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Correlations Between Urban Green Areas and Euglossine Males' Abundance

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Abstract

Green areas are important environments in the urban landscape where many bee species can find essential resources, such as nectar, pollen, and nesting sites. However, few studies have evaluated the effects of urban green areas attributes on bee assemblages, mainly in the bees showing high forest dependence as Euglossini bees. These orchid bees are essential pollinators in the Neotropical urban ecosystems, and the forest loss associated with urbanization can negatively affect euglossine communities. Here, we evaluated the role of urban green areas (UGAs) on euglossine assemblages and the abundance of dominant euglossine species. For this, we quantified different local and landscape attributes in twelve UGAs in Campos dos Goytacazes city, southeast Brazil. We expected a higher euglossine abundance in UGAs with a higher number of trees, diameter at breast height- DBH, and flower cover (%), and with a lower paved area (%), number of high buildings, and surrounding paving area (%). The euglossine males were sampled with three bait traps in each UGA. We sampled 2465 euglossine bees of four species. *Eulaema nigrita* Lepeletier, 1841 was the most abundant species (*N* = 1319; 53.5%), followed by *Euglossa cordata* (Linnaeus, 1758) (*N* = 1139; 46.2%). We found a positive effect of flower cover (%) on the abundance of these dominant euglossine species, highlighting the importance of floral resources in urban matrices, even for synanthropic species.

Introduction

The United Nations predicts that by 2050, more than 60% of the world's population will live in cities (United Nations, 2018), increasing people's demand for services, housing, and transportation. Urbanization has several consequences on ecosystems, such as native vegetation suppression and waterproofing, resulting in changes in the environment and landscape structure (Fortel et al., 2014). Moreover, biological homogenization related to population losses and local species extinction is a critical consequence of urbanization (McKinney, 2006), affecting ecological processes essential to the ecosystem's functioning, such as pollination.

Urbanization can influence bee populations in different ways. Because bees depend on different floral resources and nesting sites to fulfill their ecological requirements, changes in resource availability related to urbanization may negatively affect bee populations (Lanner et al., 2020). Public awareness of bee decline has increased the studies evaluating the impacts of urbanization on bees (Wenzel et al., 2020). The results have shown that the effects of urbanization are not always adverse since bee responses depend on the taxon and environmental attributes (Wilson & Jamielson, 2019; Graf et al., 2022). Ground-nesting bees with solitary behavior (i.e., no overlapping generations) usually show negative responses to urbanization, while bees nesting in preexistent cavities with eusocial behavior (i.e., overlapping

generations and social division) present positive responses to urbanization (Alves & Gaglianone, 2021; Graf et al., 2022).

Furthermore, urban green areas such as squares, parks, and gardens can act as refuges for bees, reducing the negative impacts of urbanization on bee species (Threlfall et al., 2015). These green areas are vegetation patches scattered in the urban landscape that may present a high plant richness including native and exotic species (Banaszak-Cibicka et al., 2016). These areas can also present environmental characteristics (e.g., lower temperature and higher resource availability) that may be friendly to bee species compared to the surrounding urban matrix. Therefore, understanding the role of urban green areas on bee populations and communities is essential to understanding how these pollinators interact with a human-dominated landscape, contributing to sustainable management strategies in cities favoring different bee species.

Euglossini bees, or orchid bees, are known for pollinating native and exotic plant species in urban areas of the Neotropical region (López-Uribe et al., 2008; Ferreira-Caliman et al., 2018). Most euglossine species exhibit a high association with forest environments (Dressler, 1982; Roubik & Hanson, 2004), and forest loss related to urbanization results in a low euglossine richness (Cândido et al., 2018). However, some species with higher environmental plasticity, such as *Euglossa cordata* (Linnaeus, 1758) and *Eulaema nigrita* Lepeletier, 1841 live in forests and cities, with some populations showing a high adaptation to urban areas over time (Rocha-Filho et al., 2020). Both species nest in preexisting cavities, display parasocial behavior (Garófalo, 1985), and may disperse across the urban landscape, contributing to the pollination of plant species with different floral traits (López-Uribe et al., 2008; Ferreira-Cáliman et al., 2018). Considering the fast urban expansion over natural ecosystems, it is essential to understand the role of urban green areas in maintaining bee populations.

Here, we evaluated the assemblage of euglossine bees in urban green areas (UGAs). Specifically, we analyzed the effects of local attributes of UGAs, including paved area (%), flower cover (%), number of trees, and diameter at breast height (DBH) on euglossine bees. Additionally, we assessed how attributes around of UGAs, such as the surrounding paved area (%) and the number of high buildings, influence the abundance of euglossine species. Considering that euglossine bees in urban areas depend on floral resources from plant species in green areas or forest patches (Ferreira-Caliman et al., 2018; Miranda et al., 2021) and that urbanization negatively affects euglossine communities (Cândido et al., 2018), we have the following expectations: there is a higher euglossine abundance in UGAs with a higher number of trees, DBH, and flower cover (%), and with a lower paving area (%), number of high buildings and surrounding paved area (%). We also expected different ecological responses from euglossine species regarding the UGA attributes.

Materials and Methods

Study area

This study was carried out in twelve urban green areas (UGAs) of Campos dos Goytacazes (21°46'23" S – 41°25'19" W) northeast of the Rio de Janeiro state, Brazil (Fig 1). This city is located in the Atlantic Forest, and almost 85% of 514.643 inhabitants living within 87,73 km² of the urban area (IBGE, 2021). The climate is hot and humid, Aw type, according to the Köppen classification, with dry winter and rainy summer.

Euglossini sampling

The twelve urban green areas (UGAs) chosen for bee sampling included seven squares (characterized by recreational areas with courts, snack bars, and a significant portion of the ground paved), four public gardens (designed for the cultivation of plants, flowers, and trees), and one grove. The UGA sizes varied from 3,481 to 44,379 m², distant by at least 1300m between them. The UGAs were delimited using aerial images from Google Earth Pro software.

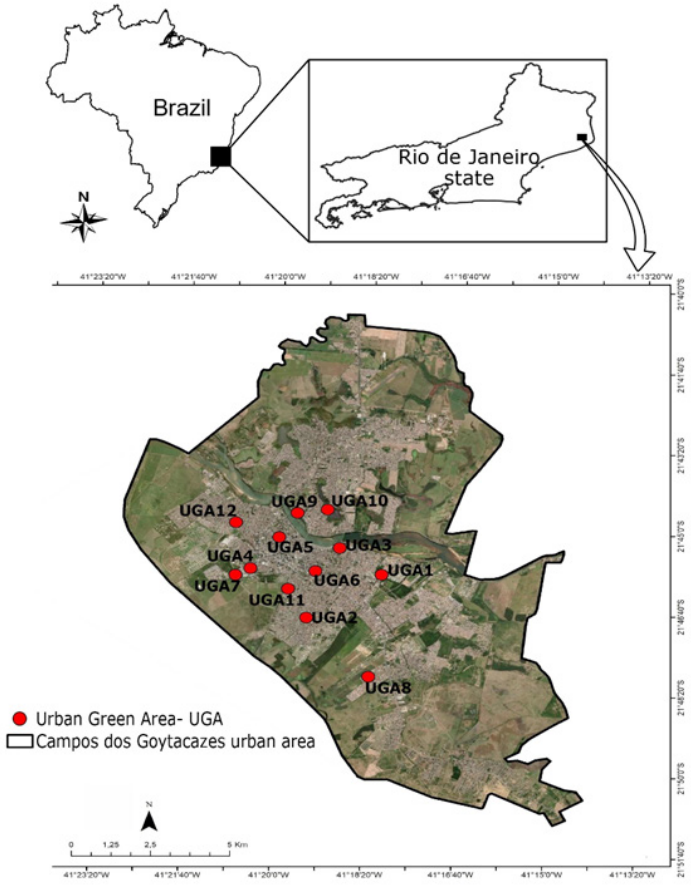

Fig 1. Each red dot indicates an Urban Green Area – UGAs used for Euglossini sampling in Campos dos Goytacazes city, Rio de Janeiro state, Brazil.

We simultaneously sampled the euglossine males in each UGA for two days in the rainy season (October/2017 to March/2018) and two days in the dry season (April to September/2018). We used three traps with eucalyptol in each UGA at a minimum distance of 5 m between them. The bait traps were placed on vegetation in the morning (07:00 am) and removed in the early afternoon (1:00 pm). We only used eucalyptol because it is the most attractive essence for euglossine males in the region, collecting the higher bee abundance and richness (Aguiar & Gaglianone, 2012; Aguiar et al., 2015). The bees were individually fixed on entomological pins and deposited in the Zoology Collection of the Environmental Sciences Lab at the Center for Biosciences and Biotechnology of the Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF). The taxonomic identification of the bees was performed at the lowest possible specific level through comparisons with bees deposited in the entomological collection and using taxonomic keys.

Urban green areas and landscape characterization

We used four attributes related to habitat quality to describe the local characteristics within each UGA: total paved area (%), flower cover (%), number of trees, and diameter at breast height- DBH of trees (minimum of 30 cm) (Table S1). These local UGA attributes have been used to evaluate the role of green urban areas on bees (Theodorou et al., 2017; Threlfall et al., 2015). The paved area (%) within each UGA was measured using a polygon tool within Google Earth Pro software (version 7.3.3.7786). The values were divided by the total area of each UGA x 100 to obtain of paved area (%). Flower cover (%) was estimated on the same days as the bee sampling. For this, we estimated the area covered (m^2) by the flowers of each plant in each UGA. We added the results of each plant and divided it by the total area of the UGA x 100 to obtain the daily UGA value of flower cover (%). We used the mean of flower cover (%) of each UGA for the statistical analyses, considering the four sampling days (Alves & Gaglianone, 2021). The number of trees was obtained by counting all trees within each UGA. Furthermore, since euglossine bees disperse in urban environments (López-Uribe et al., 2008) and may respond to the urban landscape context (Cândido et al., 2018), we also analyzed the effects of the urban landscape surrounding the UGAs on euglossine bees. For this, within a 500-m buffer considering each UGA as its center, we quantified the surrounding paved area (%), and verticalization level using as a proxy the number of buildings with more than three floors (Table S1). While paving reduces green areas (Alves & Gaglianone, 2021), high buildings can act as a barrier to bee dispersion in the urban landscape (Geslin et al., 2013; Alves & Gaglianone, 2021). The surrounding paved area (%) was quantified with the polygon tool, and the values were divided by the total area of the buffers x 100 to obtain the surrounding paved area (%) of each UGA. The street view tool was used to count the number of buildings with more than three floors. Both UGA landscape attributes were quantified with Google Earth Pro software (version 7.3.3.7786).

Data analysis

We used Generalized Linear Models – GLMs to analyze the effects of UGAs attributes on the abundance of *E. cordata* and *E. nigrita*. Before that, the collinearity between the predictor variables was tested using the Variance Inflation Factor (VIF). The explanatory variables showed low collinearity (VIF < 3.0), and then we used all of them in the modeling (Table S2). We used global models with all explanatory variables (UGA local attributes: paved area (%), number of trees, DBH, and flower cover (%); UGA landscape attributes: surrounding paved area (%) and number of high buildings). The response variables used were the abundances of *E. cordata* and *E. nigrita*. Although abundance is a count data, the GLMs with Poisson distribution showed overdispersion. Then, we used GLMs with a negative binomial distribution. We ranked the models using the Akaike's Information Criterion corrected for small samples (AICc) (Burnham & Anderson, 2002). The model with the lowest ΔAICc was considered the best to explain the results. We also considered plausible models with ΔAICc < 2.0 and Akaike's weight (wi) > 0.1. A null model- representing the absence of effect- was also used in the model ranking. All analyses were performed using R software (R Core Team, 2020). The VIF's value was obtained with the *vif* function of the car package (Fox & Weisberg, 2019), and we used the *dredge* function from the MuMIn package for model selection (Barton, 2022).

Results

Euglossini assemblages

Euglossini assemblage showed a very richness with only two genera and four species from 2465 euglossine males. *Eulaema nigrita* Lepeletier, 1841 was the most abundant species (N = 1319; 53,5%), followed by *Euglossa cordata* (Linnaeus, 1758) (N = 1139; 46,2%), both species were sampled in all UGAs (Table S3). *Eulaema cingulata* (Fabricius, 1804) (N = 5; 0.2%) and *Exaerete smaragdina* (Guérin-Méneville, 1845) (N = 2; 0.08%) were sampled in three and two UGAs, respectively (Table S3). Due to the low abundance of the two previous species, only *E. cordata* and *E. nigrita* were used in the correlation analysis.

Effects of UGA attributes on euglossine abundance

We observed that *Euglossa cordata* and *Eulaema nigrita* abundances were mainly influenced by local attributes of urban green areas (Table 1; Table S4, S5). In contrast, surrounding landscape attributes did not influence these orchid bees. *E. cordata* abundance was best explained by a positive

effect of flower cover (%) (df = 3; wi = 0,61; AIC = 0,0) (Table 1; Fig 2a). The model combining a positive effect of flower cover (%) and a negative effect of DBH also explained the *E. cordata* abundance (Table 1). Flower cover (%) also better explained the *E. nigrita* abundance, with a positive effect (df = 3; wi = 0,24; AIC = 0,0) (Table 1, Fig 2b). However, the null model was in the set of plausible models to explain the abundance of this orchid bee species (Table 1).

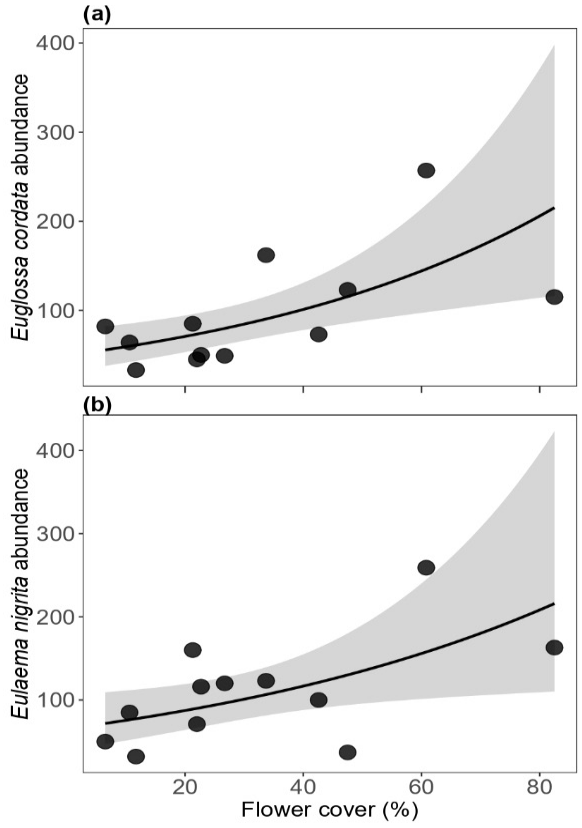

Fig. 2 Influence of flower cover (%) on the abundance of **(a)** *Euglossa cordata* and **(b)** *Eulaema nigrita*. The black line represents the fit of the GLM models and the gray shade the 95% confidence interval.

Discussion

Our results showed a decrease between 50% and 66% in euglossine richness in the urban area compared to a previously surveyed natural neighbor area (see Aguiar & Gaglianone, 2011; Aguiar et al*.,* 2014). Although remarkable, this decline in richness is expected. First, euglossine bees show a habitat preference for rainforests, and only species with high plasticity seem to stay in urban environments (Rocha-Filho et al., 2020). When comparing species composition from nearby euglossine communities of conserved fragments of rainforest (Ramalho et al., 2009; Aguiar et al., 2014) and seasonal semi-deciduous forest (Aguiar & Gaglianone, 2011; Aguiar et al., 2014), we observed that those species with more remarkable plasticity can adapt to the conditions exposed in urban environments The urbanization process exposes bee species to different stress caused by landscape changes, such as increased impervious surfaces and decreased green areas (Fortel et al., 2014), challenging specialist bees' capacity to sustain viable populations.

The euglossine assemblage was 99% dominated by *E. nigrita* and *E. cordata*. According to Magurran (2004), this pattern may reflect the environmental pressures on the communities, resulting in a decrease in rare species abundance and a dominance increase in more resilient species. Indeed, a species turnover by the abundant species *E. cordata* and *E. nigrita* has been observed over time in euglossine communities in urban areas (Rocha-Filho et al., 2020), indicating the ability of these bee populations to adjust to the urban characteristics. Moreover, the urban area is a mosaic of human constructions and small patches of green areas (e.g., gardens, squares), which can be considered a challenging environment for bees' mobility. Although euglossine bees show an astonishing flying capacity (Pokorny et al., 2015), several species depend on forest fragments for their ecological requirements (Millet-Pinheiro & Schlindwein, 2005; Aguiar et al., 2015), and the dominance herein observed reinforces that.

Table 1. Summarized best models to explain the abundance of *Euglossa cordata* and *Eulaema nigrita* based on local and surrounding landscape attributes of Urban Green Areas – UGA.

Response variable	Model	ΔAICc	df	wi
***Euglossa cordata* abundance**	Flower cover	0.0	3	0.61
	Flower cover + Diameter at breast height	1.81	4	0.24
***Eulaema nigrita* abundance**	Flower cover	0.0	3	0.24
	Null	0.68	2	0.17
	Flower cover + Numer of trees	1.75	4	0.10

The modeled relationship between UGA attributes and abundances of *E. nigrita* and *E. cordata* suggests that landscape components surrounding the UGAs play a minor role compared to the inside ones. This result contrasts with studies highlighting a high explanatory power of landscape context on the euglossine dominant species (e.g., Carneiro et al., 2021, 2022), but it is important to underscore that those studies did not analyze the influence of local factors. Moreover, it is important to emphasize that these studies were carried out in landscapes with a high spatial heterogeneity related to different types of land use. This heterogeneity can indicate landscape complementation for euglossine bees (Carneiro et al., 2021), but this seems unimportant in the urban area because it has less diversified landscapes, composed mainly of paved areas and buildings. Even in urban areas with few buildings and low waterproofing, other factors, such as high temperatures and the absence of a plant community, may negatively affect orchid bees. Our results showed that abiotic landscape components only play some role in predicting the *E. nigrita* abundance. Both *E. cordata* and *E. nigrita* are cavities-nesting bees that explore unpaved surfaces or preexisting cavities for nidification (Garófalo, 1985). Since this kind of resource is irregularly distributed throughout the studied sites (Alves & Gaglianone, 2021), it is predictable that other biotic attributes, such as food availability, would be the main predictors of bee abundance.

As we observed herein, the flower cover (%) was the most important variable in explaining euglossine species abundance, which is in line with other studies covering different bee taxa (Somme et al., 2016; Alves & Gaglianone, 2021). Flower cover is essential for euglossine bees since males rely on collecting fragrances, often flower-provided, as part of their reproductive process (Dressler, 1982; Eltz et al., 2005; Schorkopf et al., 2011). Moreover, euglossine species are constant on their site regarding nectar resources and may establish foraging territories based on resource availability in urban areas (López-Uribe, 2008). The abundance of euglossine males also can be a proxy for female abundance (Opedal et al., 2016). Then, urban green areas with higher flower cover can indicate a more heterogeneous environment with a higher floral resource availability essential for the ecological requirements of euglossine males and females. Although *E. cordata* and *E. nigrita* are food generalists (Ferreira-Caliman et al., 2018), these species show a pollen preference for floral resources provided mainly by native plant species (Miranda et al., 2021). We indicate the importance of urban green environments as floral and nesting resource sources for orchid bees, acting as refuges in the highly homogeneous urban landscape and compensating for the adverse effects of urbanization.

Conclusion

This study showed that urbanization negatively influenced the orchid bee assemblage and that urban green areas play an important role in the abundance of dominant species. Only species with more remarkable plasticity remained in an altered environment, such as urban areas, and showed increased abundance. The urban landscape, primarily paved, may prevent species' dispersion and make it more sensitive to vegetation absence. However, the importance of flower cover for the dominant species indicated that is possible to reconcile urban expansion with bee conservation.

Within the urban landscape context, UGAs play a fundamental role in maintaining vegetated areas and friendly environmental conditions for the euglossine bee populations. In urban landscapes with low vegetation cover, UGAs can be a refuge where bees can find resources and conditions. We suggest increasing the number of green areas in cities, considering a high plant richness with different bloom seasons to keep the resources available throughout the year. A higher number of urban green areas in different parts of the cities can also facilitate the dispersion of orchid bees and other bee species in the urban environment, contributing to bee conservation and maintenance of their ecological services.

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Author's Contributions

SGA: conceptualization, methodology, investigation, formal analysis, writing-initial draft, writing-review and editing;
MCG: conceptualization, methodology, writing-initial draft, writing-review and editing;
LSC: formal analysis, writing-initial draft, writing-review and editing;
WSF: formal analysis, writing-initial draft, writing-review and editing;

Competing Interests

The authors declare no conflict of interest.

Availability of data and material

Additional data is available in the supplementary material.

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