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Bee diversity in urban green areas of a tropical metropolis: a multi-sampling approach

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Abstract

Human land use and land cover changes threaten biodiversity and ecosystem services, including pollination. Bees, which are key pollinators of many angiosperms, are particularly vulnerable to land use change. In this context, fragments of native vegetation can serve as crucial refuges for these insects, especially in heavily disturbed areas such as urban environments. In this study, we present an inventory of bee species found in green areas, such as parks and protected areas of a 2 million people tropical metropolis located in a highly biodiverse region, Belo Horizonte, MG, Brazil. Bees were sampled at five sites using three different methods: active sampling, scent traps, and pan traps. We identified a total of 97 species belonging to the five families of bees found in Brazil, and most (79.3%) of them were sampled by only one of the sampling methods applied. The generalist native bee species *Eulaema nigrita* Lepeletier, 1841, *Trigona spinipes* (Fabricius, 1793), *Paratrigona lineata* (Lepeletier, 1836), and the invasive species *Apis mellifera* Linnaeus, 1758 were the most abundant at all sampling sites. The use of complementary sampling methods allowed the recording of highly diverse bee assemblages, one of the most complete lists so far in the region. This knowledge is the first step towards an integrated urban planning that also aims at the conservation of ecosystem services. Ultimately, this study shows that a more comprehensive description of pollinator fauna requires complementary sampling methods, which are essential for effective management and monitoring plans of urban biodiversity.

Introduction

Primary vegetation cover is indispensable for the conservation of biodiversity (Gibson et al., 2011; Solar et al., 2016). However, human population expansion and the ever-increasing demand for natural resources have transformed the Earth's surface (Vitousek et al., 1997). Changes in land use and land cover and excessive extractive activities are the main drivers of global biodiversity loss (Vitousek et al., 1997; Jaureguiberry et al., 2022) as they have led to habitat destruction and the introduction of exotic species (Meyer & Turner, 1996; Bartlett et al., 2016), threatening terrestrial biodiversity and ecosystem services (Pereira et al., 2010; Tittensor et al., 2014; Newbold et al., 2015; Shah et al., 2023). Urban areas doubled from 1992 to 2015, making urbanization the largest percentage change in land use in recent decades, with the largest increases occurring primarily in tropical and subtropical savannas and grasslands (IPBES, 2019). Current studies estimate that by 2100, habitat loss resulting from intense land use changes will be the primary driver of biodiversity loss (Sala et al., 2000), when combined with other stressors, such as climate change, these effects could be catastrophic (IPBES, 2019; França et al., 2020; Millard et al., 2021).

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A recent study analyzed trends in insect diversity loss and found that insect richness and abundance decline more significantly when the effects of land use and climate change are combined (Outhwaite et al., 2022). Among insects, bees play a critical role in ecosystems as pollinators of both natural and cultivated plant species (Potts et al., 2010; Garibaldi et al., 2011), and are heavily impacted by land-use changes (Potts et al., 2010). Most angiosperms are primarily or exclusively dependent on bees for pollination, and the vast majority of bees feed exclusively on floral resources (Ollerton et al., 2011; Pinheiro et al., 2014; Ollerton, 2017), establishing an important mutualistic relationship between plant species and bees (Steiner & Whitehead, 1996; Pacheco Filho et al., 2015; Portman et al., 2019; Valadão-Mendes et al., 2022). In addition, wild bees are important for ensuring the reproductive success of urban trees and plant species present in green spaces (Hausmann et al., 2016). In this way, native bees help to maintain complex ecological networks, strengthening the resilience of urban ecosystems and contributing to the environmental health of cities (Sirohi et al., 2022; Anderson et al., 2023).

Landscape composition and habitat richness directly and indirectly influence bee communities (Papanikolaou et al., 2017), with species possessing specific functional traits, such as larger body size and solitary behavior, being particularly vulnerable to land-use changes (Rader et al., 2014). In addition, urbanization can cause the loss of ground-nesting species (Pereira et al., 2021). On a regional scale, forest loss negatively affects the abundance of bees that nest above ground in living or dead trees (Ferreira et al., 2015). The alpha taxonomic and phylogenetic diversity of bees is also negatively affected by urbanization and agricultural habitats, while the effects on beta and gamma diversity vary and studies at different scales are needed to assess these effects (Tsang et al., 2025). In addition, some studies have shown the replacement of native species by the exotic species *Apis mellifera* Linnaeus, 1758 in places where floral resources are limited, such as in environments modified by human activity (Aizen & Feinsinger, 1994; Thomson, 2004; Brosi et al., 2008; Cane & Tepedino, 2017; Wojcik et al., 2018).

The reduction in native vegetation cover regulates bee responses on a local scale, negatively affecting the abundance of these organisms (Ferreira et al., 2015). Urban green spaces play an important role as refuges for a wide diversity of pollinators, especially generalist and social bees (da Rocha-Filho et al., 2020; Silva et al., 2023; Gomes et al., 2025). Furthermore, an essential component of bee conservation in urban areas is the development and maintenance of sites that provide abundant and diverse floral resources and nesting substrates (Wilson & Jamieson, 2019). Thus, the creation and maintenance of large green areas in densely populated areas benefits the maintenance and protection of bee communities, as well as improving the quality of life of local citizens by providing essential ecosystem services (Wolch et al., 2014; Banaszak-Cibicka et al., 2018; Guimarães Alves & Gaglianone, 2021; Kolimenakis et al., 2021).

Understanding the diversity of bees in green areas affected by changes in land use and land cover is essential to guide management of these areas and protect local species. Although other studies have assessed bee species in the metropolitan region of Belo Horizonte, they have used only one sampling method (e.g. active sampling, Gomes et al., 2025) and most have focused on specific groups, such as the Euglossini tribe (Nemésio & Silveira, 2007, 2010) and cavity nesters (Loyola & Martins, 2006). In particular, it is known that different sampling methods better represent a specific group of bees (e.g. odor baits for orchid bees) and do not capture the general diversity of bees. Therefore, comprehensive studies including all bee groups, which are essential for understanding local bee diversity in these urban green remnants, require complementary sampling approaches. In this context, here we use a combination of sampling methods to provide a baseline list of bee species in urban green areas in the Belo Horizonte metropolitan area, a region with high endemism and significant anthropogenic pressures.

Materials and Methods

Study Areas

Sampling was conducted at five sites in the metropolitan region of Belo Horizonte, in the state of Minas Gerais, Brazil. The city of Belo Horizonte is known as the most populous city in the state of Minas Gerais, with approximately 2,315,560 inhabitants in 2022, according to IBGE (2022). The climate of the region is classified by Köppen as high-altitude tropical (Alvares et al., 2013), with two seasons characterized by high temperatures and high humidity from October to March, and lower temperatures and drought from April to September (Carmo & Jacobi, 2012; de Sá Júnior et al., 2012). The region rarely has a maximum temperature above 30°C; the average annual temperature is mostly just below 20°C, and rainfall can vary from just under 1500 mm to just over 2000 mm (Dorr, 1969).

The study area is located in an ecotone between the Cerrado and the Atlantic Forest, two biomes known as biodiversity hotspots due to their high biodiversity, high rates of endemism, and high risk of species extinction (Eisenlohr et al., 2015; Strassburg et al., 2017). In addition, the great geological and soil diversity and altitudinal variation allow for the existence of different populations and biological communities, guaranteeing the region's high biodiversity rates (Carmo & Jacobi, 2012; Fernandes et al., 2020). The region has formations known as "Campo Rupestre", characterized by a landscape formed by mountainous vegetation, with grasses and shrubs, and the presence of rocky outcrops of quartz, sandstone or ferruginous (Viana & Lombardi, 2007; Messias et al., 2012; Silveira et al., 2016). One of these formations is the region, named "Quadrilátero Ferrífero" (Iron Quadrangle in English), which has part of its area in our study area, and is known for having altitudes that vary between 700 and 2000 m above sea level (Viana & Lombardi, 2007).

The region covers approximately 7200 km² and represents one of the most unique landscapes in Brazil (Dorr, 1969) and due to its environmental heterogeneity, represents an area of great ecological importance and a priority for conservation (Drummond, 2005; Jacobi et al., 2007; Garcia et al., 2009; Salgado & Fonseca do Carmo, 2015). However, the region is home to different types of land use, such as agriculture, limestone mining and iron ore mining, and clay extraction, as well as a disorderly process of urban growth that actively contributes to the de-characterization of the vegetation cover (Garcia et al., 2009; Salgado & Fonseca do Carmo, 2015).

Sample Design

The study area is dominated by two anthropogenic land uses: urbanization and mining. Sampling was conducted at five sites corresponding to some of the green areas in the Belo Horizonte metropolitan area (Table 1). Due to the flight radius and foraging distance of bees (Gathmann & Tscharntke, 2002; Araújo et al., 2004; Darvill et al., 2004; López-Uribe et al., 2008; Zurbuchen et al., 2010a; Zurbuchen et al., 2010b), the collection points are separated from each other by a buffer of at least 2 km radius to guarantee the independence of the collections (Fig 1). These sites corresponds

Table 1. Description of the five green areas of Belo Horizonte Metropolitan Region included in the study. MNSM – Monumento Natural da Serra da Moeda, PERBM – Parque Ecológico Roberto Burle Marx, PESRM – Parque Estadual da Serra do Rola Moça, PMFLN – Parque Municipal Fazenda Lagoa do Nado and PSC – Parque da Serra do Curral. (Source: Prefeitura de Belo Horizonte and Unidades de Conservação no Brasil).

Green Area	Coordinate	Vegetation type	Extension	Creation year
MNSM	20°04'46.8"S 43°59'32.1"O	Seasonal semi-deciduous forest with Campo Rupestre formations	2,372 ha	2010
PERBM	19°59'50.1"S 43°59'54.7"O	Brazilian savannah, with savannah grasslands and riparian forest formations	17.6 ha	1994
PESRM	20°03'32.6"S 44°01'33.0"O	Semi-deciduous seasonal forest and Brazilian savannah with Campo Rupestre formations	3,941 ha	1994
PMFLN	19°49'54.6"S 43°57'39.5"O	Brazilian savannah, mostly riparian forest	31.1 ha	1994
PSC	19°57'41.7"S 43°55'05.9"O	Transition between the Atlantic Forest and the Brazilian Savannah, with typical savannah formations and the presence of Campos Rupestres.	40 ha	2012

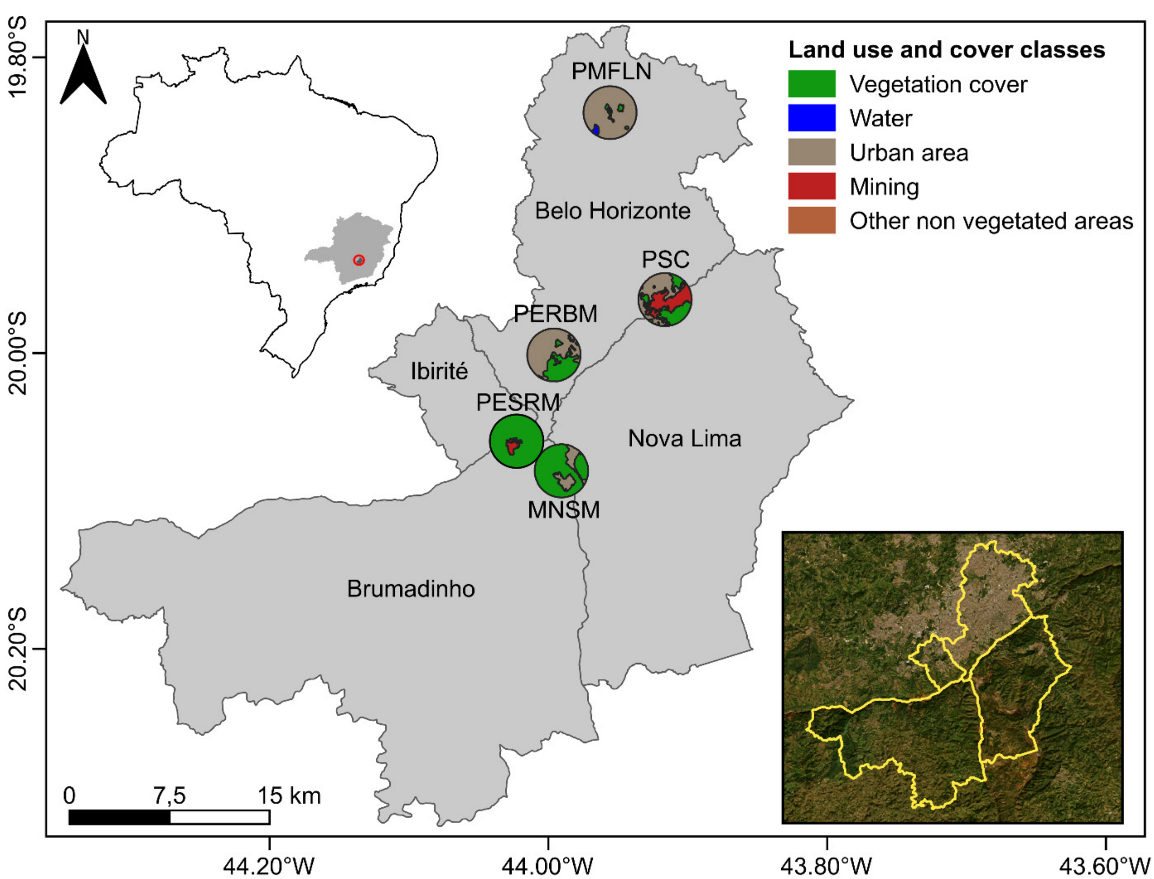

Fig 1. Map of the buffers of the five sampling sites and the land use and land cover classes present at each one: MNSM – Monumento Natural da Serra da Moeda, PERBM – Parque Ecológico Roberto Burle Marx, PESRM – Parque Estadual da Serra do Rola Moça, PMFLN – Parque Municipal Fazenda Lagoa do Nado and PSC - Parque da Serra do Curral (Datum SRC: EPSG:31983 – SIRGAS 2000).

to three municipal parks ("Parque Ecológico Roberto Burle Marx" – PERBM, "Parque da Serra do Curral" – PSC and "Parque Municipal Fazenda Lagoa do Nado" – PMFLN), one state park ("Parque Estadual da Serra do Rola Moça" – PESRM) and one site in the "Monumento Natural da Serra da Moeda" (MNSM). The green area within each of the five buffers is affected to varying degrees by some type of disturbance: urbanization and/or mining development. The percentage of land use type (Table 2) was calculated based on the land use and land cover classification produced by MapBiomas (2023). In addition, due to the possibility of errors in map resolution, as the spatial scale of each point is local and small, the satellite image from the ESRI imagery extension (ESRI) in the QGIS software (QGIS Development Team, 2021) was used for comparison with the MapBiomas classification. When incorrect land cover classifications were found, the polygon was changed to the correct classification and the area data of the polygons of each class were then used to calculate the percentage of that land cover in relation to the total area of the corresponding buffer. When calculating the percentages of land cover type, green areas such as parks and hills were considered as vegetation cover, regardless of the type of vegetation formation and whether the vegetation was native or not. Therefore, when different classes were found, such as "Grassland" and "Forest Formation", according to the MapBiomas classification, these classes were unified into "Vegetation Cover".

Table 2. Percentage of each land use and land cover class present in each 2 km radius buffer where the bees were sampled. Percentage values for each land use and land cover class were calculated from satellite imagery using QGIS software. MNSM – Monumento Natural da Serra da Moeda, PERBM – Parque Ecológico Roberto Burle Marx, PESRM – Parque Estadual da Serra do Rola Moça, PMFLN – Parque Municipal Fazenda Lagoa do Nado and PSC – Parque da Serra do Curral.

Green Area	Vegetation cover	Water	Mining	Urban area	Other non-vegetated area
PESRM	94.48%	0.00%	5.52%	0.00%	0.00%
MNSM	81.02%	0.00%	0.00%	18.98%	0.00%
PERBM	33.42%	0.00%	0.00%	65.63%	0.95%
PSC	30.72%	0.00%	30.81%	38.47%	0.00%
PMFLN	3.85%	2.35%	0.00%	93.80%	0.00%

Five campaigns were made in the Monumento Natural da Serra da Moeda and four in each of the other green areas, only on days when weather conditions were favorable for bee activity (e.g. sunny days, with low wind speeds). The sampling period corresponded to the rainy season due to the greater diversity of insects in the period and lasted from November 2022 to April 2023, when there was heavy rainfall. Due to the heavy rainfall, which sometimes made field work impossible, sampling was carried out at intervals of between 5 and 74 days, with a total of 21 collections during this period.

Sampling Bees

To characterize the diversity of bees, three complementary sampling methods were used: i) pan traps, ii) scent traps, and iii) active collections based on floral observations. Each sampling campaign was conducted across all five sites, with each site being sampled on a different day within the same campaign period. At each site, three sets of pan traps were installed at least 10 m apart. Pan traps are attractive traps that collect bees attracted by their color, which land in a liquid solution of water, salt (5%), and soap (5%) (Vrdoljak & Samways, 2012). The soap is used to break the surface tension of the water, causing the insect that lands in the liquid to drown. Each set of pan traps consisted of a 1,000 ml plastic bowl in each color: one white, one blue, and one yellow. The sets of pan traps were placed on the ground in open fields and 1 m above the ground, attached to a stake, in areas of dense forest. In addition, six scent traps were installed at each site to sample Euglossini bees. These traps were used to collect the males of these bees using synthetic compounds that attract these animals by simulating the resources they collect from flowers (Dodson et al., 1969; Coswosk et al., 2019). One of the following compounds was selected for each trap: Eugenol, Eucalyptol, Methyl cinnamate, Vanillin, Methyl salicylate or Benzyl acetate. These compounds are some of those known to attract a variety of males of the Euglossini bees (Dodson et al., 1969; Ackerman, 1989), which are known to collect floral and non-floral odors (Dressler, 1982; Whitten et al., 1993) used in sexual behaviors of competition between males and selection by females (Zimmermann et al., 2009; Henske et al., 2023). Scent traps were placed at least 10 m apart from each other and from the pan traps, and were installed about 1.5 m above the ground, attached to tree branches on the edges of capon or trails. These traps were made of PET bottles with four openings 2.5 cm in diameter at the top into which plastic funnels were inserted (Antonini et al., 2017). The inside of these funnels was sanded to form an artificial landing plane with a rougher surface. Inside the PET, a cotton pad with one of the essences was attached to a pick, keeping it slightly below the line of the openings. The inside of the traps was half filled with a solution of water, salt (5%) and soap (5%), in which these organisms were temporarily stored.

The active sampling of bees was conducted by floral observation, at each sampling site, during the interval from 8:00 a.m. to 1:00 p.m., a period that covers the peak activity of most bee species (Polatto et al., 2014). During this period, 10-minute observations were made at each flowering plant along the route, and flower-visiting bees were collected for later identification. In total, 115 hours of observations were made by groups of 2 to 4 observers. In areas of dense vegetation, observations were limited to the edges of fragments and trails. All bees sampled were identified to the smallest taxonomic level aided by Dr. Favízia Freitas de Oliveira, using available identification keys (Silveira et al., 2002; Nemésio, 2009; Engel et al., 2023) and deposited in the reference collection of CSEC – UFMG.

Statistical Analysis

To evaluate sampling sufficiency and estimate species richness, rarefaction and extrapolation curves based on abundance was used (Chao et al., 2014). This analysis estimates observed and expected sampling coverage and species richness at different sample sizes. To calculate the confidence intervals (95% CI) of the estimates, 500 bootstrap resamplings were carried out. Sampling coverage was calculated for the aggregated data from all the sampling sites, considering diversity of order q = 0 (species richness). These analyses were performed using the *iNEXT* package (Hsieh et al., 2020) in R v. 4.4.3 (R Core Team, 2025). Additionally, a Venn diagram was constructed to illustrate the number of bee species sampled by each sampling method, the number of species shared between different methods. This visualization was generated using the *VennDiagram* package (Chen, 2022), providing a graphical representation of species overlap among sampling techniques. An Analyses of Variance (ANOVA) were carried out to estimate whether there was a difference between the bee sampling methods in terms of species richness and abundance of individuals sampled. In these analyses, the predictor variable was the collection method used, while the response variables were species richness and the abundance of individuals sampled by each method. Finally, ANOVA was also carried out to test whether there were differences in species richness and abundance of individuals sampled between sampling sites. In these analyses, the sampling sites were the predictor variable, while the species richness and abundance of individuals collected at each site were the response variables.

Results

A total of 1260 specimens were collected during the study, representing a diverse group of 97 species belonging to the five families found in Brazil: Andrenidae (1 species), Apidae (56 species), Colletidae (3 species), Halictidae (33 species), and Megachilidae (4 species). All specimens were identified to at least the genus level, and of these, 41 species were determined, while the remaining 56 were classified

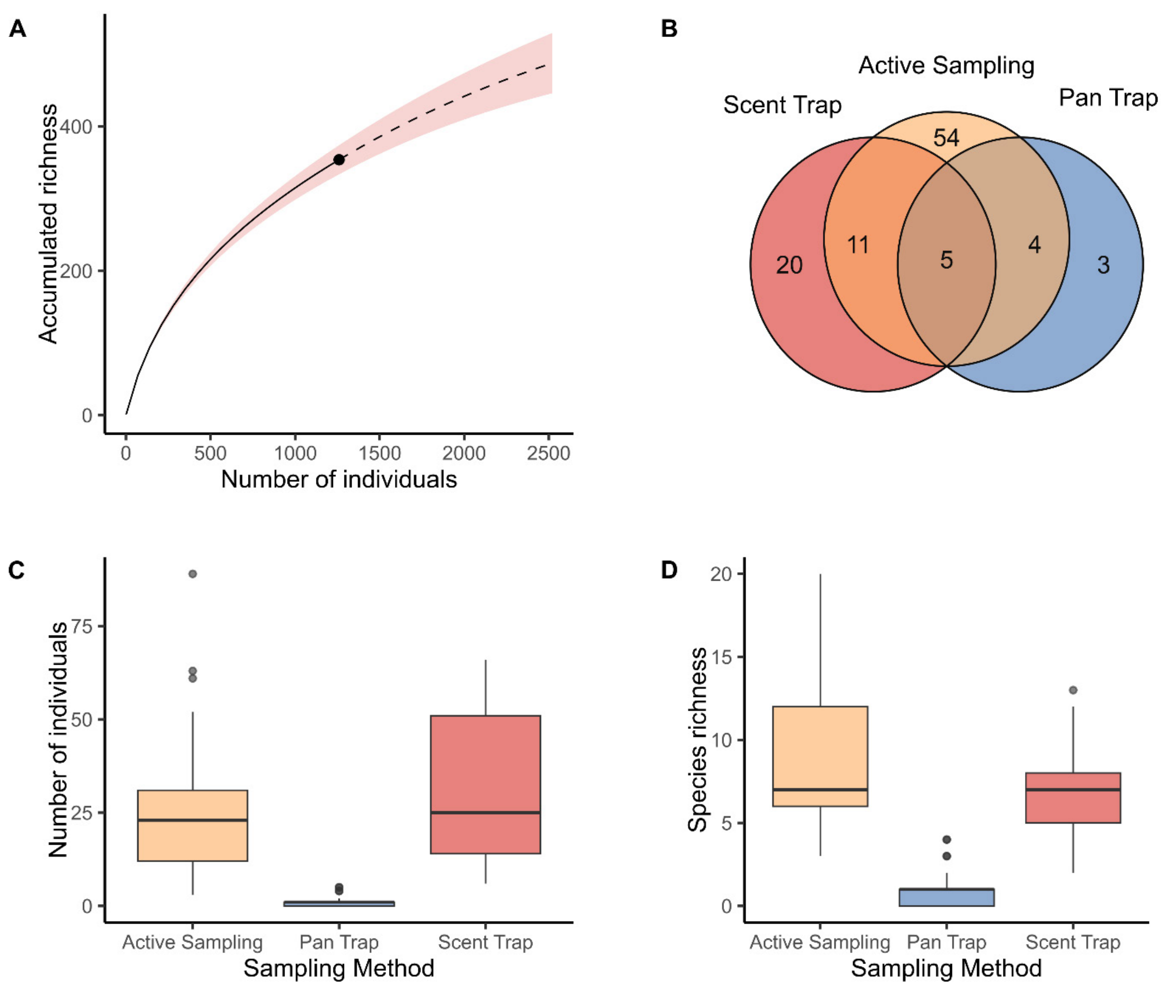

Fig 2. a. Extrapolation curve of accumulated species richness as a function of the number of individuals collected in the study, b. Venn diagram showing the richness of bees collected by different sampling methods, c. abundance and d. richness of bee individuals by collection method.

as morphospecies (Table 3). Specimens of three different species were collected that showed some differences from the known species – *Centris trigonoides* Lepeletier, 1841; *Hypanthidium nigritulum* Urban, 1998; and *Plebeia droryana* (Friese, 1900) – and were treated as morphospecies close to them – *Centris* aff. *trigonoides*, *Hypanthidium* aff. *nigritulum*, and *Plebeia* aff. *droryana*, respectively. However, it remains to be investigated whether these morphospecies are still undescribed species or whether they represent intraspecific variation in the morphology of these animals. The species accumulation curve did not assume an asymptotic pattern (Figure 2A) and the sampling coverage was 97.14%.

Only 5 species were collected by all three collection methods and, in total, 15 species were collected by two of the three methods while 77 species were collected by only one of the methods (Fig 2B, Table 3). In addition, the sampling methods showed differences in abundance ($F_{(2,60)}$= 33.901, p<0.001, Figure 2C) and richness ($F_{(2,60)}$= 18.303, p<0.001, Figure 2D) of individuals, with pan traps showing the lowest values compared to scent traps and active sampling. This suggests that the different collection methods are not equally effective in sampling the bee community, with pan traps being less efficient for capturing the overall richness and abundance of individuals in this study.

Table 3. List of bee species collected during the rainy season between 2022 and 2023. The values represent the number of specimens of each species collected in each site: MNSM – Monumento Natural da Serra da Moeda, PERBM – Parque Ecológico Roberto Burle Marx, PESRM – Parque Estadual da Serra do Rola Moça, PMFLN – Parque Municipal Fazenda Lagoa do Nado and PSC – Parque da Serra do Curral.

Species	**Author**	**Green Area**				
		PERBM	**PESRM**	**PMFLN**	**PSC**	**MNSM**
ANDRENIDAE						
Oxaea flavescens	Klug, 1807	1	0	0	0	0
APIDAE						
Apis mellifera	Linnaeus, 1758	7	25	9	27	35
Bombus brevivillus	Franklin, 1913	1	5	0	6	8
Bombus morio	(Swederus, 1787)	1	1	0	0	0
Centris aff. *trigonoides*	Lepeletier, 1841	0	3	0	4	0
Centris analis	Lepeletier, 1841	3	0	0	0	0
Cephalotrigona capitata	(Smith, 1854)	2	0	0	0	0
Ceratina (*Ceratinula*) *fioreseana*	Oliveira, 2020	0	0	0	2	0
Ceratina (*Ceratinula*) sp.1		0	0	0	1	0
Ceratina (*Ceratinula*) sp.2		0	0	0	1	5
Ceratina (*Ceratinula*) sp.3		0	0	0	2	1
Ceratina (*Ceratinula*) sp.4		0	0	0	1	0
Ceratina (*Ceratinula*) sp.5		0	0	0	0	1
Ceratina (*Crewella*) sp.1		0	1	0	0	0
Ceratina (*Crewella*) sp.2		0	0	1	0	0
Ceratina (*Rhysoceratina*) sp.1		0	0	0	0	1
Ceratina maculifrons	Smith, 1854	0	1	0	0	1
Epicharis flava	Friese, 1900	6	0	0	0	0
Eufriesea auriceps	(Friese, 1899)	0	2	0	3	4
Eufriesea nigrohirta	(Friese, 1899)	0	1	0	1	0
Eufriesea sp.1		0	1	0	0	3
Eufriesea sp.2		0	1	0	0	0
Euglossa annectans	Dressler, 1982	3	0	0	0	2
Euglossa cordata	Cockerell, 1904	16	1	42	6	0
Euglossa melanotricha	Moure, 1967	4	24	1	22	29
Euglossa modestior	Dressler, 1982	0	9	0	11	6
Euglossa sp.		2	0	0	7	3
Euglossa truncata	Rebêlo & Moure, 1996	1	0	0	5	5
Eulaema cingulata	(Fabricius, 1804)	3	9	25	3	0
Eulaema nigrita	Lepeletier, 1841	18	116	28	65	70
Exaerete smaragdina	(Guérin, 1844)	2	0	0	1	0

Table 3. List of bee species collected during the rainy season between 2022 and 2023. (Continuation)

Species	Author	Green Area				
		PERBM	PESRM	PMFLN	PSC	MNSM
APIDAE						
Exomalopsis analis	Spinola, 1853	1	0	1	0	0
Exomalopsis fulvipennis	Schrottky, 1910	7	0	0	0	0
Geotrigona subterranea	(Friese, 1901)	11	5	0	11	1
Lestrimelitta limao	(Smith, 1863)	1	0	2	0	0
Nannotrigona testaceicornis	(Lepeletier, 1836)	4	0	6	14	0
Paratetrapedia sp.1		0	0	0	1	0
Paratetrapedia sp.2		1	0	0	0	0
Paratetrapedia sp.3		0	0	0	0	1
Paratrigona lineata	(Lepeletier, 1836)	7	8	8	15	7
Paratrigona subnuda	Moure, 1947	2	0	0	9	0
Partamona helleri	(Friese, 1900)	4	0	0	0	4
Plebeia aff. *droryana*	(Friese, 1900)	1	0	34	19	1
Scaptotrigona bipunctata	(Lepeletier, 1836)	0	0	0	0	3
Tetragona clavipes	(Fabricius, 1804)	7	0	1	0	0
Tetragonisca angustula	(Latreille, 1811)	14	0	24	9	1
Tetrapedia sp.		0	0	0	0	1
Thygater anae	Urban, 1999	4	0	0	0	0
Thygater analis	(Lepeletier, 1841)	1	0	0	0	2
Trigona braueri	Friese, 1900	40	0	0	3	0
Trigona hyalinata	(Lepeletier, 1836)	12	0	0	0	1
Trigona spinipes	(Fabricius, 1793)	18	13	35	3	23
Trigonopedia sp.1		0	1	0	0	4
Trigonopedia sp.2		0	0	0	0	1
Xylocopa grisescens	Lepeletier, 1841	0	0	2	0	0
Xylocopa sp.1		0	0	0	0	1
Xylocopa sp.2		1	0	0	0	0
COLLETIDAE						
Hylaeus (*Hylaeopsis*) sp.1		0	2	0	0	0
Ptiloglossa sp.1		4	0	0	1	0
Ptiloglossa sp.2		0	0	0	0	2
HALICTIDAE						
Augochlora aurinasis	(Vachal, 1911)	1	0	7	3	0
Augochlora morrae	Strand, 1910	3	1	16	0	2
Augochlora sp.1		0	0	1	0	0
Augochlora sp.2		0	0	0	1	0
Augochlora sp.3		1	0	0	0	0
Augochlora sp.4		0	0	0	1	0
Augochlora sp.5		1	0	0	1	1
Augochlora sp.6		1	0	2	0	0
Augochlora sp.7		0	1	1	0	1
Augochlora sp.8		0	0	0	1	0
Augochlorella sp.1		0	2	0	0	0
Augochloropsis sp.1		0	3	0	0	0
Augochloropsis sp.2		0	3	0	0	1
Augochloropsis sp.3		0	0	0	0	1
Augochloropsis sp.4		0	0	0	2	0

Table 3. List of bee species collected during the rainy season between 2022 and 2023. (Continuation)

Species	Author	Green Area				
		PERBM	PESRM	PMFLN	PSC	MNSM
HALICTIDAE						
Augochloropsis sp.5		1	0	0	0	0
Augochloropsis sp.6		0	1	0	0	0
Augochloropsis sp.7		0	1	0	0	0
Caenohalictus sp.		0	0	0	0	1
Dialictus opacus	(Moure, 1940)	0	1	0	0	0
Dialictus sp.1		3	0	7	3	0
Dialictus sp.2		1	2	5	6	1
Dialictus sp.3		0	0	0	1	0
Dialictus sp.4		0	1	0	0	0
Dialictus sp.5		0	0	0	1	0
Dialictus sp.6		0	0	0	1	0
Dialictus sp.7		0	0	1	0	0
Dialictus sp.8		0	0	1	1	0
Dialictus sp.9		0	0	1	0	0
Neocorynura sp.1		0	5	0	0	1
Neocorynura sp.2		1	0	0	0	0
Neocorynura sp.3		7	0	0	0	0
Pseudaugochlora graminea	(Fabricius, 1804)	0	0	3	0	0
MEGACHILIDAE						
Epanthidium tigrinum	(Schrottky, 1905)	1	0	1	0	0
Hypanthidium aff. *nigritulum*	Urban, 1998	1	0	0	0	0
Megachile (*Pseudocentron*) sp.		0	1	0	0	0
Megachile sp.		0	0	0	0	1
TOTAL		232	251	265	275	237

Discussion

Here we provide a systematized list of bees in the green areas of the region using different sampling methods to sample bees in the metropolitan region of Belo Horizonte, which is part of the Quadrilátero Ferrífero. The use of different sampling methods proved to be essential in describing the overall bee diversity, as the majority of species (79%) were sampled using only one of the methods applied, and only generalist bees such as *Apis mellifera*; *Bombus brevivillus* Franklin, 1913; *Dialictus* sp.2; *Trigona spinipes* (Fabricius, 1793). and *Trigonopedia* sp.1 were sampled using all methods. This diverse sampling resulted in one of the most complete and robust list of bee species found for the region (see also Gomes et al., 2025), with the sampling coverage of 97.14% (Roswell et al., 2021) and recorded the occurrence of species that had never been recorded for the region (Antonini & Martins, 2003; Zanette et al., 2005; Loyola & Martins, 2006; Nemésio & Silveira, 2007, 2010; Gomes et al., 2025).

Considering specific groups, our study resulted in the sampling of 12 species of Euglossini, of which *Eufriesea auriceps* (Friese, 1899) has not been previously recorded in the region. Previous studies in the area (Nemésio & Silveira, 2007, 2010) sampled a total of 14 Euglossini species using similar aromatic compounds, and their year-long sampling efforts found five species that we did not collect in our study: *Euglossa fimbriata* Moure, 1968; *Euglossa imperialis* Cockerell, 1922; *Euglossa leucotricha* Rebêlo & Moure, 1995; *Euglossa pleosticta* Dressler, 1982; and *Euglossa securigera* Dressler, 1982.

Additionally to these studies focused on Euglossini, other efforts have been conducted to record the presence of bees in the study region. To understand the effect of urbanization on the diversity of bees and wasps, Zanette et al. (2005) sampled 69 bee species through active sampling in public squares in the city of Belo Horizonte. Gomes et al. (2025) also recorded 97 species of bees through active sampling in Belo Horizonte but included more sampling sites (12) and campaigns (8), underscoring the efficiency of using different sampling methods in describing bee fauna of our study. Notably, only 21 (21.65%) of bee species are the same with our study. Our study, using a multi-sampling approach including scent traps and pan traps, was able to record species *Exaerete smaragdina* (Guérin-Méneville, 1844); *Lestrimelitta limao* (Smith, 1863) and genera such as *Hylaeus* Fabricius , 1793 and *Eufriesea* Cockerell, 1908 which, due to their size or behavior, are more difficult to collect during only floral observations. Loyola & Martins (2006) used a different method than the one used in this study, trap-nests, with the aim of assessing the temporal variation in the nesting of solitary bees and wasps in forest fragments in Belo Horizonte, and sampled seven solitary bee species. Thus, compared to previous studies, our work recorded 17 new species for the region, while these studies together recorded 113 species that were not sampled in our study (Antonini & Martins, 2003; Loyola & Martins, 2006; Nemésio & Silveira, 2007, 2010; Gomes et al., 2025). Given this number of species not sampled in our study, new efforts should be made to understand whether this is an effect of seasonality, since we only sampled during the rainy season, or a loss of species due to increasing changes in land use and land cover in the region.

Native generalist species, such as *Eulaema nigrita* Lepeletier, 1841; *Trigona spinipes* and *Paratrigona lineata* (Lepeletier, 1836), and the invasive generalist *Apis mellifera* were the most abundant in all the green areas included in this study. This is probably because different bee groups respond differently to changes in land use, depending on how they forage and nest (Brosi et al., 2008). Areas with less remnant habitat mainly support these generalist bees, as they can forage on a greater variety of flowers present in these locations (Ferreira et al., 2015). On the other hand, bees with more specific feeding and nesting requirements and specific traits, such as larger body size and solitary behavior are more vulnerable to habitat changes (Rader et al., 2014; Ferreira et al., 2015). In addition, the substrate where bees can nest is extremely important for maintaining the assemblage of ground-nesting bees (Pereira et al., 2021). Native habitat loss has a negative impact mainly on bees that nest above ground in living or dead trees (Ferreira et al., 2015). Thus, a greater richness of flowering plant species and a greater availability of nesting habitats have a positive effect on bee diversity (Papanikolaou et al., 2017). Therefore, the conservation of local native vegetation is essential to maintain a greater diversity of native bees (Brosi et al., 2008).

The metropolitan region of Belo Horizonte is a region of high biological diversity with a heterogeneous landscape (Jacobi et al., 2007; Eisenlohr et al., 2015; Salgado & Fonseca do Carmo, 2015; Strassburg et al., 2017). In addition, the plant diversity of the metropolitan region of Belo Horizonte depends for the most part, either directly or indirectly, on the diversity of bees (Gomes et al., 2023). However, this environment is suffering from the effects of extensive mineral extraction and rapid urban growth (Versieux & Wendt, 2007; Garcia et al., 2009). Mining has been responsible for the destruction of the peaks of the region's mountain ranges, and there are few protected iron ore areas in these environments (Salgado & Fonseca do Carmo, 2015). Therefore, measures to support local biodiversity are urgently needed, and the species list provided by this work can guide management efforts in green areas to conserve the diversity of bees found in the region. Importantly, complementary sampling methods were essential to have a more comprehensive description of the bee fauna in this highly diverse region.

Analysis of variance showed significant differences in bee richness and abundance between sampling methods, with pan traps showing the lowest values. This difference can be attributed to the intrinsic limitations of each method in capturing the total diversity of the bee community. Although pan traps are effective at capturing generalist bees or those foraging in lower vegetation strata and attracted to colorrs (Chamorro et al., 2023), they may be less efficient for bees foraging in higher vegetation strata. In addition, these traps depend on light incidence to attract insects. In contrast, active sampling through floral observation enables the direct collection of bees at their food sources. This method is particularly effective for species that are less likely to interact with passive traps. Although this method is dependent on observation time and flower availability, it tends to capture a more accurate representation of foraging bee fauna. Similarly, Euglossini scent traps are highly specialized and extremely effective for a specific taxonomic group (Viana et al., 2021), contributing to the high richness and abundance captured by this method in a selective manner. These distinctions between methods reinforce the conclusion that complementarity is crucial. Using only one method would severely underestimate the representation of local diversity, as each method has a capture bias that makes it more suitable for certain groups of bees. For instance, scent traps were instrumental in sampling Euglossini, whereas pan traps and active sampling were vital for capturing the diversity of other bee groups, such as the Halictidae family, which are not attracted to aromatic compounds. It is this complementarity that allowed this study to achieve high sampling coverage, thereby highlighting the importance of a multifaceted sampling effort in complex, diversity-rich landscapes.

Conclusions

Knowing the bee species present in fragments of natural vegetation in areas modified by anthropic actions is essential for planning the management and monitoring of these environments, with the aim of protecting this very important group that provides critical ecosystem functions and services. In summary, this study represents one of the most complete lists of bees currently available in the metropolitan region of Belo Horizonte, which was only possible by using complementary sampling methodologies, and can serve as a subsidy for the development of practices to protect the biodiversity of local green areas.

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Authors' Contributions

LL: Conceptualization, methodology, formal analysis, writing-original draft preparation, investigation.
LFR: Conceptualization, methodology, writing-review and editing, supervision.
PKM: Conceptualization, methodology, writing-review and editing, resources, supervision.
AD: Investigation, writing-review and editing.
CV: Investigation, writing-review and editing.
IB: Investigation, writin review and editing.
MCRD: Investigation, writing-review and editing.
MS: Investigation, writing-review and editing.
TC: Methodology, investigation, writing-review and editing.
VSF: Methodology, investigation, writing-review and editing.
RS: Conceptualization, methodology, formal analysis, writing-review and editing, funding acquisition, resources, supervision.

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