



Spatial gradient and vegetation cover affecting species diversity and composition of bees in Atlantic Forest remnants of South Brazil

Júlia Alberti de Liz^{1*} , Alessandra Mikich² , Vitória Ramos Macedo³ ,
Rodrigo Barbosa Gonçalves¹ , Sandra Bos Mikich⁴

¹Universidade Federal do Paraná (UFPR), Laboratório de Abelhas, Curitiba, PR, Brasil.

²Universidade Federal do Paraná (UFPR), Laboratório de Estudos de Lepidoptera Neotropical, Curitiba, PR, Brasil.

³Universidade Estadual Paulista (Unesp), Instituto de Biociências, Letras e Ciências Exatas (IBILCE), Programa de Pós-Graduação em Biodiversidade, São José do Rio Preto, SP, Brasil

⁴Embrapa Florestas, Laboratório de Ecologia, Colombo, PR, Brasil.

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ABSTRACT

Given that the Atlantic Forest is one of the most threatened biomes in the world, this study aims to compare alpha and beta diversity of the bee assemblage sampled in a site covered by remnants of the Atlantic Forest, in the municipality of Colombo, Paraná State, with those from ten other sites along the Curitiba Metropolitan Region, previously sampled under similar methodology. Our objective is to analyze if species diversity and composition are influenced by spatial gradients and vegetation cover. The study site's bee assemblage is composed of 91 species, including *Apis mellifera*. The assemblage consists of 42 Apinae, 33 Halictinae, eight Megachilinae, five Colletinae, and three Andreninae species. Compared to the other sites, 11 species were sampled exclusively in Colombo, including *Bombus brasiliensis* Lepelletier, 1836, *Centris proxima* Friese, 1899, and *Trichoceraapis mirabilis* (Smith, 1865). The most abundant native species were *Trigona spinipes* (Fabricius, 1793) (204 individuals), *Paratrigona subnuda* Moure, 1947 (176) and *Scaptotrigona bipunctata* (Lepelletier, 1836) (113). Despite its high vegetation cover, Colombo exhibited intermediate values of species richness and diversity when compared to other sites, with a high dominance of Meliponini species. The sites could be separated based on beta diversity and the north-south gradient and vegetation cover were significantly related to species composition at this study's spatial scale. Understanding the regional communities and the factors that influence species composition is essential for planning effective biodiversity conservation actions.

Introduction

Bees play a fundamental role in biodiversity maintenance through pollination, contributing significantly to food security and human health (Giampieri et al., 2022). They also hold sociocultural significance, particularly for indigenous peoples and traditional communities (Camargo and Possey, 1990). Pollination sustains plant diversity by facilitating new genetic combinations and increasing fruit and seed production, with 90% of plant species depending on pollinators in natural ecosystems (Ollerton et al., 2011). This ecosystem service extends to agriculture, where 75% of major crops depend on animal pollination (Klein et al., 2007) and benefits from increased production, quality, and durability (Klatt et al., 2014). In Brazil, it is estimated that 60% of food-related crops exhibit high dependence on pollination (Wolowski et al., 2019). Over 75% of the country's food crops rely to some extent on animal pollination, primarily bees (Wolowski et al., 2019). The estimated

value of this ecosystem service for food production in the country is approximately R\$ 43 billion annually (Wolowski et al., 2019). For the Curitiba Metropolitan Region, Hoffmann and Gonçalves (2023) estimated an annual value of R\$ 382 million for the pollination service.

The loss of natural habitats reduces the availability of floral resources and nesting sites, thereby hindering the provision of ecosystem services such as pollination (Aizen and Feinsinger, 2003). In Brazil, over the past 20 years, there are more documented cases of a decline in insect abundance and diversity than an increase across all biomes (Lewinsohn et al., 2022). One of the primary threats, urbanization, is a process that alters the structure of natural spaces, causing fragmentation and habitat loss, which, in turn, can lead to a decrease in diversity and richness of the biological communities and a reduction in landscape complexity (Hernandez et al., 2009; Brancher et al., 2023; Nagamitsu et al., 2023).

The Metropolitan Region of Curitiba has the most extensive monitoring of bees in urban environments in Brazil, with several long-term studies from the 1950s to the present (Tauro and Laroca, 2001; Martins et al.,

*Corresponding author.

E-mail: julializ@outlook.com (J.A. Liz).

2013; Cardoso and Gonçalves, 2018; Pereira et al., 2021). Collectively, these initiatives have identified a reduction in bee abundance and the disappearance of some species. Recently, Graf et al. (2022) investigated the relationship of the urban landscapes with the bee communities in ten different sites, analyzing how the functional traits of bees influence their responses to urbanization. The authors found that species richness and their functional groups, such as solitary, specialist and cleptoparasites, are negatively influenced by urbanization. Despite these results, it is important to recognize that cities which maintain environmental heterogeneity can sustain ecological processes in their green spaces, thus serving as refuges for bees and protecting their pollination services (Hernandez et al., 2009; Cardoso and Gonçalves, 2018; Graf et al., 2022).

In this contribution, we present original data on the bee assemblage from a new site within the Curitiba Metropolitan Region: Embrapa Florestas, Colombo. In addition to providing a species list for this locality, we aimed to compare the alpha and beta diversity among different sites within this region and to analyze the effects of spatial gradients and vegetation cover on species diversity and composition.

Material and methods

Study site

Sampling was conducted within the Empresa Brasileira de Pesquisa Agropecuária - Embrapa Florestas (25° 19' 24.05" S, 49° 09' 31.56" W), located in the municipality of Colombo, Curitiba Metropolitan Region (RMC), Paraná (Figure 1). The study area, hereafter referred to as Colombo, covers 301 hectares and comprises forest remnants (124 hectares), forest crops, arboretums, and gardens. Situated at an altitude of 928 meters, the area is covered by Mixed Ombrophilous Forest (FOM), also known as Araucaria Forest, one of the subformations of the Atlantic Forest biome (IBGE, 2012). According to Possette et al. (2015), the study site has the highest plant richness ever sampled for this subformation in the State

of Paraná, with 512 registered species. Based on the Köppen-Geiger classification, its dominant climatic type is Cfb - temperate climate, with an average annual temperature of 18°C and annual precipitation ranging between 1,400-1,600 mm (Nitsche et al., 2019).

Sampling design

Throughout a period of one year, from April 2019 to March 2020, 122 plant species were monitored and their flower visitors were actively collected using an entomological net. Each plant was sampled for 30 minutes at a time by a single collector, but the time of the day varied throughout the flowering phase of each species. Sampling occurred two days per week for every month, from 08 AM to 05 PM, as long as the weather was favorable. In total, 102 days were sampled, investing a cumulative effort of 245 hours. This method is similar to the one used by Sakagami et al. (1967) and Graf et al. (2022), given that all available and accessible flowering species were monitored for bee collection. All bees that interacted with the flowers of a monitored plant were collected. Exceptions were *Apis mellifera* and *Trigona spinipes*, for which an average of two individuals per plant were collected. As this study is part of a larger project deeming other flower visitors and objectives, most of the specimens of these common plant visitors were identified in the field and not sampled, therefore their high abundance is underestimated.

There is at least one properly mounted and labeled voucher for each species collected (except *A. mellifera*) deposited in the Padre Jesus Santiago Moure Entomological Collection (DZUP) and duplicates in a working collection housed at Embrapa Florestas. Bee identification was carried out by JAL and RBG following Silveira et al. (2002), as well as identification keys in taxonomic publications referenced by Moure and Melo (2022). In addition, the specimens were compared with the material deposited in the DZUP collection. All plant species were collected, herbarized and deposited in the Embrapa Florestas Herbarium, with duplicates sent to the Museu Botânico de Curitiba. The bee-plant interaction data will be explored in a further contribution.

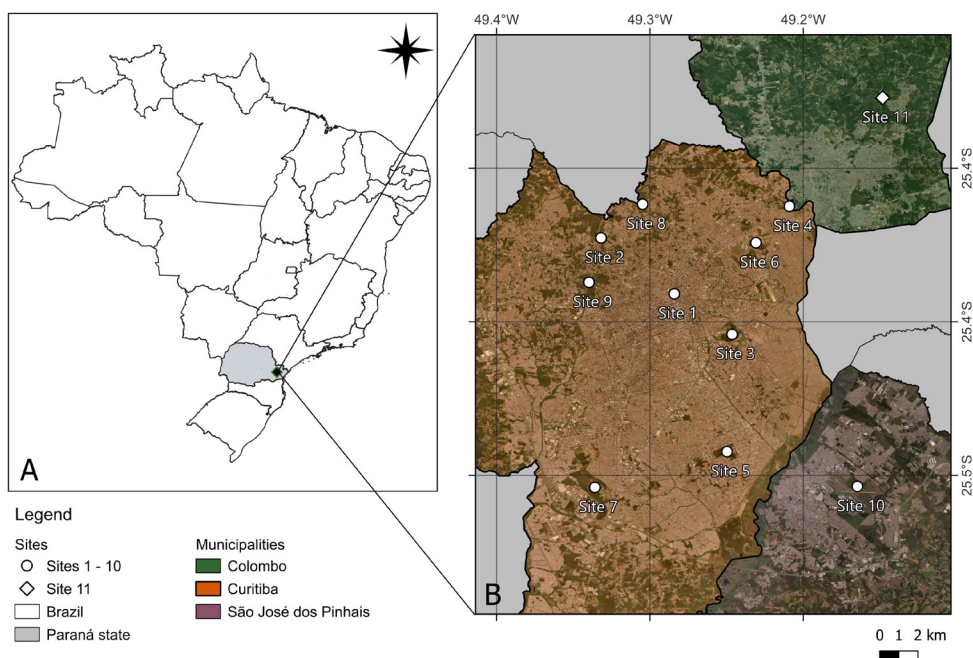


Figure 1 Curitiba Metropolitan Region sampling sites. A. RMC in Brazil. B. Details of Colombo (greenish), Curitiba (yellowish) and São José dos Pinhais (reddish). Site 1: Passoio Público; Site 2: Parque Tingui; Site 3: Campus Jardim Botânico - UFPR; Site 4: Parque Atuba; Site 5: Quartel 5° GAC AP; Site 6: Parque Regional de Manutenção/5; Site 7: Quartel General 5° DE; Site 8: Parque Tanguá; Site 9: Cemitério Parque Iguaçú; Site 10: Aeroporto Internacional Afonso Pena; Site 11: Colombo.

Site comparison

We compiled the data from the ten RMC bee assemblages sampled by Graf et al. (2022) to contextualize the Colombo assemblage (Table 1). Graf et al. (2022) sampling design can be considered similar, each site was sampled monthly over a year, using the same methodology described above. For the Colombo dataset, the species *Apis mellifera* was excluded from comparative analyses since it was not sampled in the other sites. The sampled location here is designated as Site 11 to maintain the original site numbering.

Comparative analyses were conducted in R version 4.2.3 through RStudio (RStudio Team, 2020; R Core Team, 2021). To estimate diversity, Hill Numbers were calculated using the “iNEXT” package (version 3.0.0) (Hsieh et al., 2022), which generates rarefaction and extrapolation curves for species diversity. The first three Hill numbers were used: $q = 0$ (species richness), $q = 1$ (the exponential of Shannon's entropy index), and $q = 2$ (the inverse of Simpson's concentration index) (Chao et al., 2014). For extrapolation, the established endpoint (1400) was approximately double the lowest recorded abundance, 701 individuals at Site 10. The confidence interval curves were used as a test to detect differences in richness and diversity among areas. We also estimated species diversity (Hill numbers with $q = 0, 1$ and 2) with a subset of 700 individuals to evaluate their responses to the predictors described below. Site ordering based on species composition was performed using the “metaMDS” function from the “vegan” package (Oksanen et al., 2022), with a species abundance matrix for each site. Non-Metric Multidimensional Scaling (NMDS) was chosen as it is an ordination technique that simplifies the analysis of multivariate data, organizing sites according to environmental variables and species compositions (Gotelli and Ellison, 2004).

To investigate the factors that might influence species composition, we chose an approach that used geospatial information from the sampled areas, specifically the north–south and east–west spatial gradients. These predictors were represented by the latitude and longitude coordinates of the 11 sampling sites. In particular, the north–south gradient may represent both the original RMC vegetation type, i.e. the tendency of Mixed Ombrophilous Forest areas on the Northern region and Natural Grasslands on the Southern region of RMC, as well as larger vegetation fragments occurring in the north (Maack, 1931; Klein and Hatschbach, 1962). The Mantel test was conducted to verify the existence of a spatial correlation between species composition and spatial gradients, i.e., to check if closer locations have more similar species compositions due solely to their proximity.

We also quantified the vegetation cover, that being the percentage of land that is covered by the existing vegetation within a 1 km buffer of sampling site centroid. A simple regression was performed for

700 individual diversity estimators and the three predictors. To evaluate the beta diversity response, we used the “envfit” function to project vectors into the ordination space representing the maximum correlation of predictor variables with the assemblages. The significance of each variable was tested by permutation test, with vectors analyzed separately, returning r^2 and p values that define the explanatory capacity of variables regarding the species composition at each location.

Results

The melissofauna of Colombo

A total of 91 bee species were sampled, including the exotic *Apis mellifera* (Table 2). Of these, 72 were identified with valid names, while the remaining 19 were indicated as morphospecies. The Colombo community is represented by 42 (46%) species of the Apinae subfamily, 33 (36%) of Halictinae, eight (8.8%) of Megachilinae, five (5%) of Colletinae, and three (3%) of Andreninae. The bee assemblage in this locality added records of 11 species (43 individuals), not previously collected in other areas of RMC: *Augochlora aurinasis* (Vachal, 1911), *Bombus brasiliensis* Lepelletier, 1836, *Caenohalictus* sp. 02, *Caenohalictus* sp. 03, *Ceratina fimbriata* Roig-Alsina, 2013, *Centris proxima* Friese, 1899, *Megachile* sp. 02, *Neocorynura euadne* (Schrottky, 1909), *Pseudaugochlora simulata* Almeida, 2008, *Tetragonisca angustula* (Latreille, 1811), and *Trichoceraapis mirabilis* (Smith, 1865).

A total of 1,535 individuals were sampled, with Apinae being the most abundant subfamily, comprising 1279 individuals, followed by Halictinae (209), Megachilinae (23), Andreninae (13), and Colletinae (11). The most abundant tribe was Meliponini, with 723 specimens. The most common species was *Apis mellifera* with 322 individuals (20.98%; even though only up to two individuals were collected per sampling unit), while 1,213 native bees (79.02%) were sampled. *Trigona spinipes* was the most abundant native species (204 – also subsampled as *A. mellifera*; see methods), followed by *Paratrigona subnuda* (176), *Scaptotrigona bipunctata* (113), *Bombus pauloensis* (72), *Dialictus* sp. 12 (65), *Plebeia emerina* (45), *Bombus morio* (43), *Plebeia remota* (43) and *Tetragonisca fiebrigi* (39).

The melissocoenology of Curitiba Metropolitan Region

By examining the species richness ($q = 0$), all extrapolation curves are ascending for most sites, except for Colombo (Site 11) ($q = 0$; Fig. 2). The assemblages of Site 1 and Site 11 indicate locations with low and intermediate species richness (61 and 90,

Table 1
Curitiba Metropolitan Region sampling sites, coordinates and proportion of vegetation cover within a 1 km buffer.

Code	Site name	Latitude	Longitude	Vegetation Cover
1	Passeio Público	-25.425419	-49.267331	4.96
2	Parque Tingui	-25.396317	-49.305548	51.25
3	Campus Jardim Botânico – UFPR	-25.446535	-49.237177	27.84
4	Parque Atuba	-25.379862	-49.207268	33.95
5	Quartel 5o GAC AP	-25.507646	-49.239813	19.76
6	Parque Regional de Manutenção/5	-25.398833	-49.224716	33.94
7	Quartel General 5a DE	-25.526246	-49.308808	56.56
8	Parque Tanguá	-25.378750	-49.283870	52.29
9	Cemitério Parque Iguaçu	-25.419457	-49.311820	66.34
10	Aeroporto Internacional Afonso Pena	-25.525735	-49.171811	65.40
11	Embrapa Florestas, Colombo	-25.323333	-49.158611	77.12

Table 2

Bee species from Embrapa Florestas, Colombo, Paraná, Brazil. N = abundance, F = females abundance, M = males abundance.

		Bee species	N	F	M
Andreninae	Protandrenini	<i>Anthrenoides corrugatus</i> Urban, 2005	5	3	2
		<i>Anthrenoides paolae</i> Urban, 2005	7	6	1
		<i>Psaenythia bergii</i> Holmberg, 1884	1	1	0
Apinae	Apini	<i>Apis mellifera</i> Linnaeus, 1758	322	322	0
	Bombini	<i>Bombus (Fervidobombus) morio</i> (Swederus, 1787)	43	43	0
		<i>Bombus (Fervidobombus) pauloensis</i> Friese, 1913	72	71	1
		<i>Bombus (Fervidobombus) brasiliensis</i> Lepeletier, 1836 *	6	6	0
	Centridini	<i>Centris (Centris) varia</i> (Erichson, 1849)	3	2	1
		<i>Centris (Hemisiella) tarsata</i> Smith, 1874	2	2	0
		<i>Centris (Melacentris) atra</i> (Friese, 1899)	1	1	0
		<i>Centris (Trachina) proxima</i> (Friese, 1899) *	1	0	1
	Emphorini	<i>Melitoma segmentaria</i> (Fabricius, 1804)	3	3	0
	Eucerini	<i>Melissoptila vulpecula</i> Berton and Schrottky, 1910	4	4	0
		<i>Thygater (Nectarodiaeta) paranaensis</i> Urban, 1967	3	1	2
		<i>Thygater (Thygater) analis</i> (Lepeletier, 1841)	5	4	1
		<i>Trichocerapis mirabilis</i> (Smith, 1865) *	1	1	0
	Exomalopsini	<i>Exomalopsis (Exomalopsis) sp. 01</i>	9	9	0
		<i>Exomalopsis (Exomalopsis) sp. 02</i>	4	4	0
		<i>Exomalopsis (Exomalopsis) vernoniae</i> Schrottky, 1909	11	11	0
	Meliponini	<i>Melipona (Eomelipona) marginata</i> Lepeletier, 1836	18	18	0
		<i>Melipona (Melipona) quadrifasciata</i> Lepeletier, 1836	25	25	0
		<i>Nannotrigona testaceicornis</i> (Lepeletier, 1836)	7	7	0
		<i>Paratrigona subnuda</i> Moure, 1947	176	176	0
		<i>Plebeia droryana</i> (Friese, 1900)	25	25	0
		<i>Plebeia emerina</i> (Friese, 1900)	45	45	0
		<i>Plebeia remota</i> (Holmberg, 1903)	43	43	0
		<i>Scaptotrigona bipunctata</i> (Lepeletier, 1836)	113	113	0
		<i>Schwarziana quadripunctata</i> (Lepeletier, 1836)	19	19	0
		<i>Tetragonisca angustula</i> (Latreille, 1811) *	9	9	0
		<i>Tetragonisca fiebrigi</i> (Schwarz, 1938)	39	39	0
<i>Trigona spinipes</i> (Fabricius, 1793)		204	204	0	
Tapinotaspidini		<i>Lophopedia pygmaea</i> (Schrottky, 1902)	4	4	0
	<i>Trigonopedia sp. 01</i>	1	1	0	
Tetrapediini	<i>Tetrapedia diversipes</i> Klug, 1810	3	3	0	
Xylocopini	<i>Ceratina (Ceratinula) oxalidis</i> Schrottky, 1907	10	10	0	
	<i>Ceratina (Ceratinula) sclerops</i> Schrottky, 1907	11	11	0	
	<i>Ceratina (Ceratinula) sp. 03</i>	1	0	1	
	<i>Ceratina (Ceratinula) sp. 04</i>	4	3	1	
	<i>Ceratina (Neoclavicera) fimbriata</i> Roig-Alsina, 2013 *	12	12	0	
	<i>Ceratina (Neoclavicera) richardsoniae</i> Schrottky, 1909	1	1	0	
	<i>Ceratina (Neoclavicera) umbricosta</i> Roig-Alsina, 2013	1	0	1	
	<i>Ceratina (Rhysoceratina) stilbonota</i> Moure, 1941	4	4	0	
	<i>Xylocopa (Neoxylocopa) augusti</i> Lepeletier, 1841	9	9	0	
	<i>Xylocopa (Megaxylocopa) frontalis</i> (Olivier, 1789)	4	4	0	
<i>Xylocopa (Stenoxycopa) artifex</i> Smith, 1874	1	1	0		
Colletinae	Hylaeini	<i>Hylaeus sp. 01</i>	3	3	0
		<i>Hylaeus sp. 03</i>	2	1	1
		<i>Hylaeus sp. 04</i>	1	1	0
	Eulonchopriini	<i>Ctenosibyne cingulata</i> (Moure, 1956)	3	3	0
	Xeromelissini	<i>Chilicola (Oediscelisca) sp. 01</i>	2	1	1

* = New species for Curitiba Metropolitan Region.

Table 2
Continued...

		Bee species	N	F	M	
Halictinae	Augochlorini	<i>Augochlora (Augochlora) caerulior</i> Cockerell, 1900	4	4	0	
		<i>Augochlora (Augochlora) cydippe</i> (Schrottky, 1910)	3	2	1	
		<i>Augochlora (Augochlora) daphnis</i> Smith, 1853	16	16	0	
		<i>Augochlora (Augochlora) phoemonoe</i> (Schrottky, 1909)	17	17	0	
		<i>Augochlora (Oxystoglossella) iphigenia</i> Holmberg, 1886	13	13	0	
		<i>Augochlora (Oxystoglossella) morrae</i> (Strand, 1910)	6	6	0	
		<i>Augochlora (Oxystoglossella) aurinasis</i> (Vachal, 1911) *	1	1	0	
		<i>Augochlorella ephyra</i> (Schrottky, 1910)	6	6	0	
		<i>Augochlorella urania</i> (Smith, 1853)	3	3	0	
		<i>Augochloropsis (Augochloropsis) diversipennis</i> (Lepeletier, 1841)	3	3	0	
		<i>Augochloropsis (Paraugochloropsis) multiplex</i> (Vachal, 1903)	4	4	0	
		<i>Megommation insigne</i> (Smith, 1853)	1	0	1	
		<i>Neocorynura atromarginata</i> (Cockerell, 1901)	1	1	0	
		<i>Neocorynura codion</i> (Vachal, 1904)	6	4	2	
		<i>Neocorynura euadne</i> (Schrottky, 1909) *	5	5	0	
		<i>Pseudaugochlora graminea</i> (Fabricius, 1804)	4	4	0	
		<i>Pseudaugochlora simulata</i> Almeida, 2008 *	4	4	0	
		<i>Temnosoma</i> sp. 01	1	1	0	
		<i>Thectochlora alaris</i> (Vachal, 1904)	4	4	0	
		Caenohalictini	<i>Agapostemon (Notagapostemon) semimelleus</i> Cockerell, 1900	2	2	0
	<i>Caenohalictus palumbes</i> (Vachal, 1903)		3	3	0	
	<i>Caenohalictus</i> sp. 01		2	2	0	
	<i>Caenohalictus</i> sp. 02 *		1	1	0	
	<i>Caenohalictus</i> sp. 03 *		1	1	0	
	<i>Caenohalictus tessellatus</i> (Moure, 1940)		7	4	3	
	<i>Habralictus macropilophorus</i> Moure, 1941		4	2	2	
	<i>Pseudagapostemon (Pseudagapostemon) cyaneus</i> Moure and Sakagami, 1984		1	1	0	
	Halictini		<i>Dialictus anisitsianus</i> (Strand, 1910)	9	9	0
			<i>Dialictus phaedrus</i> (Schrottky, 1910)	6	6	0
<i>Dialictus</i> sp. 09		1	1	0		
<i>Dialictus</i> sp. 12		65	47	18		
<i>Dialictus</i> sp. 15		2	2	0		
<i>Dialictus</i> sp. 16		3	3	0		
Megachilinae	Anthidiini	<i>Moureanthidium subarenarium</i> (Schwarz, 1933)	1	0	1	
		Megachilini	<i>Coelioxys (Acrocoelioxys) tolteca</i> Cresson, 1878	1	0	1
	<i>Coelioxys (Cyrtocoelioxys) sp. 01</i>		2	1	1	
	<i>Coelioxys (Cyrtocoelioxys) sp. 02</i>		4	3	1	
	<i>Megachile (Austromegachile) susurrans</i> Haliday, 1836		8	5	3	
	<i>Megachile (Leptorachis) sp. 02</i> *		2	1	1	
	<i>Megachile (Moureapis) apicipennis</i> Schrottky, 1902		2	2	0	
	<i>Megachile (Moureapis) maculata</i> Smith, 1853	3	3	0		

* = New species for Curitiba Metropolitan Region.

respectively, Fig. 2 $q=0$). These assemblages statistically differ from the others and between themselves, according to non-overlapping confidence intervals. Among all sites, Site 10 is the richest with a total of 133 bee species. Regarding Shannon and Simpson diversity ($q = 1$, $q = 2$, Figs. 2), all curves tend to approach an asymptote and the order of the sites remains the same as the richness curves, with Site 10 having the highest values for Shannon diversity index ($q = 1$)

and Simpson diversity index ($q = 2$), while Sites 1 and 11 have lower values. The position of Site 8 in the curves is noteworthy, as the site shows relatively high Shannon diversity values but low values of Simpson diversity index. Regarding the regression analyses between the three Hill numbers and predictor variables, only Simpson diversity ($q = 2$) showed a relationship with the north-south gradient ($r^2 = 0.2926$, $p = 0.0497$).

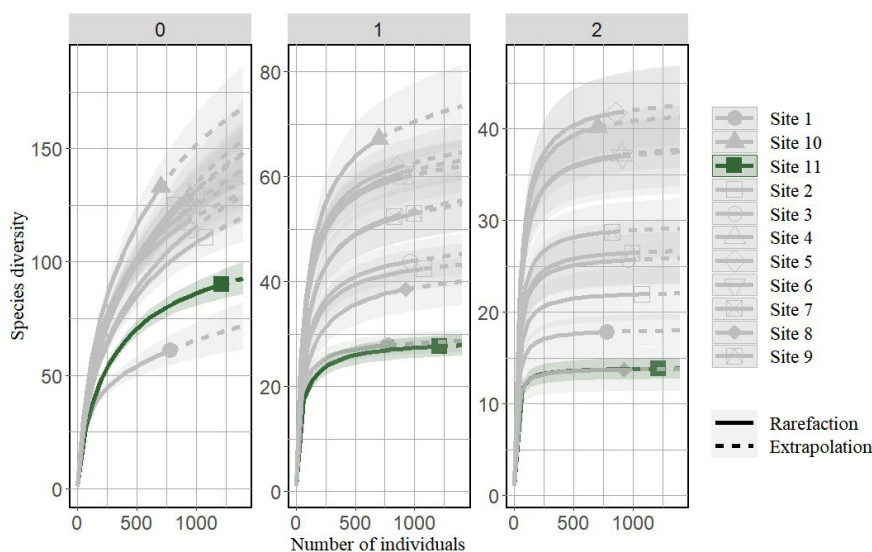


Figure 2 Interpolation and extrapolation of Hill number with orders 0, 1 and 2; with confidence interval of 0.95. Site numbers according to Table 1, Colombo site indicated in green.

Table 3 Statistical values for the geographic variables (Latitude and Longitude) and environmental variable (Vegetation cover) returned by the envfit function. * Represent significant values.

	NMDS 1	NMDS 2	r ²	Pr (>r)
Latitude	-0.82119	-0.57066	0.7047	0.005 *
Longitude	-0.17915	0.98382	0.0181	0.931
Vegetation cover	0.18204	-0.98329	0.5507	0.028 *

The Mantel test yielded $r^2 = 0.27$, $p = 0.092$, indicating low significance of spatial autocorrelation. In other words, the distance between the areas would explain only 27% of the variation in species composition among them, with other factors influencing species composition. The NMDS returned a stress value of 0.095, indicating good resolution (< 0.1). In a visual inspection, Sites 1, 10, and 11 are at the extremes of the plot (Figure 3), while the remaining sites form a cluster in the center with a high density of species points, indicating that they have a more homogeneous species composition. From the species scores of the NMDS, it is possible to identify those that most influenced the arrangement of the sites (Supplementary Material). The only predictor related to NMDS1 is the north-south gradient ($r^2 = 0.7047$, $p = 0.005$, NMDS1 = -0.82119; Table 3), with northernmost and southernmost sites with NMDS 1 extreme values. Contrasting the assemblages, the northernmost Site 11, has a higher negative value on NMDS1 (-0.60748958), while Site 10, the southernmost, appears with a higher positive value on the axis (0.69696867). The only predictor related to NMDS2 is the vegetation cover ($r^2 = 0.5507$, $p = 0.028$, NMDS2 = -0.98329), with Site 1 separated from the remaining in this axis.

Discussion

Apinae and Halictinae subfamilies exhibited higher richness and abundance than Megachilinae, Colletinae and Andreninae, which is consistent with findings from other melissofauna surveys from southern Brazil (Barbola and Laroça, 1993; Taura and Laroça, 2001; Alves-dos-Santos, 2007; Kamke et al., 2011; Martins et al., 2013; Graf et al., 2022). Halictinae is frequently identified as the most species-rich subfamily in inventories conducted in this territory (Barbola and Laroça, 1993; Taura and Laroça, 2001; Gonçalves and Melo, 2005; Kamke et al., 2011). However, in the Curitiba Metropolitan Region, the richness of

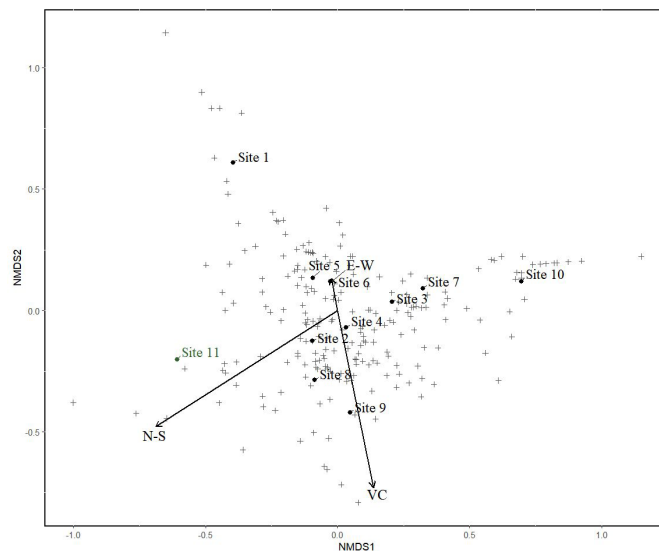


Figure 3 NMDS ordination plot. N-S: north-south gradient, E-W: east-west gradient, VC: vegetation cover. Site numbers according to Table 1.

both Halictinae and Apinae was found to be comparable, with 40 and 43 species, respectively (Graf et al., 2022). In the case of Colombo specifically, Apinae emerged as the most speciose group with 42 recorded species. This outcome contrasts with the relatively lower number of Halictinae species documented (33).

The most abundant species were the highly eusocial *Apis mellifera*, *Trigona spinipes*, and *Paratrigona subnuda*, altogether accounting for 45.7% of the specimens. The first two species share several characteristics: they

form very large colonies, are super generalists with broader niche when compared to other species and do not require pre-existing cavities for nesting (Laroca and Winston, 1978; Neves and Viana, 2002; Gonçalves and Melo, 2005; Biesmeijer and Slaa, 2006). These traits likely contribute to their status as the most abundant species in this context. Also, the abundance of *A. mellifera* and *T. spinipes* were underestimated since not all specimens were sampled (see Material and Methods). The honeybee is an introduced species, managed, and with feral populations, being frequently recorded as the most common bee in other studies (Gonçalves and Melo, 2005). *Trigona spinipes* has been recorded in other studies with high abundance and shows a considerable increase for RMC over the last years (Martins et al., 2013; Cardoso and Gonçalves, 2018; Graf et al., 2022). This species is widely distributed in South America and can disperse over long distances and prevail in disturbed areas (Kleinert and Giannini, 2012; Moure and Melo, 2022). *Paratrigona subnuda* is a ground-nesting bee depending on pre-existing cavities made by ants (Mouga, 2014). Graf et al. (2022) recorded a high abundance of this species in four areas that show a high cover of FOM, all in the northern Curitiba (Sites 2, 4, 8, and 9), being an ecological indicator of forested formation. As discussed below, the presence and high abundance of this species is an important factor explaining the diversity and composition of Colombo.

The diversity and species composition of a particular site can reflect both its evolutionary history and current ecological conditions (Maack, 1981). The 11 native species collected only in this assemblage are not very abundant, ranging from one to 12 individuals, and most lack known associations with specific vegetation types or habitat specialization. However, three species are associated with Dense Ombrophilous Forest (FOD), near the Serra do Mar (Graf et al., 2022). *Tetragonisca angustula*, a stingless bee of significant economic interest in meliponiculture (Iwama, 1977; Macêdo et al., 2023), is commonly found in agricultural and urban settings, and its presence in the study area could also be associated with nearby meliponaries commonly reported in Curitiba Metropolitan Region. *Bombus brasiliensis* historically sampled in Araucaria Forest areas around Curitiba in the 1970s (Laroca, 1974), has not been recently collected in the city (Graf et al., 2022), but has records for Almirante Tamandaré and São José dos Pinhais. Its distribution covers the Brazilian coastal Atlantic Forest (Moure and Melo, 2022). *Trichocera mirabilis* is associated with Dense Ombrophilous Forest, and has been recorded in Seasonal Semideciduous Forests (Gonçalves and Oliveira, 2013). Also, this species does not have records for areas of FOM and Natural Grasslands (Pereira et al., 2024). *T. mirabilis* occurs, in Brazil, from southern Minas Gerais to Santa Catarina (Urban, 1989), including FOD areas in Piraquara within the Curitiba Metropolitan Region (Moure and Melo, 2022). Among the other nine newly records, *Centris proxima*, a Malpighiaceae oil-collecting bee (Torretta et al., 2022) lacks published records for Curitiba (Graf et al., 2022). In Brazil, it occurs in the Parque Estadual de Vila Velha, an area in Paraná mostly covered with Natural Grasslands (Gonçalves and Melo, 2005), Santa Catarina, São Paulo and Rio Grande do Sul (Patrício et al., 2014; Torretta et al., 2022; Moure and Melo, 2022). The Colombo site is composed of remnants of FOM, as well as native and exotic cultivated species (Possette et al., 2015). The areas of forest remnants constitute relics of the original formation and represent the preservation efforts amidst significant FOM reduction to less than 1% of its original extension (Maack, 1981; Castella and Brites, 2004). It is probable that the proximity of these natural remnants with the areas of FOD, together with the history of reforestation (Embrapa Florestas, 2023), and the potential effect of increased temperature in the urban environment may have facilitated the occupation of bee species that are more associated with closed vegetation areas, such as *B. brasiliensis* and *T. mirabilis*.

Despite presenting the highest vegetation cover among the 11 RMC sites, Colombo showed intermediate values of richness and low diversity.

This partially can be attributed to the high dominance of stingless bee species in this area, representing 13% of the total assemblage and 47% of its abundance (723 specimens), and the comparative low richness of Halictinae. The Meliponini species have functional traits that make them less sensitive to urbanization, being more abundant in disturbed areas than solitary bees, for example (Graf et al., 2022). The contrast in the presence and abundance of stingless bees between different sites is revealing. Passeio Público (Site 1) is the most urbanized study site, surrounded by buildings and streets, with very low vegetation cover that is constantly modified to achieve continuous and varied flowering, hosting a high number of ornamental plant species (Taura and Laroca, 2001). On the other hand, Afonso Pena International Airport (Site 10), the site with higher diversity, is an important remnant of Natural Grasslands, where Meliponini occur in low richness and abundance (Martins et al., 2013; Graf et al., 2022). According to our regression results, the Simpson's diversity significantly increases towards the south. This coefficient is largely influenced by the frequency of the most common species (Chao et al., 2014), thus highlighting the contrast between high dominance in the northern areas and low dominance in the southern assemblages. These differences probably emerge from vegetation types, with the FOM being dominant in the north and the Natural Grasslands in the south.

The vegetation cover was also significantly related to composition in the RMC (NDMS2). Vegetation cover is an important predictor and plays a fundamental role in maintaining bee diversity (Graf et al., 2022). Different bee species have specific habitat and nutrition needs, and green areas, especially with native vegetation, can provide nesting substrates and food sources, helping to maintain essential ecological interactions (Santos et al., 2022). Several urbanization studies have already shown how the vegetation loss and even fragmentation result in a decline in bee abundance and richness by affecting the quantity of available resources and their ability to move through landscapes (Hernandez et al., 2009; Ferreira et al., 2015; Boscolo et al., 2017; Graf et al., 2022; Brancher et al., 2023; Nagamitsu et al., 2023). This is underscored by the significant difference in vegetation cover among Site 1 and the others (Table 3) which correlates with variations in bee abundance and richness. The diversity reduction can be mitigated by ensuring vegetation cover of at least 35 to 40% of forest remnants (Ferreira et al., 2015). The diversity of pollinators tends to increase with the number of green areas in the landscape, bringing quality and availability of floral and non-floral resources (Wenzel et al., 2020). Graf et al. (2022) showed that the proportion of vegetation cover, landscape diversity, followed by the proximity between fragments are important predictors of urbanization regarding bee richness.

Regarding species composition, the NMDS revealed that Colombo is more similar to the northern areas of Curitiba, those with higher vegetation cover (Sites 2, 8, 9), despite its isolated position (Figure 3). The north-south gradient is observed on the NMDS1 axis. Examples of species that are typical of the northern sites include the abundant *P. subnuda*, also *Plebeia remota* and *Schwarziana quadripunctata*. As this study focuses on locally relevant scales, hence the north-south gradient is most likely to reflect differences on phytophysionomy or landscape configuration than a true latitudinal gradient derived from climate (Willig et al., 2003; Boyero, 2011). Regarding the vegetation structure, there is a clear difficulty in characterizing the limits of vegetation types in Curitiba, considering the extensive human interference and the lack of more detailed data for site classification (Klein and Hatschbach, 1962; Maack, 1981; Kersten and Galvão, 2014). Still, it is known that historical and ecological factors, dating back to Maack's texts (1931), explicitly indicate that the regions located to the north and northwest of the municipality were covered by dense forests distinctly separated from the areas characterized by Natural Grasslands (Klein and Hatschbach, 1962). These grasslands, now reduced, are currently observed more

continuously in the surrounding municipalities (Kersten and Galvão, 2014). Nevertheless, the composition of bee species addressed here captures some of the expected vegetation typing for the RMC.

In summary, the assemblage in Colombo exhibits intermediate levels of species richness and diversity, despite having the highest vegetation cover among the 11 areas studied. Nevertheless, the species composition in Colombo is similar to those of the preserved sites from the northern RMC. We conclude that these contrasting patterns between alpha and beta diversity could indicate that the local assemblage composition has a complexity that must also be influenced by qualitative factors, such as local and edge landscape. Other factors not addressed here include the diversity and composition of floral sources, as well as the effect of collector efficiency. It is also important to highlight that the database from the other 10 sites (Graf et al., 2022) were originally built under a different goal. The results for the bee assemblage, along with the available floristic data (Possette et al., 2015), emphasize the importance of conserving remnants of Atlantic Forest and the biodiversity present in the Colombo Embrapa Florestas.

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Conflicts of interest

The authors declare no conflicts of interest.

Author contribution statement

JAL: Conceptualization, data curation, formal analysis, methodology, writing original draft, writing review and editing. AM: Conceptualization, data curation, investigation, methodology, writing original draft. VRM: Conceptualization, data curation, investigation, methodology. RBG: Conceptualization, data curation, formal analysis, methodology, project administration, supervision, validation, visualization. SBM: Conceptualization, data curation, funding acquisition, methodology, project administration, supervision, validation, visualization.

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Supplementary Material

The following online material is available for this article:

Supplementary material - NMDS species scores. Species 1: *Acamptopoeum prinii* (Holmberg, 1884); 2: *Callonychium* (*Callonychium*) *petuniae* Cure & Wittmann, 1990; 3: *Anthrenoides admirabilis* Urban, 2005; 4: *Anthrenoides alvarengai* Urban, 2007; 5: *Anthrenoides antonii* Urban, 2005; 6: *Anthrenoides araucariae* Urban, 2005; 7: *Anthrenoides corrugatus* Urban, 2005; 8: *Anthrenoides larocai* Urban, 2005; 9: *Anthrenoides meridionalis* (Schrottky, 1906); 10: *Anthrenoides ornatus* Urban, 2005; 11: *Anthrenoides paolae* Urban, 2005; 12: *Anthrenoides petuniae* Urban, 2005; 13: *Anthrenoides rodrigoii* Urban, 2005; 14: *Anthrenoides* sp. 01; 15: *Cephalurgus anomalus* Moure & Lucas de Oliveira, 1962; 16: *Psaenythia annulata* Gerstaecker, 1868; 17: *Psaenythia bergii* Holmberg, 1884; 18: *Psaenythia capito* Gerstaecker, 1868; 19: *Psaenythia collaris* Schrottky, 1906; 20: *Psaenythia quadrifasciata* Friese, 1908; 21: *Psaenythia* sp. 1; 22: *Psaenythia* sp. 2; 23: *Rhophitulus politus* (Schlindwein & Moure, 1998); 24: *Rhophitulus* sp. 1; 25: *Rhophitulus* sp. 3; 26: *Rhophitulus* sp. 4; 27: *Rhophitulus* sp. 5; 28: *Rhophitulus* sp. 6; 29: *Rhophitulus* sp. 7; 30: *Rhophitulus* sp. 8; 31: *Rhophitulus* sp. 9; 32: *Bombus* (*Fervidobombus*) *morio* (Swederus, 1787); 33: *Bombus* (*Fervidobombus*) *pauloensis* Friese, 1913; 34: *Bombus* (*Fervidobombus*) *brasiliensis*; 35: *Eulaema* (*Apeulaema*) *nigrita* Lepeletier, 1841; 36: *Lestrimelitta sulina* Marchi & Melo, 2006; 37: *Melipona* (*Eomelipona*) *bicolor* Lepeletier, 1836; 38: *Melipona* (*Eomelipona*) *marginata* Lepeletier, 1836; 39: *Melipona* (*Melipona*) *quadrifasciata* Lepeletier, 1836; 40: *Melipona* (*Michmelia*) *scutellaris* Latreille, 1811; 41: *Nannotrigona testaceicornis* (Lepeletier, 1836); 42: *Paratrigona subnuda* Moure, 1947; 43: *Partamona helleri* (Friese, 1900); 44: *Plebeia droryana* (Friese, 1900); 45: *Plebeia emerina* (Friese, 1900); 46: *Plebeia remota* (Holmberg, 1903); 47: *Scaptotrigona bipunctata* (Lepeletier, 1836); 48: *Scaptotrigona postica* (Latreille, 1807); 49: *Schwarziana quadripunctata* (Lepeletier, 1836); 50: *Tetragonisca fiebrigi* (Schwarz, 1938); 51: *Tetragonisca angustula* (Latreille, 1811); 52: *Trigona spinipes* (Fabricius, 1793); 53: *Centris* (*Centris*) *varia* (Erichson, 1849); 54: *Centris* (*Hemisiella*) *trigonoides* Lepeletier, 1841; 55: *Centris* (*Hemisiella*) *tarsata* Smith, 1874; 56: *Centris* (*Melacentris*) *atra* (Friese, 1899); 57: *Centris* (*Trachina*) *proxima* (Friese, 1899); 58: *Melitoma segmentaria* (Fabricius, 1804); 59: *Ptilothrix relata* (Holmberg, 1903); 60: *Gaesischia* (*Gaesischia*) *fulgurans* (Holmberg, 1903); 61: *Gaesischia* (*Gaesischia*) *undulata* Urban, 1989; 62: *Gaesischia* (*Gaesischiopsis*) *aurea* Urban, 1968; 63: *Gaesischia* (*Gaesischiopsis*) *flavoclypeata* Michener, LaBerge & Moure, 1955; 64: *Melissodes* (*Eclectica*) *nigroaenea* (Smith, 1854); 65: *Melissoptila aureocincta* Urban, 1968; 66: *Melissoptila buzzii* Urban, 1998; 67: *Melissoptila cnecomala* (Moure, 1944); 68: *Melissoptila fiebrigi* Brèthes, 1909; 69: *Melissoptila larocai* Urban, 1998; 70: *Melissoptila minarum* (Bertoni & Schrottky, 1910); 71: *Melissoptila paraguayensis* (Brèthes, 1909); 72: *Melissoptila richardiae* Bertoni & Schrottky, 1910; 73: *Melissoptila setigera* Urban, 1998; 74: *Melissoptila thoracica* (Smith, 1854); 75: *Melissoptila vulpecula* Bertoni & Schrottky, 1910; 76: *Peponapis fervens* (Smith, 1879); 77: *Thygater* (*Nectarodiaeta*) *paranaensis* Urban, 1967; 78: *Thygater* (*Nectarodiaeta*) *sordidipenis* Moure, 1941; 79: *Thygater* (*Thygater*) *analisis* (Lepeletier, 1841); 80: *Exomalopsis* (*Diomalopsis*) *bicellularis* Michener & Moure, 1957; 81: *Exomalopsis* (*Exomalopsis*) *analisis* Spinola, 1853; 82: *Exomalopsis* (*Exomalopsis*) *vernoniae* Schrottky, 1909; 83: *Exomalopsis* (*Exomalopsis*) sp. 01; 84: *Exomalopsis* (*Exomalopsis*) sp. 02; 85: *Exomalopsis* (*Phanomalopsis*) *aureosericea* Friese, 1899; 86: *Exomalopsis* (*Phanomalopsis*) *perikalles* Silveira & Almeida, 2009; 87: *Exomalopsis* (*Phanomalopsis*) *trifasciata* Brèthes, 1910; 88: *Brachynomada* sp. 01; 89: *Brachynomada* sp. 03; 90: *Leiopodus lacertinus* Smith, 1854; 91: *Nomada* sp. 1; 92: *Nomada* sp. 2; 93: *Nomada* sp. 3; 94: *Nomada* sp. 4; 95: *Nomada* sp. 5; 96: *Nomada* sp. 6; 97: *Nomada* sp. 7; 98: *Pseudepeolus angustatus* (Moure, 1954); 99: *Trophocleptria variolosa* Holmberg, 1886; 100: *Trophocleptria* sp. 01; 101: *Osiris* sp. 03; 102: *Parepeolus minutus* Roig-Alsina, 1989; 103: *Arhysoceble picta* (Friese, 1899); 104: *Lanthanomelissa betinae* Urban, 1995; 105: *Lanthanomelissa clementis* Urban, 1995; 106: *Lophopedia nigrispinis* (Vachal, 1909); 107: *Lophopedia pygmaea* (Schrottky, 1902); 108: *Monoeca xanthopyga* Harter-Marques, Cunha & Moure, 2001; 109: *Paratetrapedia fervida* (Smith, 1879); 110: *Trigonopedia* sp. 01; 111: *Trigonopedia* sp. 03; 112: *Tetrapedia diversipes* Klug, 1810; 113: *Ceratina* (*Ceratinula*) *melanochroa* (Moure, 1941); 114: *Ceratina* (*Ceratinula*) *oxalidis* Schrottky, 1907; 115: *Ceratina* (*Ceratinula*) *sclerops* Schrottky, 1907; 116: *Ceratina* (*Ceratinula*) sp. 01; 117: *Ceratina* (*Ceratinula*) sp. 02; 118: *Ceratina* (*Ceratinula*) sp. 03; 119: *Ceratina* (*Ceratinula*) sp. 04; 120: *Ceratina* (*Crewella*) *asuncionis* Strand, 1910; 121: *Ceratina* (*Crewella*) sp. 03; 122: *Ceratina* (*Neoclavicera*) *asunciana* Strand, 1910; 123: *Ceratina* (*Neoclavicera*) *richardsoniae* Schrottky, 1909; 124: *Ceratina* (*Neoclavicera*) *subcarinata* Roig-Alsina, 2013; 125: *Ceratina* (*Neoclavicera*) *umbricosta* Roig-Alsina, 2013; 126: *Ceratina* (*Neoclavicera*) *fimbriata* Roig-Alsina, 2013; 127: *Ceratina* (*Rhysoceratina*) *canaliculata* Roig-Alsina, 2016; 128: *Ceratina* (*Rhysoceratina*) *stilbonota* Moure, 1941; 129: *Ceratina* (*Rhysoceratina*) *volitans* Schrottky, 1907; 130: *Xylocopa* (*Neoxylocopa*) *augusti* Lepeletier, 1841; 131: *Xylocopa* (*Stenoxycopa*) *artifex* Smith, 1874; 132: *Xylocopa* (*Neoxylocopa*) *frontalis* (Olivier, 1789); 133: *Colletes argentinus* Friese, 1908; 134: *Colletes michenerianus* Moure, 1956; 135: *Colletes rugicollis* Friese, 1900; 136: *Hylaeus* (*Hylaeopsis*) *cecidonastes* Moure, 1972; 137: *Hylaeus* sp. 01; 138: *Hylaeus* sp. 02; 139: *Hylaeus* sp. 03; 140: *Hylaeus* sp. 04; 141: *Hylaeus* sp. 05; 142: *Hylaeus* sp. 06; 143: *Hylaeus* sp. 07; 144: *Hylaeus* sp. 08; 145: *Hylaeus* sp. 09; 146: *Belopria zonata* Moure, 1956; 147: *Belopria* sp. 02; 148: *Bicolletes tauraphilus* Laroca & Almeida, 2005; 149: *Ctenosibyne cingulata* (Moure, 1956); 150: *Eulonchopria psauenythioides* Brèthes, 1909; 151: *Tetraglossula anthracina* (Michener, 1989); 152: *Chilicola* (*Oediscelisca*) sp. 01; 153: *Chilicola* (*Oediscelisca*) sp. 02; 154: *Chilicola* (*Prosopoides*) cfr. *prosopoides* (Ducke, 1907); 155: *Augochlora* (*Augochlora*) *caerulior* Cockerell, 1900; 156: *Augochlora* (*Augochlora*) *cydippe* (Schrottky, 1910); 157: *Augochlora* (*Augochlora*) *daphnis* Smith, 1853; 158: *Augochlora* (*Augochlora*) *nausicaa* (Schrottky, 1909); 159: *Augochlora* (*Augochlora*) *perimelas* Cockerell, 1900; 160: *Augochlora* (*Augochlora*) *phoemonoe* (Schrottky, 1909); 161: *Augochlora* (*Augochlora*) *seitzii* Cockerell, 1929; 162: *Augochlora* (*Augochlora*) *esox* (Vachal, 1911); 163: *Augochlora* (*Augochlora*) *genalis* Lepeco & Gonçalves, 2020; 164: *Augochlora* (*Oxystoglossella*) *iphigenia* Holmberg, 1886; 165: *Augochlora* (*Oxystoglossella*) *morrae* (Strand, 1910); 166: *Augochlorella ephyra* (Schrottky, 1910); 167: *Augochlorella iopocila* Moure, 1950; 168: *Augochlorella urania* (Smith, 1853); 169: *Augochlorella acarinata* Coelho, 2004; 170: *Augochloropsis* (*Augochloropsis*) *diversipennis* (Lepeletier, 1841); 171: *Augochloropsis* (*Augochloropsis*) *brachycephala* Moure, 1943; 172: *Augochloropsis* (*Augochloropsis*) *rotalis*; 173: *Augochloropsis* (*Glyptobasia*) *chloera* (Moure, 1940); 174: *Augochloropsis* (*Paraugochloropsis*) *cleopatra* (Schrottky, 1902); 175: *Augochloropsis* (*Paraugochloropsis*) *cupreola* (Cockerell, 1900); 176: *Augochloropsis* (*Paraugochloropsis*) *iris* (Schrottky, 1902); 177: *Augochloropsis* (*Paraugochloropsis*) *multiplex* (Vachal, 1903); 178: *Augochloropsis* (*Paraugochloropsis*) *sparsilis* (Vachal, 1903); 179: *Augochloropsis* (*Paraugochloropsis*) sp. 02; 180: *Augochloropsis* (*Paraugochloropsis*) sp. 03; 181: *Augochloropsis* (*Paraugochloropsis*) sp. 05; 182: *Augochloropsis* (*Paraugochloropsis*) sp. 09; 183: *Augochlora* (*Oxistoglossella*) *aurinasis* (Vachal, 1911); 184: *Augochloropsis* (*Paraugochloropsis*) sp. 10; 185: *Augochloropsis* (*Paraugochloropsis*) sp. 12; 186: *Augochloropsis* (*Paraugochloropsis*) sp. 13; 187: *Augochloropsis* (*Paraugochloropsis*) sp. 14; 188: *Augochloropsis* (*Paraugochloropsis*) sp. 15; 189: *Ceratalictus psoraspis* (Vachal, 1911); 190: *Corynurella cognata* Gonçalves, 2010; 191: *Halictillus loureiroi* (Moure, 1941); 192:

Megommation insigne (Smith, 1853); 193: Neocorynura atromarginata (Cockerell, 1901); 194: Neocorynura codion (Vachal, 1904); 195: Neocorynura dilutipes (Vachal, 1904); 196: Neocorynura hebe Gonçalves, 2019; 197: Neocorynura iopodion (Vachal, 1904); 198: Neocorynura laevistriata Gonçalves, 2019; 199: Neocorynura euadne (Schrottky, 1909); 200: Neocorynura roxane (Schrottky, 1909); 201: Paroxystoglossa andromache (Schrottky, 1909); 202: Paroxystoglossa brachycera Moure, 1960; 203: Paroxystoglossa jocasta (Schrottky, 1910); 204: Paroxystoglossa spiloptera Moure, 1960; 205: Pseudaugochlora graminea (Fabricius, 1804); 206: Pseudaugochlora indistincta Almeida, 2008; 207: Pseudaugochlora simulata Almeida, 2008; 208: Rhectomia pumilla Moure, 1947; 209: Rhinocorynura vernoniae (Schrottky, 1914); 210: Temnosoma sp. 01; 211: Temnosoma sp. 02; 212: Temnosoma sp. 03; 213: Thectochlora alaris (Vachal, 1904); 214: Agapostemon (Notagapostemon) semimelleus Cockerell, 1900; 215: Caenohalictus curticeps (Vachal, 1903); 216: Caenohalictus incertus (Schrottky, 1902); 217: Caenohalictus palumbes (Vachal, 1903); 218: Caenohalictus tessellatus (Moure, 1940); 219: Caenohalictus sp. 01; 220: Caenohalictus sp. 02; 221: Caenohalictus sp. 03; 222: Habralictus canaliculatus Moure, 1941; 223: Habralictus macrospilophorus Moure, 1941; 224: Oragapostemon divaricatus (Vachal, 1904); 225: Pseudagapostemon (Neagapostemon) cyanomelas Cure, 1989; 226: Pseudagapostemon (Pseudagapostemon) cyaneus Moure & Sakagami, 1984; 227: Pseudagapostemon (Pseudagapostemon) pruinusos Moure & Sakagami, 1984; 228: Dialictus anisitsianus (Strand, 1910); 229: Dialictus opacus (Moure, 1940); 230: Dialictus phaedrus (Schrottky, 1910); 231: Dialictus rostratus (Moure, 1947); 232: Dialictus sp. 01; 233: Dialictus sp. 02; 234: Dialictus sp. 03; 235: Dialictus sp. 04; 236: Dialictus sp. 05; 237: Dialictus sp. 06; 238: Dialictus sp. 08; 239: Dialictus sp. 09; 240: Dialictus sp. 11; 241: Dialictus sp. 12; 242: Dialictus sp. 13; 243: Dialictus sp. 14; 244: Dialictus sp. 15; 245: Dialictus sp. 16; 246: Dialictus sp. 17; 247: Dialictus sp. 18; 248: Dialictus sp. 19; 249: Dialictus sp. 24; 250: Melissocleptis capriciosa (Schrottky, 1906); 251: Microsphecodes russeiclypeatus (Sakagami & Moure, 1962); 252: Austrosphecodes asmodeus Gonçalves & Pereira, 2022; 253: Austrosphecodes brasiliensis Schrottky, 1910; 254: Austrosphecodes cerberus; 255: Nesosphecodes depressus Gonçalves, 2021; 256: Anthidium manicatum (Linnaeus, 1758); 257: Anthodioctes claudii Urban, 1999; 258: Anthodioctes megachiloides Holmberg, 1903; 259: Ctenanthidium gracile Urban, 1993; 260: Dicranthidium aff. soniae Urban, 1993; 261: Dicranthidium sp. 01; 262: Epanthidium autumnale (Schrottky, 1909); 263: Epanthidium nectarinioides (Schrottky, 1902); 264: Hypanthidium divaricatum (Smith, 1854); 265: Moureanthidium paranaense Urban, 1995; 266: Moureanthidium subarenarium (Schwarz, 1933); 267: Coelioxys (Acrocoelioxys) tolteca Cresson, 1878; 268: Coelioxys (Cyrtoceelioxys) sp. 01; 269: Coelioxys (Cyrtoceelioxys) sp. 02; 270: Coelioxys (Cyrtoceelioxys) sp. 03; 271: Coelioxys (Glyptoceelioxys) cerasiopleura Holmberg, 1903; 272: Coelioxys (Glyptoceelioxys) chacoensis Holmberg, 1903; 273: Coelioxys (Glyptoceelioxys) sp. 01; 274: Coelioxys (Neocoelioxys) praetextata Haliday, 1836; 275: Coelioxys (Neocoelioxys) sp. 01; 276: Megachile (Acentron) lentifera Vachal, 1909; 277: Megachile (Acentron) sp. 01; 278: Megachile (Austromegachile) facialis Vachal, 1909; 279: Megachile (Austromegachile) susurrans Haliday, 1836; 280: Megachile (Austromegachile) trigonaspis Schrottky, 1913; 281: Megachile (Austromegachile) sp. 01; 282: Megachile (Chryosarus) cfr. tuberculifera Schrottky, 1913; 283: Megachile (Chryosarus) sp. 01; 284: Megachile (Leptorachina) sp. 01; 285: Megachile (Leptorachis) aetheria Mitchell, 1930; 286: Megachile (Leptorachis) paulistana Schrottky, 1902; 287: Megachile (Leptorachis) sp. 01; 288: Megachile (Leptorachis) sp. 02; 289: Megachile (Melanosarus) aff. brasiliensis Dalla Torre, 1896; 290: Megachile (Moureapis) apicipennis Schrottky, 1902; 291: Megachile (Moureapis) maculata Smith, 1853; 292: Megachile (Moureapis) nigropilosa Schrottky, 1902; 293: Megachile (Pseudocentron) curvipes Smith, 1853; 294: Megachile (Tylomegachile) orba Schrottky, 1913; 295: Megachile sp. 01; 296: Megachile sp. 02; 297: Trichocerapis mirabilis (Smith, 1865).