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Different urban fragments, similar Euglossini bee (Hymenoptera: Apidae) communities

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A B S T R A C T

Euglossini bees are a key pollinator group in the Neotropics, and as they are related to tropical forests, they are considered bioindicators of that environment. This study aimed to estimate the richness, abundance, and seasonality of the community of male orchid bees in two urban fragments in Salvador, Bahia State, Brazil, as well as to investigate the influence of abiotic factors on their abundance. As bees were collected monthly from June 2018 to May 2020, and the abundance and seasonality of the most abundant species were analyzed using circular statistics. We calculated the Shannon-Wiener richness index (H') and the Pielou evenness index (J') for each fragment studied. In total, we collected n=577 individuals of eight species. *Euglossa cordata* and *Eulaema nigrita* were the most abundant species and together accounted for over 92% of the total in both areas. Euglossine richness: $H'_{site\ A}=0.92$ and $H'_{site\ B}=-0.84$ and similarity: $J'_{site\ A}=0.51$ and $J'_{site\ B}=-0.41$ were similar between areas. The results confirm the absence of seasonality patterns and relationship with climate variables (p>0.05). The homogenization of species composition in the fragments and the abundance of indicator species of anthropic environments and generalist species rekindle the discussion regarding the maintenance of ecosystem services in forest remnants of different sizes surrounded by an urban or peri-urban matrix. Forest fragments are a reality in large cities located in original areas of the Atlantic Forest biome, and they can be important for maintaining the urban pollinator.

RESUMO

As abelhas Euglossini são um grupo-chave de polinizadores na região neotropical, e por serem relacionados às florestas tropicais são consideradas bioindicadoras do ambiente. Este trabalho teve como objetivo avaliar a riqueza, a abundância e a sazonalidade da comunidade de machos de abelhas das orquídeas em dois fragmentos urbanos de Salvador, Bahia, Brazil, bem como investigar a influência de fatores abióticos na sua abundância. As abelhas foram coletadas mensalmente de junho de 2018 a maio de 2020, e a abundância e a sazonalidade das espécies mais abundantes foram analisadas utilizando estatísticas circulares. Para cada fragmento foram realizados o índice de riqueza de Shannon-Wiener (H') e o de equabilidade de Pielou (J'). No total, foram coletados n=577 indivíduos e oito espécies. *Euglossa cordata* e *Eulaema nigrita* foram as espécies mais abundantes e somam juntas > 92% do total em ambas as áreas. A riqueza de euglossíneos: $H'_{site\ A}=0.92$ e $H'_{site\ B}=-0.84$ e a similaridade: $J'_{site\ A}=0.51$ e $J'_{site\ B}=-0.41$ foram semelhantes entre as áreas. Os resultados confirmam a ausência dos padrões de sazonalidade e de relação com as variáveis climáticas (p>0.05). A homogeneização da composição específica dos fragmentos e a abundância de espécies indicadoras de ambientes antropizados e generalistas reacendem a discussão quanto à manutenção dos serviços ecossistêmicos dos remanescentes florestais diversos tamanhos circundados por uma matriz urbana ou periurbanas. A ocorrência de fragmentos florestais de é uma realidade nas grandes cidades que ocorrem em áreas originais do bioma Florestal Atlântico, mas podem ser importantes para a manutenção de polinizadores urbanos.

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Introduction

Euglossini bees are known as "orchid bees" due to the intrinsic relationship between males of this tribe and Orchidaceae flowers during the collection of aromatic substances, usually produced in those flowers. Although Orchidaceae flowers seem to be the most important for the group, occasionally, aromatic compounds can be obtained from other botanical families, *e.g.*, Araceae, Gesneriaceae, or Solanaceae, and even from fungi and other extrafloral sources (Silveira et al., 2002).

How bees use these substances is not known yet, but it is believed they may play a role in chemical signaling for reproductive purposes or territory marking. These bees are exclusively distributed in the Neotropical region, comprising approximately 240 species (Moure et al., 2012). They are more diverse and abundant in forests, with only a few species restricted or occurring preferably in other biomes. In Brazil, the greatest diversity of Euglossini species is attributed to the Amazon Forest (especially further inland and to the south of its distribution) and the Atlantic Forest (Silveira et al., 2002).

Euglossini is a taxonomically well-known and inventoried group, mainly due to the passive collection of males using aromatic baits. Therefore, over the decades, several studies and inventories were carried out along the Atlantic Forest (*e.g.*, Peruquetti et al., 1999; Nemésio & Silveira, 2007; Ramalho et al., 2009; Mattozo et al., 2011; Nemésio, 2009, 2013a,b,c; Giangarelli et al., 2014; Aguiar et al., 2017; Ferronato et al., 2017), summing nearly 50 species for this critically endangered biome, considered a biodiversity and endemism hotspot (Myers et al., 2000).

The consolidated taxonomic knowledge of the group made Euglossini an interesting biological model to understand the edge effect, changes in the local habitat structure (Nemésio & Silveira, 2006; Mateus et al., 2015; Coswosk et al., 2017; Pinto et al., 2019; Ribeiro et al., 2019), and ecological niche overlap (Lima, 2017). Euglossini can also be used as models to predict how species move between habitat patches in the landscape (Ferronato et al., 2017; Moreira et al., 2017), and models of the potential species distribution in the face of changes in environmental variables (Glória, 2018; Miranda et al., 2019), as many species can play a role as indicators of different habitats. Hence, long-term studies on the community diversity of these bees are still needed in anthropized environments, reforested areas, or areas at different regeneration stages. These studies are crucial for adopting environmental public policies.

Urban forest fragments are remnants of natural vegetation surrounded by an urban matrix, making them critical areas for biodiversity conservation in anthropogenic landscapes. These areas tend to show reduced species richness and more homogeneous pollinator communities. This phenomenon occurs due to the surrounding urban matrix, which subjects these fragments to intense anthropogenic pressures, such as increased edge effects, habitat fragmentation, and environmental changes contrasting with the conditions of the central forest (e.g., higher humidity, lower luminosity, and cooler temperatures). These changes directly impact the structure and functionality of fragments, leading to population isolation and declines in species with specific habitat requirements. As observed in studies (e.g., Miranda et al., 2019; Pinto et al., 2019), the richness and abundance of Euglossine bees are negatively correlated with proximity to fragment edges, where environmental factors such as light, temperature, and humidity are significantly altered.

In addition, the creation of paths and trails within these forest fragments exacerbates these effects, reducing their ecological value and potential for biodiversity (Melo et al., 2011). Therefore, many urban forest fragments may not be functional for certain ecosystem services, as these areas are often small and low in diversity.

Low diversity increases the chances of biotic homogenization across different fragments of the same vegetation physiognomy, a reality for various taxa or communities. Generally, these habitat fragments provide shelter and food within and around urban centers, supporting a generalist, ruderal, and synanthropic fauna (Brun & Brun, 2007), and can form a mosaic of different environments or ecosystems. However, these habitat fragments can also connect other forest fragments in the heterogeneous mosaic of urban and peri-urban landscapes, serving as a complementary food source for species typical of native forests, such as those inhabiting native forests surrounding urban centers.

Given these challenges, it is essential to monitor and understand how these changes impact the dynamics of Euglossine bee communities, which play a critical role in pollination services in urban environments. In this study, we investigated the richness, abundance, and seasonality of male orchid bees in two urban rainforest fragments in Salvador, Bahia State, Brazil. We addressed the following questions: 1. Does the species richness and abundance of Euglossini differ between forest fragment edges and inside? 2. Is the Euglossine species richness similar between the fragments studied? 3. Is there seasonality in the most abundant Euglossine species throughout the year? 4. Is the abundance Euglossini of Euglossini bees abundances influenced by abiotic factors such as temperature and humidity?

Material and methods

Sampling sites

The study was carried out in two urban fragments of the Atlantic Forest in the municipality of Salvador, the capital of the State of Bahia, Northeastern Brazil, monthly between 2018 and 2020. Fragment size varies between 17 ha and 125 ha. Table 1 presents detailed information about the location, size, sampling year, and the number of traps used in each site. Sites A and B are fragments approximately 12 km away from each other inserted in an urban matrix. Site B is vast and relatively well preserved, whereas site A is bordered by avenues under intense anthropic pressure, surrounded by high-density neighborhoods. For detailed information, see Santos (2020) for site A and Azevedo (2020) for site B. The region's original vegetation comprises seasonal and ombrophilous forests, characteristic of coastal areas of the Atlantic Forest biome. Currently, the original forest in the fragments is almost entirely subjected to different anthropic pressures at different successional stages, as in most areas of this biome (Azevedo, 2020; Santos, 2020).

Table 1.

Sites and detailed sampling information of the community of Euglossini Bees in the two urban forest fragments that were sampled in the municipality of Salvador, Bahia State, Brazil.

Site code	Site name	Coordinates	Size	Number of traps (and disposition)	Number of area sampled	Sampling period
Site A	Pedra de Xangô Network Park (PXNP)	12°53'55.01" S, 38°23'36.95" W	17 ha	06 (the traps were positioned at different points within and at the edge of the urban forest fragment, 20 m from each other)	2 (interior and border of the urban forest patch, 115 m from each other)	Jun.19 to Feb.20
Site B	Vale Encantado Wild Life Refuge (VEWLR)	12°56’11” S, 38°23’37” W	125 ha	09 (the traps were positioned at different points only at the border of the urban forest fragment, 2 m from each other)	3 (on the border of the urban forest patch, 35 m from each other)	Jun.18 to May.19

Data collection

The sampling data comprise several seasons of approximately one year in each site (Table 1). Euglossini sampling was carried out using PET-bottle odor traps containing cotton swabs with drops of eucalyptol essence, following Krug and Alves-Dos-Santos (2008). While other scents are commonly used to attract male euglossine bees, eucalyptol stands out as the most attractive scent for these bees. Therefore, it can be recommended to conduct rapid surveys of the Euglossini fauna. We hung bait traps on tree branches at the edge and core of the fragment, approximately 10 m apart from each other and 1.5 m above ground (Table 1). Sampling was carried out from 06:00 h or 07:00 h to 17:00 h in all sites, considering both core and edges of the fragment (Table 1). Dr. Edinaldo Luz das Neves mounted and identified bees. Vouchers were deposited in the Entomological Collection of the Museum of Natural History/Museum of Zoology of the Federal University of Bahia (MHNBA/MZUFBA). Bee classification followed Michener (2000) and Silveira et al. (2002). The abiotic factors of rainfall and average maximum and minimum temperatures were obtained for each sampling period from the meteorological station located in Salvador, Bahia State, Northeastern Brazil, through the Inmet website (2020).

Statistical analysis

We tested for differences in the number of individuals attracted to the edge and core of the fragments studied using the non-parametric Kruskal-Wallis test (H) due to the nature of the data. Next, we estimated site diversity using the Shannon-Wiener Diversity Index (H') and evenness using the Pielou Index (J') (Magurran, 2004). Finally, used the Spearman correlation (rs) (Zar, 1996) to assess the potential effect of climate variables (average minimum and maximum temperatures and total monthly rainfall) and the number of bees. The analyses were performed in the R 4.2.2 software (R Core Team, 2023).

We also tested the seasonality of species abundance using the circular analysis in the Oriana 4.2 software (trial version) (Kovach, 2011). Circular statistical techniques are more suitable for testing seasonality hypotheses due to the periodic nature of the data (Zar, 1996). Hence, we converted months to angles, with 30° intervals between them, so that 1° corresponded to January and 330° corresponded to December. For each species listed in a fragment, we obtained the following statistical parameters: (i) mean angle (corresponds to the period of highest abundance); (ii) circular standard deviation (expresses the degree of dispersion of collection records); (iii) length of the vector r (represents the intensity of the concentration of values around the mean angle). This parameter can be assumed as a measure of seasonality ranging from 0 to 1, where 0 represents that the abundance is evenly distributed throughout the year and 1 represents that the abundance is entirely concentrated around a single period of the year (see Morellato et al., 2000).

The significance of the mean angle was assessed using (iv) Rayleigh test (Z) (p = 0.05), *i.e.*, in case the highest abundance is concentrated around it (Morelato et al., 2010). In this last test, the null hypothesis states that there is no seasonality when the abundance is evenly distributed throughout the year (different angles). However, if the null hypothesis is rejected, the mean angle is significant, and the pattern is assumed to be seasonal.

We carried out analyses to explore the seasonality of each species in different spatial and temporal contexts, considering (i) the annual abundance variation of each species in each fragment and (ii) the abundance variation of each species regarding the entire sampling effort (all fragments together), following Margatto et al. (2019). In all cases, only species with an abundance higher than 30 individuals were included the analyses. We used Watson's U^2 tests (U^2) to test whether the mean angles differ between fragments for each species.

Results

Similarity between fragments

We collected 136 individuals in site A, distributed in six species and three genera: *Euglossa*, *Eulaema*, and *Exaerete*. In site B, we sampled 441 individuals of eight species, including the same three genera and the two most abundant species found in site A (Table 2, Table S1). *Euglossa (Euglossa) cordata* (Linnaeus, 1 758) and *Eulaema (Apeulaema) nigrita*

(Lepeletier, 1841) together represented more than 92% of the specimens sampled in both areas. The other species were less abundant and representative over the months in the areas. The similarity in composition and abundance between sites was corroborated by the Kruskal-Wallis test = 4.66, df = 4, p-value = 0.32, the ecological richness index: $H'_{site\ A} = 0.92$ and $H'_{site\ B} = -0.84$ (Shannon- Wiener), and Pielou Evenness: $J'_{site\ A} = 0.51$ and $J'_{site\ B} = -0.41$.

We only compared the bee fauna in the edge and core of the fragment in site A. Although the core was more speciose ($H'_{site\ A\_core} = 1.12$) than the edge ($H'_{site\ A\_edge} = 0.74$), the difference was not significant (Kruskal-Wallis test: 4.14, df = 3, p-value = 0.25). Although dominant species were the same in both areas, they showed half the abundance in the edge ($J'_{site\ A\_edge} = 0.67$) than in the core ($J'_{site\ A\_core} = 0.62$).

Table 2.

Euglossini bee species sampled in two urban forests fragments of the Atlantic Forest, between June 2018 and May 2020, in the municipality of Salvador, Bahia State, Brazil.

n	Species	Site A		Site B	
		n	%	n	%
1	*Euglossa (Euglossa) cordata* (Linnaeus, 1758)	43	31.6	98	22.2
2	*Euglossa (Euglossa) fimbriata* Moure, 1968	--	--	1	0.2
3	*Euglossa (Euglossa) liopoda* Dressler, 1982	1	0.7	1	0.2
4	*Euglossa (Euglossa) truncata* Rebêlo & Moure, 1996	--	--	1	0.2
5	*Euglossa* sp.	1	0.7	2	0.5
6	*Eulaema (Apeulaema) nigrita* Lepeletier, 1841	84	61.8	308	69.8
7	*Eulaema (Eulaema) flavescens* (Friese, 1899)	1	0.7	1	0.2
8	*Exaerete smaragdina* (Guérin, 1844)	4	2.9	1	0.2
	Total	**136**	**--**	**441**	--

Seasonality in species abundance

We collected the two most abundant species, *Eg. cordata* and *El. nigrita*, nearly throughout the year in sites A and B (Fig. 1). Besides, all mean vector values (*r*) were different from one, confirming the absence of seasonality patterns. However, most individuals were concentrated in January and February in the two areas studied (almost all p-values in the Rayleigh test < 0.001, see Table 3), without a relationship with climate variables (p > 0.01 in the Spearman correlations, Table 4). Although, the values of the circular metrics of the two most abundant species were similar in the two fragments (Table 3), the values of Watson's U^2 Test indicate differences in the temporal behavior of *Eg. cordata* and *El. nigrita* in each area studied (Table 4, Fig. 1).

Figure 1

Temporal behavior of the most abundant Euglossini bees in two urban forests fragments of the Atlantic Forest, in the municipality of Salvador, Bahia State, Brazil, between June/2018 and May/2020. A. Euglossa cordata. B. Eulaema nigrita.

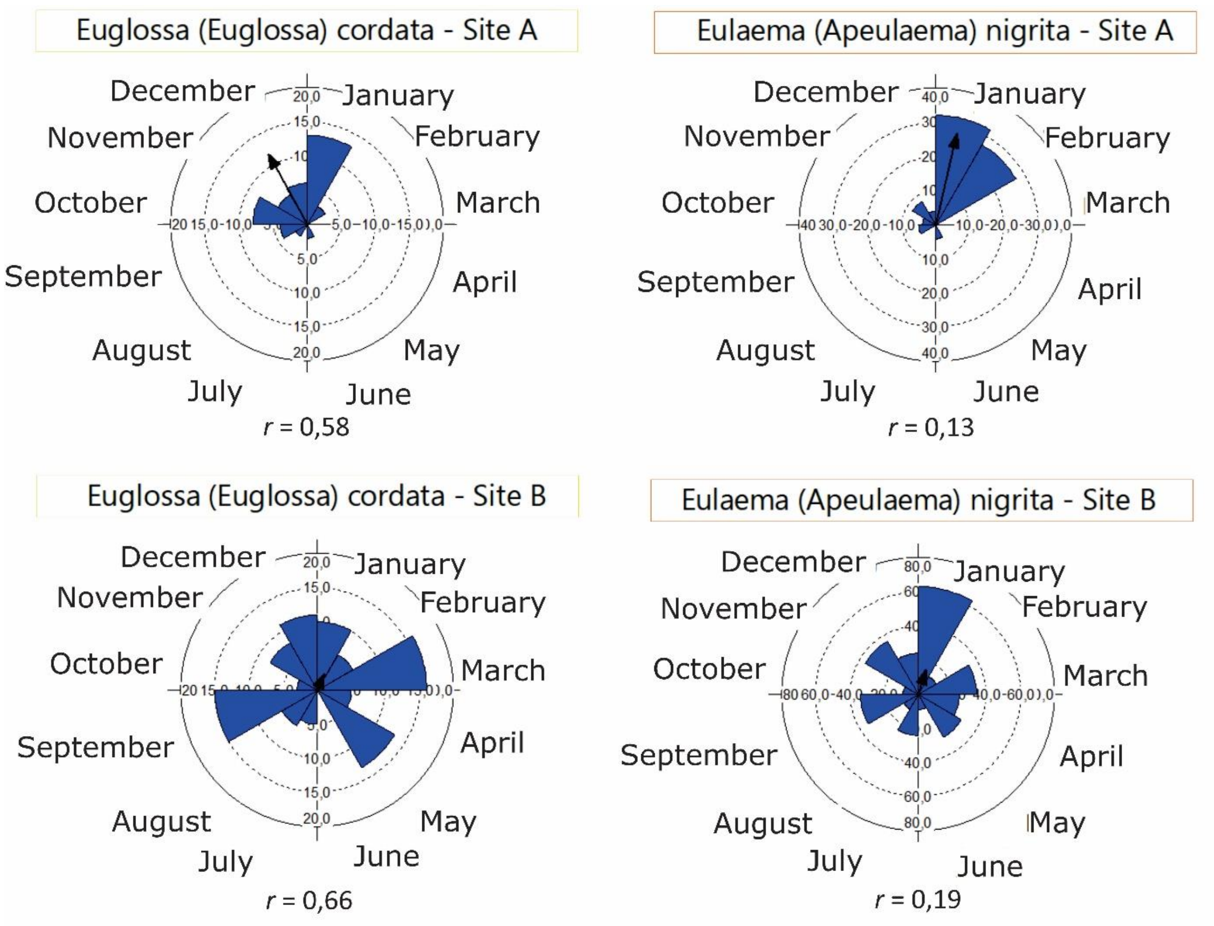

Table 3

*Bee phenology in two urban forests fragments in the municipality of Salvador, Bahia State, Brazil: mean vector (month), circular standard deviation, length vector (r) and Rayleight test (Z) result (*** p < 0.001).*

Specie	**Site**	**Mean vector** (Mean month)	**Circular standard deviation**	**Length of mean vector** (r)	**Rayleight test** (Z)
Euglossa (Euglossa) cordata	A	330.48° (December)	60.43°	0.58	Z = 14.14, p < 0.001***
	B	13.27° (January)	50.73°	0.66	Z = 38.36, p < 0.001***
	A, B	Watson's U² tests: $U^2_{\text{Site A, B}}$ = 0.60, p < 0.001***, df = 140			
Eulaema (Apeulaema) nigrita	A	23.11° (January)	114.74°	0.13	Z = 1.78, p = 0.17 ns
	B	18,30° (January)	104.29°	0.19	Z = 11.21, p < 0.001***
	A, B	Watson's U² Tests: $U^2_{\text{Site A, B}}$ = 1.23, p < 0.001***, df = 391			

Table 4

Results of the Spearman correlation (rs) (p <0.01) between climatic variables and the temporal distribution of abundance of Euglossini bees, between June.18 and May.20, in two urban forest fragments in the municipality of Salvador, Bahia State, Brazil. Statistical values do not differ significantly (ns).

Climate variables	Site A (abundance of bees)	Site B (abundance of bees)
Precipitation	rs = -0.056, p = 0.86 ns	rs = -0.182, p = 0.57 ns
Average Minimum Temperature	rs = 0.503, p = 0.10 ns	rs = 0.503, p = 0.10 ns
Average Maximum Temperature	rs = 0.503, p = 0.10 ns	rs = 0.503, p = 0.10 ns

Discussion

The species richness of orchid bees found in the urban forest fragments studied in Salvador are surprisingly similar to each other and other studies carried out in the same municipality, even those that used different aromatic essences besides eucalyptol (Viana et al., 2002; Santos et al., 2014; Silva et al., 2017). The abundance and dominance of *Eg. cordata* and *El. nigrita* strongly influenced the abundance peaks of Euglossine abundance over the months, which were present in all areas. These species do not exhibit a seasonal pattern. They occur nearly throughout the year and tend to dominate, representing over 75% of the abundance of all individuals collected in inventories for the municipality of Salvador, Bahia State, Brazil (Viana et al., 2002; Santos et al., 2014; Silva et al., 2017; the present study). Forty-nine species are estimated for Bahia (Nemésio, 2009). Euglossini richness is more diverse in rainforests (Silveira et al., 2002), such as the Atlantic Forest, which is rivaled only by the Amazon Forest. There are three Brazilian biomes in the state of Bahia: Caatinga (more present in the center), Cerrado (concentrated in the West region), and the Atlantic Forest (which borders the entire coastal region). The last one comprises most studies and inventories, as it represents one of the diversity hotspots of this group of bees (see Table 5).

The summary and compilation of all studies carried out in Bahia (see Table 5) show that the southern part of the Atlantic Forest biome in the state harbors the richest and most diverse community of Euglossine bee species. These studies encompass over three decades (1997 – 2021) of research on the composition of the Euglossine bee fauna. However, few recent studies adopt a more experimental approach beyond documenting species richness, abundance, and the use of associated odoriferous baits. This region is characterized by larger and better-preserved fragments (including climax tree species) than other forest fragments of the Atlantic Forest in Brazil (Nemésio, 2013a, c; Aguiar et al., 2017; Miranda et al., 2019; Pinto et al., 2019). In addition, the southern and far-southern part is further away from the main cities of the state, and comprise larger fragments, despite the advance of fragmentation, resource exploitation, and silviculture that threatens the flora and fauna diversity of this region (Ramalho et al., 2009; Nemésio, 2013b; Ramalho et al., 2013; Ribeiro et al., 2019).

The studies listed in Table 5 also show the gap in the northern part of the Atlantic Forest biome and the incipience of studies with significant sampling efforts in drier and more open biomes. The status of this scenario hampers conservation efforts and the understanding of the relationship between Euglossini - bees sensitive to habitat fragmentation (Ramalho et al., 2009) - and the matrix surrounding forest remnants.

However, it is worth noting that differences in the sampling effort, the number of aromatic compounds, and the efficiency of the sampling method can affect the results of species richness and abundance in Euglossine bee communities presented and compared in Table 5. Nevertheless, the most pronounced results are that, following the inventory conducted in 2017 (Melo & Pigozzo, 2017, in Table 5), the most abundant species represent >90% of the individuals collected in all studies (except Almeida et al., 2020, in Table 5). Although this work is not a meta-analysis – where data is standardized and relativized for comparable comparisons – these data are concerning because they indicate excessive concentration in the most abundant species (hyperdominance), a phenomenon that can be detrimental to community diversity and resilience, making them more susceptible to environmental changes and stochastic events, as well as alterations in interaction patterns (pollinators, dispersers, pathogens, etc.).

Euglossine bees have been considered bioindicators of environmental quality for decadas. Therefore, some studies have used them to assess the effects of habitat loss, floristic diversity, and quality of the surrounding landscape (Ferronato et al., 2017; Moreira et al., 2017; Enríquez-Espinosa et al., 2022; Brown et al., 2024). The size, quality, sampling area (e.g., plot, transect, or grid), and floristic diversity of fragments positively influence species richness, as well as the abundance and composition of euglossine bees (Ramalho et al., 2009; Ferronato et al., 2017; Miranda et al., 2019; Pinto et al., 2019; Hipólito et al., 2023). Our results showed that smaller fragments inserted in the urban matrix had not only their richness but also diversity affected, as a few or one dominant species tended to account for most of the specimens found in these areas.

Besides these two dominant species, the abundance and representativeness of other bee species were insignificant (ranging from one to four specimens collected) when considering the edge or core of the fragments or the two study areas. The hyperdominance of these two species in the two urban forest remnants suggests homogeneity of the biota or compositional similarity (Devictor, 2008). Environmental heterogeneity is among the main factors related to biota diversity and among the most affected when working with small fragments or those inserted in the urban matrix, more susceptible to the edge effect, habitat modification, and invasion and competition with exotic species (studies compiled in Melo et al., 2011).

Apparently, the behavior of the dominant species was not affected by climate variables in the present study. The lack of seasonality in *Eg. cordata* and *El. nigrita* was expected, as these species show a broad distribution and generalist behavior, based on exploiting a broad trophic niche (Lima, 2017). In Atlantic Forest areas in southeastern Brazil, whose climate is different from the tropical climate of the northeastern region (which includes the State of Bahia), the seasonality of many euglossine species has been repeatedly reported in the literature. This fact may exert significant influence on the seasonal activities of these bees (*e.g*., Dressler, 1982; Ackerman, 1983; Rebêlo & Garófalo, 1991; Oliveira & Campos, 1995; Oliveira, 1999; Peruquetti et al., 1999; Nemésio & Silveira, 2006; Ramalho et al., 2009; Mattozo et al., 2011; Mateus et al., 2015). However, we did not find this correlation in the present study, nor did it affect the dominance of *Eg. cordata* and *El. nigrita*.

Euglossa cordata and *El. nigrita* are species broadly distributed, and perhaps, for this reason, they are also abundant in 50% (*Eg. cordata)* and 67% *(El. nigrita)* of the studies carried out in the state of Bahia (Table 5). We found a high dominance of a few species in the two areas studied here, *Eg. cordata* and *El. nigrita,* which seems to be a common pattern in many studies. When we consider all Euglossine inventory studies summarized for the state of Bahia, a few dominant species (between two and five) represent at least 60% of all individuals collected (see Table 5).

The results also confirm this pattern. *Eg. cordata* and *El. nigrita* are often considered indicator species of degraded environments. According to analyses by Lima (2017) based on pollen loads of bees collected in urban areas, these species share floral resources, even though *El. nigrita* requires higher amounts of food due to its larger body size. *Eulaema nigrita* (Lima, 2017) and *Eu. cordata* (Glória, 2018) are the species of the Euglossini tribe with the highest flight capacity, being able to cover great distances. *Euglossa cordata* is frequently recorded in anthropic and urban environments but can also be found in areas with good conservation status. This plasticity regarding the success in obtaining trophic resources was corroborated by Glória (2018), based on genetic analyses of *Eg. cordata* populations with samples from many regions of Brazil.

In this context, the summarization of these findings converges to the hypothesis that *El. nigrita* is a plastic species, tolerant to environmental disturbances, in deforested areas or with low vegetation cover (Brown et al., 2022), potentially acting as an indicator of anthropogenic areas. However, an experiment conducted in a municipality in Mato Grosso State presented contradictory results. Menezes et al. (2023) were unable to validate the hypothesis that *El. nigrita* serves as an indicator of anthropogenic areas, as the distribution of the bees was similar in both open and wooded areas, showing no significant differences between them. Although this study presents limitations related to fragment sampling and location, it provides valuable insights for future investigations, with a larger and more robust sampling addressing the species' distribution.

To better understand this specific bee community, future studies should consider not only usual variables such as abundance, richness, fragment size, and matrix surroundings, but also the consolidation time of the studied fragment or matrix. According to Brown et al. (2022), significant differences between conservation units and settlement zones were only observed after ten years of settlement consolidation in the Rondônia State, in the Brazilian Amazon. Additionally, the use of spatial variables, such as canopy cover (open vs. closed), tends to provide more robust results than analyses solely based on physiognomy or vegetation type at the sampling locations (e.g., interior and edge, as performed in this present study).

Final considerations

This study highlights the importance of urban forest fragments in the Atlantic Forest for maintaining Euglossini bee fauna, even in highly anthropized contexts. Despite differences in composition and abundance among the analyzed fragments, patterns of similarity indicate a relative resilience of Euglossini communities, primarily driven by the dominance of generalist species such as *Euglossa cordata* and *Eulaema nigrita*. Species richness was stable between the edges and the interior of the fragments, while the absence of clear seasonality and the independence of abundances concerning climatic variables underscore the contribution of these species to a stable temporal dynamic in the studied fragments.

Future research should prioritize the integration of different approaches to explore the dynamics of Euglossini bee communities in urban environments. The interaction between the ecological niche requirements of species, landscape connectivity metrics, environmental variables, and cross-sectional analysis methods is essential. It is recommended to combine vertical traps (to assess variations in vegetation strata) with sampling at various points (longitudinal variability), as well as medium- and long-term studies that incorporate multiple methodologies, such as the phenology of bees and plants, diversity of odoriferous baits, and natural history observations. These strategies can provide a more comprehensive and detailed understanding of the factors shaping Euglossini bee communities in these fragments.

More broadly, our results reinforce that urban fragments play a unique role in conserving pollinator fauna in urban environments. Although they share similarities in parameters such as abundance and richness, each fragment contributes specifically to mitigating the microclimatic effects of pollution and urbanization. Recognizing these fragments as elements of a broader and interconnected landscape context is crucial, especially in planning large urban infrastructure projects. While such projects may negatively impact Euglossini bee communities, the preservation of well-conserved areas surrounding urban fragments is essential to ensure the functionality of ecological services, such as pollination, and to minimize the impacts of urbanization on biodiversity.

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Survey of Euglossini bees and more detailed information on studies carried out in the State of Bahia, between 1997 and 2020.

n	**Site name**	**City of Bahia**	**Area size**	**Ecosystem**	**Traps in each area** (n)	**Essences or method**	n **individuals /** n **species**	**Abundant species** (= % represent together)	**Sampled period**	**Reference**
1	Cajaíba Village	Valença	--	Mangrove (Ecosystem associated Atlantic Rainforest)	15	Citronella, eucalyptol, eugenol, methyl salicylate, and vanilla	1.114 / 12	*Eg. cordata* and *El. nigrita* (= 94%)	Ago.94 to Jul.95	Neves and Viana (1997)
2	Environmental Protection Area (EPA) of the Lagoons and Dunes of Abaeté	Salvador	--	Dunes and Restingas (Ecosystem associated Atlantic Rainforest)	--	Benzyl benzoate, eucalyptol, eugenol, methyl salicylate, and vanilla	670 / 03	*Eg. cordata* and *El. nigrita* (= 98%)	Fev.96 to Jan.97	Viana et al. (2002)
3	Areas adjacent to the Private Natural Heritage Reserve (PNHR) Veracruz Station	Eunápolis and Porto Seguro	6.069 ha, 100-250 ha,	Atlantic Rainforest/ Eucalyptus Plantation	--	Eucalyptol, methyl salicylate, and vanilla	3.872 / 22	*Eg. ignita, Eg. imperialis, Eg. mixta* and *Eg. cordata*	Mar, Jun, Ouc.03 and Jan.04	Melo (2005)
4	Fazenda Formosa: Braúna Cambuí, and Pindoba	Campo Formoso	280 ha, 179 ha, and 100 ha	Arboreal Caatinga	18 at each fragment	Benzyl acetate, β-ionone vanillin, eucalyptol, eugenol, and methyl salicylate	627 / 14	*El. nigrita, Eg. carolina, and Eg. marcii* (= 71%),	May.09 to April.10	Andrade-Silva et al. (2012)
5	Monte Pascoal National Park, Discovery National Park and Three Forest Patches	Porto Seguro, Prado and Itamaraju	22.38 ha, 21.21 ha, and entre 1-300 ha	Atlantic Rainforest	17	Entomological net and Benzyl acetate, benzyl alcohol, r-carvone, 1,8-cineole, p-cresol acetate, dimethoxybenzene, eugenol, β-ionone, methyl benzoate, methyl trans-cinnamate, heneicosane, methyl salicylate, skatole,	4.764 / 36	*Eg. carolina, Eg. ignita, Eg. imperialis, Eg. roubiki* and *El. nigrita* (= 65%)	Nov.08 to Nov.09,	Nemésio (2013a)

n	Site name	City of Bahia	Area size	Ecosystem	Traps in each area (n)	Essences or method	n individuals / n species	Abundant species (= % represent together)	Sampled period	Reference
						tricosane, p-tolyl acetate, vanillin, and a mixture (1:1) of methyl trans-cinnamate and p-tolyl acetate				
6	Pau Brasil National Park and Private Natural Heritage Reserve (PNHR) Estação Veracel	Porto Seguro	8.500 ha and 6.00 ha	Atlantic Rainforest	17	Benzyl acetate, benzyl alcohol, r-carvone, 1,8-cineole, p-cresol acetate, dimethoxybenzene, eugenol, b-ionone, methyl benzoate, methyl trans-cinnamate, heneicosane, methyl salicylate, skatole, tricosane, p-tolyl acetate, vanillin, and a mixture (1:1) of methyl trans-cinnamate and p-tolyl acetate	712 / 20	*Eg. carolina*, *Eg. ignita*, *Eg. imperialis*, *Eg. mixta* and *Eg. roubiki* (= 70%)	Fev. and Apr.09	Nemésio (2013b)
7	Una Biological Reserve	Una	18.000 ha	Atlantic Rainforest	17	Benzyl acetate, benzyl alcohol, r-carvone, 1,8-cineole, p-cresol acetate, dimethoxybenzene, eugenol, β-ionone, methyl benzoate, methyl trans-cinnamate, heneicosane, methyl salicylate, skatole, tricosane, p-tolyl acetate, vanillin, and a mixture (1:1) of methyl	859 / 26	*Eg. carolina*, *Eg. despecta*, *Eg. imperialis*, *El. atleticana* and *El. nigrita* (= 60%)	Jan and Feb.09 and Jan.10	Nemésio (2013c)

n	Site name	City of Bahia	Area size	Ecosystem	Traps in each area (n)	Essences or method	n individuals / n species	Abundant species (= % represent together)	Sampled period	Reference
						trans-cinnamate and p-tolyl acetate				
8	Michelin Ecological Reserve	Igrapiúna	--	Atlantic Rainforest/ Rubber Plantation Mosaic	--	--	1.779 / 11	*Eg. ignita, Eg. imperialis,* and *El. atleticana* (= 75%)	Mar, Apr, Jun., Aug. to Oct. and Dec.06	Ramalho et al. (2013)
9	Boa Nova National Park and Wildlife Refuge	Boa Nova	27.09 ha	Atlantic Rainforest and Caatinga	12	Eugenol, methyl salicylate, and vanilla	254 / 15	*Eg. stellfeldi* and *El. nigrita* (= 59%)	Set.12 to Ago.13	Americano-Santos (2014)
10	Environmental Protection Area (EPA) of the Pratigi	Ibirapitanga	85.69 ha	Atlantic Rainforest	--	Benzyl acetate, beta-ionone eucalyptol, eugenol, methyl cinnamate, methyl salicylate, and vanillin	1.947 / 25	*Eg. cordata, Eg. ignita, Eg. leucotricha* and *El. atleticana* (= 66%)	Jun.12 to May.13	Medeiros (2014, 2017)
11	19th Hunters Battalion - Pirajá Battalion	Salvador	240 ha	Atlantic Rainforest	04	Eucalyptol and methyl salicylate	1.110 / 06	*Eg. cordata* and *El. nigrita* (= 92%)	Jan to Dez.07	Santos et al. (2014)
12	Pituaçu Metropolitan Park	Salvador	450 ha	Restinga Transition - Atlantic Rainforest	--	Entomological net	236 / 11	*Ef. mussitans, Eg. cordata,* and *El. nigrita* (= 86%)	Ouc.97 to Dec.98	Silva et al. (2015)
13	Two fragments of Caatinga	Pé de Serra	50 ha, 250 and ha	Caatinga surrounded by a predominant pasture matrix	21	Benzyl acetate, β-ionone, methyl cinnamate, eucalyptol, eugenol, methyl salicate and vanillin	80 / 5	*Eg. cordata,* and *El. nigrita* (= 85%)	Nov.15 to Oct.16	Carneiro et al. (2017)
14	Guimarães Farm (Private Property)	Amélia Rodrigues	200 ha	Seasonal Forest (phytophysiognomy of Atlantic Rainforest)	---	Eucalyptol	371 / 05	*Eulema* sp. and *El. nigrita* (93%)	Jul.16 to Jun.17	Melo and Pigozzo (2017)

n	Site name	City of Bahia	Area size	Ecosystem	Traps in each area (n)	Essences or method	n individuals / n species	Abundant species (= % represent together)	Sampled period	Reference
15	Mucugê Municipal Park	Mucugê	38 km^2	Rupestrian field (phytophysiognomy of Savannah)	54	Eucalyptol, methyl salicylate, and vanillin	647 / 05	*Eg. leucotricha, Eg. melanotricha* and *El. nigrita*, (= 97%)	Jan to Dec.18	Moreira et al. (2017)
16	Environmental Protection Area (EPA) of the Pratigi	Ibirapitanga	85.69 ha	Atlantic Rainforest	---	--	423 / 03	*Eg. cordata*, *Eg. ignita* and *El. atleticana* (= 100%)	Jun.14 to May.15	Ribeiro et al. (2019)
17	Mucugê Municipal Park and Chapada Diamantina National Park	Mucugê and Jacobina	--	Rupestrian field (phytophysiognomy of Savannah)	--	Eucalyptol, eugenol, methyl salicylate, and vanillin	42 / 05	*Eg. despecta* and *El. marcii* (= 67%)	May to Dec.18 and May to Jun.19	Almeida et al. (2020)
18	Environmental Protection Area (EPA) of the Mangue Seco	Jandaíra	3.40 ha	Restinga (Ecosystem associated Atlantic Rainforest)	20	Eucalyptol and methyl salicylate	310 / 03	*Eg. cordata* and *El. nigrita* (= 98%)	Jun and Nov.13, Fev and Jul.14, Fev.15	Goes et al. (2021)
19	Vale Encantado Wild Life Refuge (VEWLR)	Salvador	125 ha	Atlantic Rainforest	18	Eucalyptol	441 / 05	*Eg. cordata* and *El. nigrita* (= 93%)	Jun.18 to May.19	This study
20	Pedra de Xangô Network Park (PXNP)	Salvador	17 ha	Atlantic Rainforest	06	Eucalyptol	136 / 06	*Eg. cordata* and *El. nigrita* (= 92%)	Jun.19 to Feb.20	This study