Seasonal semideciduous forest	Marimbondo Farm (18° 53' 28" S/48° 12' 03" W)	49	October 2012 to September 2013
GF ₁	Gallery forest	Ecological Station of Panga (19° 10' 04" S/48° 23' 41" W)	16	February 2007 to January 2008
WS ₁	Woody savanna	Ecological Station of Panga (19° 10' 04" S/48° 23' 41" W)	148.8	February 2007 to January 2008
WS ₂	Woody savanna	Clube Caça e Pesca Itororó de Uberlândia (18° 59' S/48° 18' W)	127	May 2007 to May 2008

cinnamate. We used baited traps to sample euglossine bees and the collection procedure was standardized for all sites and samplings. One researcher monitored all baited traps, hung 1.5 m above the soil, and distanced 5 m from each other (see Ramalho et al. 2009). If the males flying around did not enter the trap, the researcher collected them with an entomological net. This procedure was used because some species of *Euglossa* are hardly collected by baited traps (Justino and Augusto 2010).

The bees were killed with ethyl acetate, identified under stereomicroscope, labeled, and deposited in the entomological collection of the Laboratory of Ecology and Behavior of Bees of the Federal University of Uberlândia. We used abbreviations for the generic names, as follows: *Euglossa* (*Eg.*), *Eulaema* (*El.*), *Exaerete* (*Ex.*), and *Eufriesea* (*Ef.*).

2.3. Data analysis

We calculated the diversity index for each area using the Shannon-Wiener (*H'*) associated with the evenness index (Brower et al. 1998) and tested the differences among the *H'* values by one sample *t* test (Hutcheson 1970).

To evaluate the differences in species richness among the eight sites and verify if our sampling effort was enough to collect most species in the community, we made extrapolation curves based on samples using the program EstimateS 9.1.0 (Colwell 2013). The extrapolation curves estimate the total of expected number of species for the community if the sampling reaches the asymptote (Colwell 2013). Therefore, it is possible to compare the richness among the areas and the quality of sampling.

To verify the possible association between species and studied sites, we used correspondence analysis. This analysis is based on the number of individuals collected and is frequently used in studies of communities to verify if there is dependence between rows (species) and columns (sites) using a contingency table (Quinn and Keough 2002). The results are represented by biplots or joint plots (where both rows and columns are shown) and the distance between two points is proportional to their chi-square distance (Quinn and Keough 2002). Species occurring in only one area were excluded, because they would necessarily be associated with such area, and this might distort the overall pattern analysis. *Exaerete smaragdina* (Guérin, 1844) was also

excluded, since this species is a cleptoparasite of *El. nigrita* and it is believed that its distribution is determined by the host. The analyses were made using FITOPAC (version 2.1.2.85).

As sampling was not conducted in completely overlapping periods in all areas, we verified the possible effect of the sampling period on the bee communities over time comparing the percentage of similarity (Σ lowest percentage for each bee species) (Brower et al. 1998) among the communities. In this sense, we compared our data to previous studies performed in the same woody savanna sites: CCPIU₁ (Alvarenga et al. 2007) and CCPIU₂ and ESP₁ (Justino and Augusto 2010).

3. RESULTS

We sampled 1,010 males of 13 species of orchid bees (Table II) in the eight areas. Bee abundance ranged from 30 to 341 individuals. The lowest abundance occurred in a forest remnant (SSF₄) while the highest happened in a woody savanna remnant (WS₂). In terms of diversity, the lowest species richness (4) occurred in a woody savanna remnant (WS₂) and the highest (12) in a forest remnant (SSF₅). Richness and abundance combined resulted in diversity indices (H') ranging from 0.38 (WS₁) to 1.82 (SSF₂) and evenness

Table II. Species of orchid bees sampled in different phytophysiognomies of the Brazilian savannas, total number of males (abundance), their relative abundance (%), and community parameters: abundance, richness, diversity (H'), and evenness (J'). Study realized in seasonal semideciduous forests (SSF₁ to SSF₅), gallery forest (GF₁), and woody savannas (WS₁ and WS₂).

Species	Abundance	Relative abundance in the sites							
		SSF ₁	SSF ₂	SSF ₃	SSF ₄	SSF ₅	GF ₁	WS ₁	WS ₂
<i>Euglossa</i> (<i>Euglossa</i>) <i>amazonica</i> Dressler	12	6.1	4.0	1.7	3.3	1.3	0.0	0.0	0.0
<i>Euglossa</i> (<i>Euglossa</i>) <i>cordata</i> (Linnaeus)	165	63.6	34.0	8.6	0.0	48.4	0.0	1.2	2.3
<i>Euglossa</i> (<i>Euglossa</i>) <i>despecta</i> Moure	1	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
<i>Euglossa</i> (<i>Euglossa</i>) <i>fimbriata</i> Moure	9	0.0	1.0	3.4	0.0	3.2	0.0	0.0	0.3
<i>Euglossa</i> (<i>Glossura</i>) <i>imperialis</i> Cockerell	126	0.0	15.0	3.4	10.0	14.8	46.1	1.2	0.0
<i>Euglossa</i> (<i>Euglossella</i>) <i>viridis</i> (Perty)	20	0.0	2.0	0.0	6.7	0.0	9.0	0.0	0.0
<i>Euglossa</i> (<i>Euglossa</i>) <i>melanotricha</i> Moure	199	9.1	17.0	10.3	0.0	3.2	1.1	2.4	47.2
<i>Euglossa</i> (<i>Euglossa</i>) <i>pleosticta</i> Dressler	51	4.5	11.0	36.2	23.3	3.2	1.7	1.2	0.0
<i>Euglossa</i> (<i>Euglossa</i>) <i>securigera</i> Dressler	4	0.0	1.0	1.7	0.0	1.3	0.0	0.0	0.0
<i>Euglossa</i> (<i>Euglossa</i>) <i>truncata</i> Rebêlo & Moure	6	3.0	0.0	1.7	3.3	1.3	0.0	0.0	0.0
<i>Eulaema</i> (<i>Apeulaema</i>) <i>nigrita</i> Lepeletier	406	13.6	14.0	32.8	40.0	20.0	41.6	92.7	50.1
<i>Eulaema</i> (<i>Apeulaema</i>) <i>cingulata</i> (Fabricius)	4	0.0	0.0	0.0	0.0	1.9	0.0	1.2	0.0
<i>Exaerete smaragdina</i> (Guérin)	7	0.0	1.0	0.0	13.3	0.6	0.6	0.0	0.0
Abundance	1,010	66	100	58	30	155	178	82	341
Richness	13	6	10	9	7	12	6	6	4
Diversity (H')	–	1.19	1.82	1.62	1.61	1.60	1.09	0.38	0.81
Evenness (J')	–	0.67	0.79	0.74	0.83	0.64	0.61	0.21	0.58

indices from 0.21 (WS₁) to 0.83 (SSF₄) (Table II). The diversity indices of orchid bees in forest remnants were significantly higher (Table III) than those observed in woody savanna areas. In general, the SSF areas presented similar diversity indices, except for SSF₁, which differed from SSF₂, SSF₃, and SSF₅. GF₁ presented a smaller diversity compared to all SSF areas (Table II).

In the forest remnants, species of *Euglossa* Latreille were the most abundant (Table II), while in WS sites, *El. nigrita* was the dominant species, especially in WS₁ (92.7 %). In WS₂, *El. nigrita* and *Eg. melanotricha* together represented 97.3 % of the sampled individuals. This pattern was similar to those observed in previous studies (Table IV). Despite the differences in relation to sampling effort, the percentage of similarity was high between WS₁/ESP₁ (75.9 %), WS₂/CCPIU₁ (93.7 %), and WS₂/CCPIU₂ (72.0 %) (Table IV).

The extrapolation curves corroborate the highest richness of orchid bee species obtained in seasonal semideciduous forests (Figure 2). Based on this analysis, between 73.26 % (WS₁) and 100 % (SSF₁, GL₁, and WS₂) of the expected number of species were sampled in the study areas (Figure 2).

The distribution pattern of relative abundance was similar in all areas, with most species presenting few individuals (Figure 3). In all areas, approximately 50 % of the species sampled represented less than 10 % of the total individuals collected.

According to the results of the correspondence analysis (total inertia=1.15, $\chi^2=1.152.3$, $P<0.001$) (Figure 4), the components 1 and 2 together explained 72.85 % of the variation observed. According to axis 1, all forest remnants (SSF and GF) were scaled on the right and all savannic areas (WS) on the left, forming two groups. Most bee species were associated with the forest remnants, except *El. nigrita* and *Eg. melanotricha*, which were associated with the woody savanna.

4. DISCUSSION

The results obtained reinforce the importance of forest environments in the Neotropical savanna to enhance the diversity of euglossine bees. Our data also suggest that some *Euglossa* species are most likely associated with these environments, while *El. nigrita* and *Eg. melanotricha* are essentially associated with the savanna.

The sampling performed in this study was considered representative of the euglossine fauna in the region. Only three other species were recorded in previous studies in the same areas but were not collected in the present study: *Eg. decorata* (Carvalho and Bego 1996), *Eufriesea* cfr. *auriceps* (Friese, 1899) (Alvarenga et al. 2007), and *Euglossa townsendi* Cockerell, 1904 (sampled only in trap-nest) (Mesquita and Augusto 2011). Considering other studies performed in areas of the Brazilian savanna in Minas Gerais State (Nemésio and Faria 2004; Faria and

Table III. Values of *t* test analyses comparing the diversity indices, among seasonal semideciduous forests (SSF₁ to SSF₅), gallery forest (GF₁), and woody savannas (WS₁ and WS₂).

Sites	SSF ₁	SSF ₂	SSF ₃	SSF ₄	SSF ₅	SSF ₆	GF ₁	WS ₁
SSF ₂	-4.06*	—						
SSF ₃	-2.22*	1.47	-0.58	—				
SSF ₄	-1.82	1.53	-0.27	0.21	—			
SSF ₅	-2.58*	1.70	-0.79	-0.07	-0.29	—		
GF ₁	0.59	7.00*	3.99*	3.48*	2.75*	4.51*	—	
WS ₁	4.61*	9.86*	7.79*	6.97*	6.11*	8.07*	5.45*	—
WS ₂	2.69*	11.30*	7.85*	5.86*	4.70*	7.93*	4.15*	3.69*

*Values statistically different at the 5 % level

Table IV. Relative abundance of euglossine bee species observed in woody savannas (WS) and total number of males. CCPIU₁ and CCPIU₂; data collected by Alvarenga et al. (2007) and Justino and Augusto (2010), respectively, at Clube Caça do Itororó; ESP₁; data collected by Justino and Augusto (2010) at the Ecological Station of Panga. These data were used in similarity analyses among samplings realized in different periods, but in the same areas.

Sites	Study period	Sampling effort	Relative abundance of species (%)						Total
			<i>El. nigrita</i>	<i>Eg. melanotricha</i>	<i>Eg. cordata</i>	<i>Eg. imperialis</i>	<i>Eg. pleosticta</i>	<i>Eg. securigera</i>	
CCPIU ₁	Oct 2003 to Sep 2004	12 months; 3 h; 3 baits	48.90	42.40	3.80	0.50	0.50	0.50	184
CCPIU ₂	Oct 2005 to Mar 2006	6 months; 3 h; 3 baits	74.20	24.70	0.00	0.00	0.00	0.00	97
ESP ₁	Nov 2006 to Apr 2007	6 months; 3 h; 3 baits	72.20	0.00	0.00	22.20	2.80	0.00	36

^a *Eufriesea* cf. *auriceps*

^b *Exaerete smaragdina*

^c *Eulaema cingulata*

Silveira 2011), the estimated richness comprises about 18 species. The richness sampled in the forest remnants studied is similar to that obtained at the Brazilian Atlantic forest *lato sensu* remnants (Rebêlo and Garófalo 1997; Nemésio and Silveira 2007a; Aguiar and Gaglianone 2008; Silveira et al. 2011; Aguiar and Gaglianone 2012; Knoll and Penatti 2012), despite the lower male abundance observed in our study.

In some cases, euglossine bees are attracted to chemical baits but will not enter traps (Justino and Augusto 2010). To deal with this, we had a researcher monitoring the traps and capturing males that were attracted to the scents but did not enter the traps. It remains possible that some species were not attracted to the odors that we presented. We, therefore, may not have sampled all of the species present in all sites, as indicated by the extrapolation curves. This is a general issue with the standard technique of using odor baits to assay euglossine diversity. However, there is no a priori reason to expect that such sampling bias should be different in the different habitats studied, and such potential bias is a general feature of studies that use baits to measure diversity.

Different landscape factors, such as size, shape, and isolation of forest fragments can affect abundance and richness of euglossine bees in many different ways (Brosi 2009). Therefore, studies suggested that the effect of landscape on the community structure can be species-specific, influencing the species composition (Aizen and Feinsinger 1994; Brosi et al. 2007; Calvillo et al. 2010; Hatten et al. 2013). Thence, we highlight the absence of *Eufriesea violacea* (Blanchard, 1840) in all forest remnants studied, which has frequently been sampled in seasonal semideciduous forest remnants in southern and southeastern Brazil (Rebêlo and Garófalo 1997; Sofia et al. 2004; Sofia and Suzuki 2004; Silveira et al. 2011). This species is sensitive to both environmental disturbance and reduction in forest remnants size (Giangarelli et al. 2009).

The causes of low abundance in the studied forest remnants are still unknown and require further investigation. We believe that long-term studies in the forest remnants assessed and research works occurring in the same region can help researchers to understand the effect of

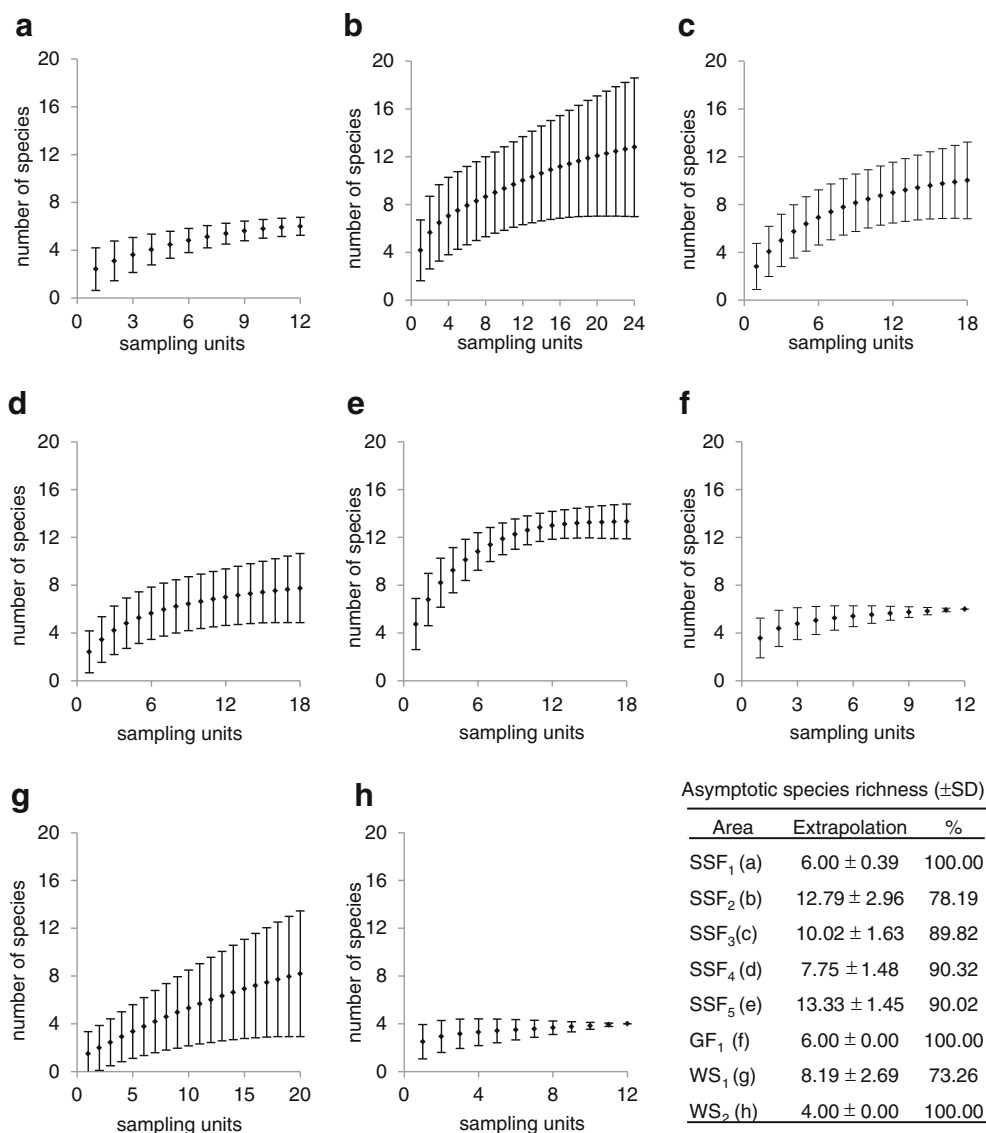


Figure 2. Extrapolation curves representing the eight sites sampled in the Brazilian savanna. **a–e** seasonal semideciduous forests (SSF₁ to SSF₅), **f** gallery forest (GF₁), and **g–h** woody savannas (WS₁ and WS₂). *Axis x* number of sampling units used to extrapolate the reference sample ($n=12$) until the curve reaches the asymptote. *Axis y* the number of species estimated.

environmental variables and landscape structure on these bee communities. These studies are necessary taking into account the increase in pasture areas and agricultural activities that reduced the forested habitats of the Neotropical savanna to small fragments in the last decades (Miles et al. 2006).

We verified that the most abundant species of *Euglossa*, such as *Euglossa pleosticta* Dressler, 1982, *Euglossa cordata* Linnaeus, 1758, *Euglossa amazonica* Dressler, 1982, *Euglossa imperialis* Cockerell, 1922, and *Euglossa viridis* (Perty, 1833), have been most frequently sampled in the forest remnants, contributing to the higher

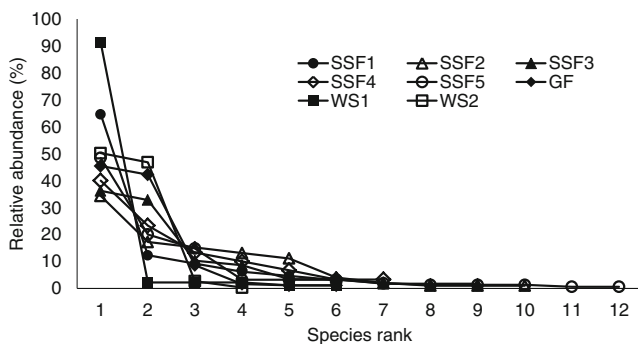


Figure 3. Relative abundance distribution pattern of the orchid bee communities sampled at three different phytophysognomies in the Brazilian savanna. Seasonal semideciduous forests (SSF₁ to SSF₅), gallery forest (GF₁), and woody savannas (WS₁ and WS₂).

diversity verified in those formations compared to woody savanna.

Euglossa pleosticta, *Eg. cordata*, *Eg. imperialis* and *Eg. viridis* are associated with

the Atlantic Forest and are frequently sampled in remnants of this biome (Morato 1994; Rebêlo and Silva 1999; Nemésio and Silveira 2007b; Giangarelli and Sofia 2011; Knoll and Penatti

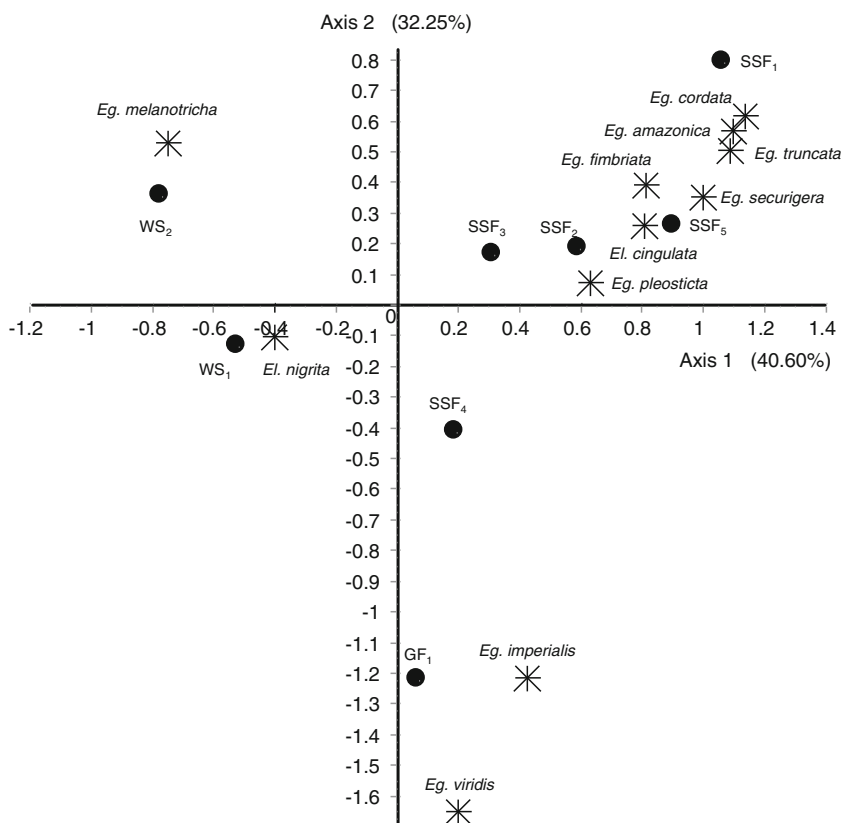


Figure 4. Correspondence analysis representing association patterns of different euglossine species with the studied sites. Seasonal semideciduous forests (SSF₁ to SSF₅), gallery forest (GF₁), and woody savannas (WS₁ and WS₂).

2012; Rocha-Filho and Garófalo 2013; Cordeiro et al. 2013; Aguiar et al. 2014), while recent records indicate the occurrence of *Eg. amazonica* outside the Amazon basin (Nemésio 2012).

On the other hand, as previously mentioned by other authors (Neves and Viana 1997; Silveira et al. 2002; Ramalho et al. 2009; Faria and Silveira 2011), *El. nigrita* and *Eg. melanotricha* are more frequently found in open fields, such as the woody savanna. This pattern was similar in the same areas over time, despite the differences in the sampling effort (Alvarenga et al. 2007; Justino and Augusto 2010).

Our results suggest that some *Euglossa* species have a higher association with forest habitats in the Brazilian savanna, since more than 70 % of the species distribution could be explained by the environmental category (forested or savannic habitats).

The higher association to forest habitats observed in the *Euglossa* species confirms our expectations and suggest that the presence of forest habitats enables the occurrence of species that would not be tolerant to the environmental conditions present in the savannic areas. However, it is worth taking into account the possibility of small variations in the detected pattern because the samplings did not completely overlap between the time frames among all sites. A long-term study with euglossine performed in Central America (Roubik and Ackerman 1987) indicated that their populations are very stable over the years and this stability is sustained mainly by the most abundant species. Although we expect a weak influence of the sampling period on the diversity of the euglossine community, we cannot completely disregard the influence of inter-annual variations within the same locality, as already observed in bee communities (Williams et al. 2001). Thus, this detected pattern deserves more investigation.

Despite the high anthropogenic impact, the studies developed in Brazilian savannas demonstrated higher diversity and richness than expected. Additionally, the occurrence of species typical of the Amazon and Atlantic forests reinforces the hypothesis that both the gallery and seasonal semideciduous forest acted as bio-corridors, especially for those species that depend on higher humidity (Moura and Schlindwein 2009; Silva et al. 2013).

As observed, there were differences in diversity between the forest and savanna environments, and

among the forest remnants studied. These results illustrate how the heterogeneity of habitats in the Brazilian savanna may contribute to enhance the orchid bee diversity in that biome. This environmental heterogeneity promotes an increase in beta-diversity among the different phytophysiognomies, as highlighted by Klink and Machado (2005). Besides, differences in the characteristics of remnants, such as landscape factors, resources availability, and genetic structure, could influence the presence and abundance of the euglossine species among these areas (Brosi 2009; Zimmermann et al. 2011).

In conclusion, our results confirm the relevance of environmental heterogeneity and the importance of forest habitats for the higher euglossine diversity in the Brazilian savanna. In this regard, the preservation of different vegetation types, especially seasonal semideciduous and gallery forests, are essential to conserve biodiversity of these important pollinators in the Brazilian savanna.

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Les abeilles à orchidée dans la savanne brésilienne: les formations forestières contribuent-elles à l'augmentation de la diversité en espèces ?

Diversité biologique / Euglossines / biogéographie / région néotropicale / pollinisateur

Die Prachtbienenfauna in der brasilianischen Savanne: Tragen Waldformationen zu einer höheren Artenvielfalt bei?

Diversität / Euglossinen / Biogeographie / Neotropen / Bestäuber

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