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Article

Effects of small-scale anthropogenic alterations in Euglossini bees at eastern Amazon forest

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ABSTRACT. In this study, through a rapid assessment, we evaluated differences in richness, abundance, species composition and beta diversity of Euglossini bees in preserved areas and areas altered by riverine human populations in the Caxiuanã National Forest (northern Amazon). Our hypotheses were: i) the species richness, diversity, abundance and composition of Euglossini bees differ between the preserved and altered areas because many species are intolerant to small anthropic disturbances; and ii) areas altered by riverine populations have higher values of beta diversity (species dissimilarity between sites) than preserved areas, due to local changes in habitat and increased heterogeneity between sites. We sampled two areas (preserved and altered) and, in each area, four transects were sampled with odorous baits. We used a Student's t test to evaluate differences in richness, abundance, and Shannon-Wiener diversity index. We also evaluated differences in composition and differences in beta diversity between areas. We collected 102 specimens, identified in 18 species and three genera, 63 individuals (61.8% of the total) in preserved areas and 39 individuals (38.2%) in altered areas. *Euglossa liopoda* (Dressler, 1982) was the most abundant in altered areas and *Euglossa imperialis* (Cockerell, 1922) the most abundant in preserved areas. Species richness was 2.5 times greater in the transects of preserved areas, and species composition also differed between the sampled areas. In contrast, species abundance did not differ between transects of both areas. Despite our small sample size, this study demonstrated that the richness, composition and beta diversity of Euglossini bees can be potentially affected by local changes in habitat caused by small-scale activities provided by traditional Amazonian groups. Our results indicate the urgency for more comprehensive studies aimed to investigate these relationships.

KEYWORDS. Anthropogenic effects, diversity, land use, orchid bees.

RESUMO. Efeitos de alterações antrópicas de pequena escala em abelhas Euglossini na floresta da Amazônia oriental. Neste estudo, por meio de uma avaliação rápida, investigamos diferenças na riqueza, abundância, composição de espécies e diversidade beta de abelhas Euglossini em áreas preservadas e áreas alteradas por populações ribeirinhas na Floresta Nacional de Caxiuanã (norte da Amazônia). Nossas hipóteses foram: i) a riqueza de espécies, diversidade, abundância e composição das abelhas Euglossini diferem entre as áreas preservadas e alteradas, uma vez que muitas espécies são intolerantes a pequenos distúrbios antrópicos; e ii) áreas alteradas por populações ribeirinhas apresentam maiores valores de diversidade beta (dissimilaridade de espécies entre locais) do que áreas preservadas, devido às mudanças locais no habitat e aumento da heterogeneidade entre locais. Amostramos duas áreas (preservadas e alteradas) e, em cada área, foram amostrados quatro transectos com iscas odoríferas. Nós utilizamos testes t de Student, para avaliar diferenças de riqueza, abundância e índice de diversidade de Shannon-Wiener. Também avaliamos as diferenças na composição e as diferenças na diversidade beta entre as áreas. Foram coletados 102 espécimes, em 18 espécies e três gêneros, 63 deles (61,8%) em áreas preservadas e 39 (38,2%) em áreas alteradas. *Euglossa liopoda* (Dressler, 1982) foi a mais abundante nas áreas alteradas e *Euglossa imperialis* (Cockerell, 1922) nas áreas preservadas. A riqueza foi 2,5 vezes maior nos transectos de áreas preservadas, e a composição de espécies também diferiu entre as áreas amostradas. Em contraste, a abundância de espécies não foi diferente entre os transectos das duas áreas. Apesar de nosso esforço amostral reduzido, nossos resultados demonstram que a riqueza, composição e diversidade beta das abelhas Euglossini podem potencialmente ser afetadas por mudanças locais no habitat causadas por atividades de pequena escala fornecidas por grupos tradicionais da Amazônia. Esses resultados indicam a urgência por estudos mais extensos no sentido de investigar as relações aqui estudadas.

PALAVRAS-CHAVE. Efeitos da antropização, diversidade, uso de solo, abelhas das orquídeas.

The Amazon rainforest is one of the most diverse regions of the world (Pack *et al.*, 2016). However, impacts generated from human activities are causing rapid loss of biodiversity, including changes in the distribution of Euglossini bee communities (Winfree *et al.*, 2009; Potts *et al.*, 2010). These habitat changes are caused mainly by the human capacity to clear native vegetation and assign different land uses to the landscape (e.g., irrigated fields or pastures areas) (Peres *et al.*, 2006; Laurance & Peres, 2006). Landscape alteration can range from large-scale agribusinessfueled activities (e.g., large-scale crops, livestock, timber extraction) to small-scale activities by small traditional populations (e.g., subsistence agriculture, local fires, plant harvesting) (Peres *et al*., 2006; De Faria *et al*., 2017). Recent studies indicate an intensification in small-scale deforestation in the Amazon forest, including that produced by small producers or landholders (Kalamandeen *et al*., 2018). These altered areas generally have lower forest cover and habitat heterogeneity than preserved areas (Aguilar-Santelices & Del Castillo, 2013). Environmental changes at different spatial scales have led to a decline in pollinators in tropical regions (Geist & Lambin, 2002; Lambin *et al*., 2003). This fact poses a serious risk to tropical flora biodiversity since many species of angiosperms depend on bees to disperse their pollen, which is essential for global food security (Pauw, 2007; Potts *et al*., 2010, 2016; Ollerton, 2017).

Euglossini bees (Hymenoptera, Apidae), also known as orchid bees, occur exclusively in the Neotropical region, especially in forested areas (Dressler, 1982a; Campos *et al*., 1989; Roubik & Hanson, 2004). They are considered a group with a relatively high dispersal capacity, covering more than 5 km per day while foraging (Tonhasca *et al*., 2003; Wikelski *et al*., 2010). One noticeable characteristic of this tribe is that males collect species-specific chemicals in diverse sources, including flowers of hundreds of plant species, especially of the orchid family, whose flowers produce aromatic essences used by these bees to compose their pheromones. This bee tribe lives almost exclusively among the tree canopies, which may be related to the susceptibility of this group to human disturbances (Bawa, 1990; Brosi, 2009). The composition of orchid bee communities can be affected by several natural and anthropogenic factors, such as environmental degradation, deforestation and microclimatic change, which can promote the reduction of local populations and local diversity of this group (Roubik & Hanson, 2004; Nemésio & Silveira, 2006; Brown & Paxton, 2009; Botsch *et al*., 2017). Consequently, orchid bees are frequently used as environmental bioindicators due to their high sensibility to changes in the habitat quality and responses to fragmentation, and the relatively good knowledge in the science of their biology, taxonomy and distribution (Brown, 1997; Brosi & Daily, 2008).

To understand how human disturbances impact natural communities, it is necessary to identify how they affect the main drivers of community assembly. The structuring of local communities has mainly been studied based on environmental filtering (Tuomisto *et al*., 1995, 2003) and dispersal processes (Hubbell, 2001; Leibold *et al*., 2004). Environmental filtering considers that environmental factors are the major drivers structuring local communities in metacommunities, resulting in similar habitats likely supporting similar species (Toumisto *et al*., 1995, 2003; Leibold *et al*., 2004). However, at larger spatial scales, some species may present dispersal limitation, that is, they may not be able to reach all locations in the region (Heino *et al*., 2015). To facilitate the study of diversity patterns in communities, Whittaker (1960, 1972) considered a distinction between local species diversity (alpha, α) within a region species pool (gamma, γ), and the compositional dissimilarity between locations, i.e., beta diversity (β). This approach makes it possible to investigate spatial patterns within a community and helps to identify which processes are driving these patterns. For instance, if beta diversity does not change with increasing habitat heterogeneity, this may indicate dispersal limitation of species between sites (Heino *et al*., 2015).

Given the intensification of the small-scale activities carried out by traditional populations in Amazon, it is important to investigate how these activities can affect key biological groups for ecosystem functioning, as Euglossini bees. In this study, we used a small dataset obtained through a rapid assessment for comparing the richness, abundance, composition of species and dissimilarity between orchid bees between preserved and altered areas in a forested region of eastern Amazon. These areas were relatively close to each other, removing the effect of dispersal limitation and highlighting the changes due to environmental filtering. We hypothesized that: i) abundance of individuals, species richness and species diversity are higher in preserved areas, and species composition of Euglossine bee communities differ between preserved and altered areas, considering that even small-scale human disturbances can change the habitat, causing a loss in bee diversity in altered areas and, also, selecting tolerant species; and ii) beta diversity is higher in altered sites than in preserved ones. We expect a higher variation in species composition because small-scale changes in the landscape can increase habitat differences and may lead to a higher compositional change of the communities between altered transects. Rapid assessments can be helpful tools for identifying ecological patterns that deserve further and more comprehensive investigations (Fennessy *et al*., 2007). Therefore, our results can be a first contribution to using orchid bees as indicators of small-scale human disturbances in the eastern Amazon.

MATERIALS AND METHODS

Study area. The study was conducted at the Caxiuanã National Forest (FLONA of Caxiuanã), located in the northeast of the Pará state in Brazil, distant 300 km from the capital of the state, Belém (Fig. 1). Caxiuanã has nearly 320,000 hectares, with vegetation mainly composed of dense lowland rain forest (Lisboa, 2009), seconded by floodplain (*igapó*) forest (Almeida & Thales, 2003). The Caxiuanã Forest has a tropical climate, i.e., hot and humid, corresponding to a Köppen's AM classification, with well-defined dry and wet seasons. The average annual precipitation is 2000 mm, with a maximum of 379 mm in March (wet season) and a minimum of 50 mm in October (dry season) (Lisboa, 2002). The air temperature can vary from 23.8ºC to 32.7ºC (Benone *et al.*, 2018). The human resident population of Caxiuanã is sparse and practices fishing, agro-extractivism and produces cassava flour as the main product for their subsistence, also growing orchards near the dwellings. Despite living in

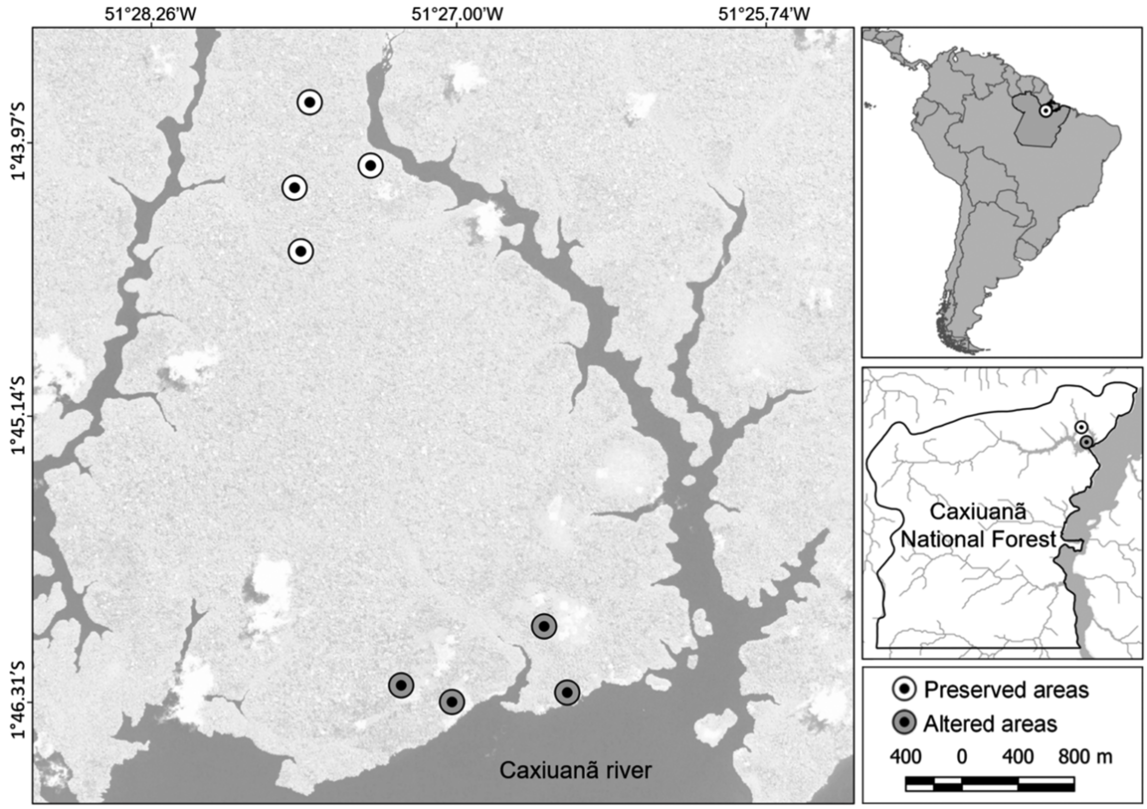

Fig. 1. Sampling transects located in the Caxiuanã National Forest, northeastern of Pará State, Brazil.

traditional ways, these populations still can impair the local environment and its biota (De Faria *et al.*, 2017).

Sampling. The biological sampling was performed during September 2018, corresponding to the dry season in the region. The sampling was carried out in two areas; the first consisted of a preserved primary forest located far from human dwellings, and the second was near two traditional riverine (*ribeirinhos*) communities, which present small deforested spots with cassava plantations, representing the altered area. The samplings in each region were performed within two consecutive days, always in the morning - the most active period of Euglossine bees in tropical forests (Oliveira & Campos, 1996). Four transects were established in each area (Fig. 1). Two transects were sampled per day, with two researchers performing two hours of active sampling in each transect. The method used was the active collection, using entomological nets (Nemésio & Vasconcelos, 2014). Each day, the collection of the first transect started at 8 am and ended at 10 am, while the second collection started at 10:20 am and finished at 12:20 pm.

The transects at each area were 15 m long and were separated by at least 400 m from each other. Euglossini bees are easily attracted by synthetic chemicals identical to those present in the flowers visited by them (Dodson *et al.*, 1969). Therefore, we placed four odoriferous baits corresponding to moistened cotton balls with an odoriferous essence composed by methyl salicylate in each transect. This type of bait is considered one of the most attractive for the males of the Euglossini tribe (Oliveira & Campos, 1996). Each cotton ball was positioned 5 m from each other, at an average height of approximately 1.5 m above the ground level, using tree trunks as support (Storck-Tonon *et al.*, 2013).

The collected individuals were euthanized in glass bottles with alcohol (70%), identified and placed in an entomological box. The identification was made up to the species level with the help of taxonomic keys (Moure, 1968, 2000; Dressler, 1982b,c; Kimsey, 1982; Roubik & Hanson, 2004, Allen & Villacampa, 2017) and the advice of specialized technicians in the Hymenoptera group. The specimens were stored in the bee's collection curatorship of Museu Paraense Emílio Goeldi (MPEG).

Data analyses. We performed independent Student's t tests ($\alpha = 0.05$) to verify differences in abundance, species richness and Shannon-Wiener (H') diversity index of Euglossini bees between preserved and altered areas. We transformed data using $\log_{10}(x+1)$ to remove high discrepancies and increase homoscedasticity and normality. To evaluate if the composition of species varied between preserved and altered transects, we performed a Permutational Multivariate Analysis of Variance (PERMANOVA) using the Bray-Curtis dissimilarity measure, also employing $\log_{10}(x+1)$ transformation to abundances. We also conducted an analysis of homogeneity of multivariate dispersions (PERMDISP) (Anderson *et al.*, 2006) to investigate which area presented greater beta diversity among transects. Finally, we used a Principal Coordinate Analysis (PCoA) to visually determine the dissimilarity patterns between sampled transects. We performed all analyzes in R program, version 3.4.1 (R Core Team, 2017), using vegan (Oksanen *et al*., 2018), BAT (Cardoso *et al*., 2015) and Car (Fox & Weisberg, 2011) packages.

RESULTS

We found a total of 102 specimens belonging to 18 species and three genera of bees. *Euglossa* was the richest and most abundant, registering 85 individuals distributed in 13 species. *Eulaema* was represented by 14 individuals distributed in three species and *Eufriesea* was recorded by three individuals of two species (Tab. I). Some photographs of the organisms, environments and methods are presented in Supplementary Material 01.

We observed a higher number of individuals in preserved (63) than altered areas (39). However, we did not find any difference in the mean abundance per transect between these two environments (t = -1.3046, df = 6, p = 0.243, Fig. 2A). With 23 individuals, *Euglossa liopoda* was the most abundant species in the altered areas (59% of the total number of individuals), being the single species with more than three registered individuals in the altered area. Seven of the 12 species found in the altered area were represented by only one individual. In the preserved areas, the species *Euglossa imperialis* was dominant, with 33.3% of the records (21 individuals). Four species showed expressive abundances, between six and nine individuals sampled: *Euglossa chalybeata* Friese, 1925, *Euglossa laevicincta* Dressler, 1982, *Euglossa liopoda* and *Eulaema meriana*.

We found higher bees species richness in preserved than altered areas (t = -2.501, df = 6, p = 0.047). On average, preserved transects showed 3.5 more species per transect (average of 7.75 species per transect) than transects with small-scale anthropogenic alterations (average of 4.25 species per transect) (Fig. 2B. We also observed higher diversity of bees in preserved areas (H'= 2.145, versus H' = 1.623 found in altered areas; Fig. 2C.

The first two axes of the PCoA represented 66% of total data variability (Fig. 3). We observed a different composition of Euglossine species between preserved and altered areas (Pseudo-F$_{(1,6)}$ = 3.069, p = 0.034). Nine species were common between the two areas; three species were recorded only in altered areas: while six species were exclusive of preserved areas (Tab. I). We found a higher average dissimilarity among transects in the altered area (mean distance to group centroid = 0.810) than in the preserved area (mean distance to group centroid = 0.590) (Fig. 3), indicating a higher beta diversity in the altered area (F-ratio$_{(1,6)}$ = 8.95, p= 0.038).

Tab. I. Genera, species, and number of individuals of Euglossini bees collected in Caxiuanã National Forest, Pará, Brazil.

Genus	Number of individuals		
Species	Preserved	Altered	Total
Eufriesea Cockerell, 1908	2	1	3
Eufriesea cf. *fallax* (Smith, 1854)	1	0	1
Eufriesea pulchra (Smith, 1854)	1	1	2
Euglossa sp.1 Latreille, 1802	51	34	85
Euglossa aff. *mixta* Friese, 1899	2	1	3
Euglossa annectans Dressler, 1982	0	1	1
Euglossa augaspis Dressler, 1982	1	1	2
Euglossa chalybeata Friese, 1925	6	0	6
Euglossa cognata Moure, 1970	1	1	2
Euglossa crassipunctata Moure, 1968	2	0	2
Euglossa gaianii Dressler, 1982	0	1	1
Euglossa imperialis Cockerell, 1922	21	2	23
Euglossa laevicincta Dressler, 1982	7	2	9
Euglossa liopoda Dressler, 1982	7	23	30
Euglossa mixta Friese, 1899	1	2	3
Euglossa orellana Roubik, 2004	2	0	2
Euglossa sp.2	1	0	1
Eulaema Lepeletier, 1841	10	4	14
Eulaema bombiformis Packard, 1869	1	0	1
Eulaema meriana (Olivier, 1789)	9	3	12
Eulaema mocsaryi Friese, 1899	0	1	1
Total	63	39	102

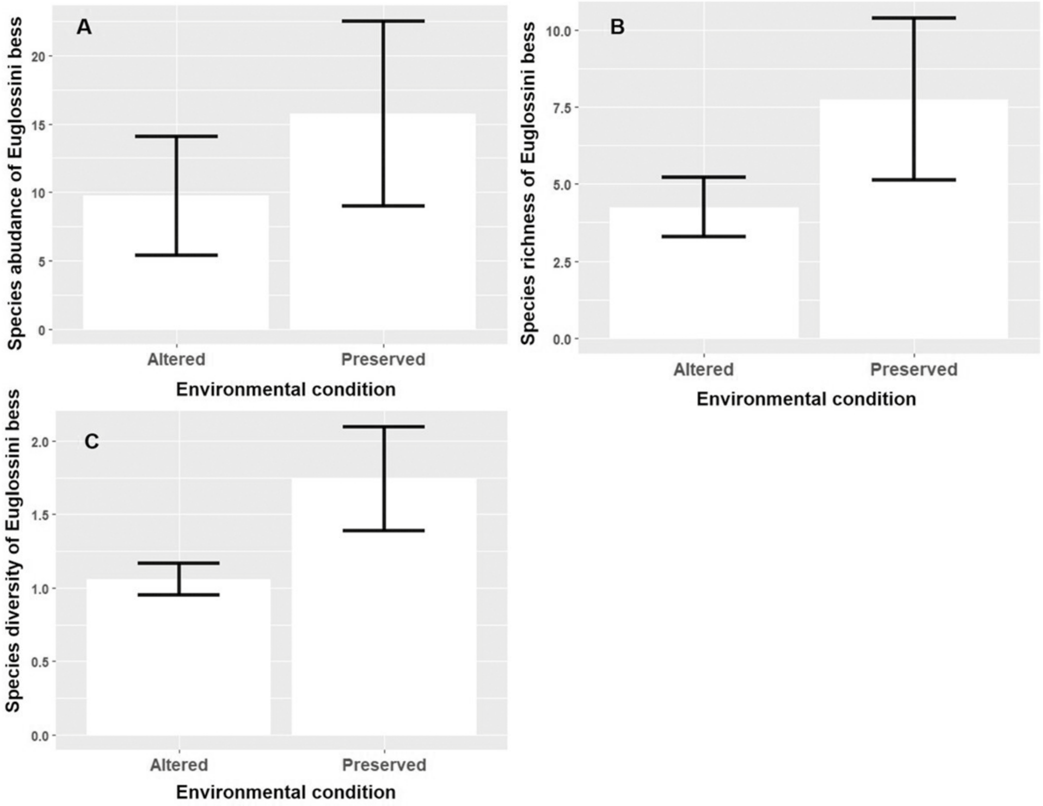

Fig. 2. Abundances of individuals (A), species richness (B) and species diversity (C) of the Euglossine bees between areas (altered and preserved) in the Caxiuanã National Forest, Pará, Brazil.

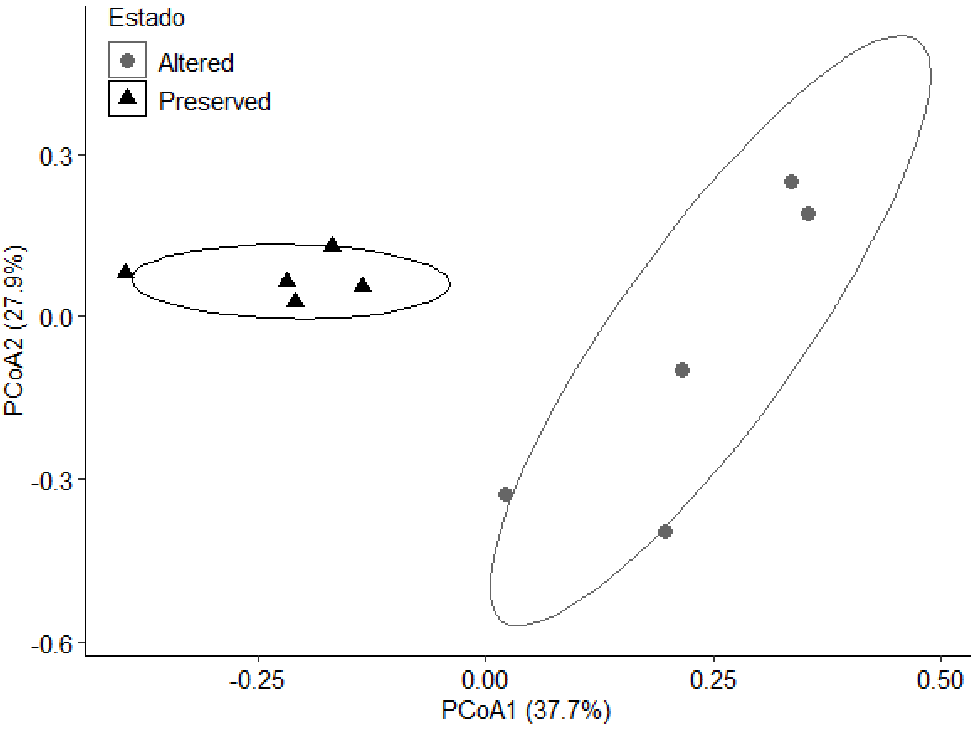

Fig. 3. PCoA ordination showing differences in species composition of Euglossini bees sampled in transects of the preserved area (triangles) and transects of the altered area (circles) at Caixuanã National Forest, Pará, Brazil.

DISCUSSION

Several studies have demonstrated the impact of fragmentation and deforestation over bee populations (Tonhasca *et al*., 2002a,b, 2003; Botsch *et al*., 2017). In the present study, we demonstrate that even small human alterations can negatively impact bee communities, causing a decrease in total abundance sampled, species richness and diversity. Our results showed that the altered area presented lower species richness and Shannon diversity, and different composition of Euglossini bees in Caxiuanã National Forest, partially corroborating our first hypothesis. These results, despite obtained through a small sample size rapid assessment, indicate that, regardless of the high dispersal capacity of bees, environmental filters were the main drivers of this compositional change among transects. However, there were no significant differences in the mean abundance of individuals between the transects of the two areas. The survival capacity of bees can be affected by the quality of the physical habitat and resources that an area offers, such as microclimate, habitat heterogeneity, competition and plant cover (Roubik & Hanson, 2004; Nemésio & Silveira, 2006; Brosi, 2009). This observed reduction of euglossine bee richness in altered areas may also negatively influence floral populations, mainly angiosperms, which can lead to further loss of habitat quality (Carvalho *et al*., 2006; Ollerton, 2017).

Regarding species composition, *Eulaema bombiformis* was found exclusively in well-preserved areas. A similar finding was indicated by Parra & Nates-Parra (2007), which evaluated the euglossine community at different environments (urban, rural, and preserved). In addition, in the preserved area, the most abundant species (*Euglossa imperialis*) represented 33.3% of the total number of individuals sampled, while in the altered area it corresponded to only 5.1% of the records. According to Morato (1994), *Euglossa imperialis* is a typical forest species, which may be sensitive to open areas. This species and *Euglossa chalybeata* belong to the subgenus *Glossura*, and were among the most abundant species in the preserved area, not being recorded in the altered area. Both species are abundant in the Amazonian forests and stand out for being relatively large (16 mm) in comparison with the other bees of the genus *Euglossa*. They have longer mouthparts in relation to the size of their body, even passing the abdominal apex (Silveira *et al*., 2002). In this study, both species were the only with large body size. This characteristic in male bees may indicate a greater capacity for dispersion and advantage in competition with other species (Kukuk, 1996). If dispersal process were the main drivers of community structuring, it would be expected to find them also in altered areas, in which *Euglossa chalybeata* was not found, and *E. imperialis* just occurred twice. Therefore, our findings suggest that, despite the high capacity of dispersal of the bees, the environmental processes (i.e., species sorting) had a considerable influence on the community structuring.

In altered areas, *Euglossa liopoda* was the most abundant species. This species belongs to *Euglossa*, the most diverse genus of the Euglossini tribe and was also observed in other inventories made in the Amazon (Anjos-Silva, 2008, 2011; Oliveira-Junior *et al*., 2015). A greater record of this species in the altered area may be an indication of tolerance to small environmental disturbances.

Of the 18 species collected in the FLONA of Caxiuanã, six species were recorded only in preserved area and three other species were recorded only in altered area, which can be a result of the availability of existing resources in each area, potentially altered by anthropogenic activities (Souza *et al*., 2005). The three species of bees found only in the altered area (*Euglossa annectans*, *E. gaianii* and *Eulaema mocsaryi*) can be considered common or generalist species, because they use various species of plants to feed, which expands their food resources (Brito & Rêgo, 2001; Giehl *et al*., 2013). They also can adapt to and are more frequent in fragmented areas (Brito & Rêgo, 2001; Cortopassi *et al*., 2009; Giehl *et al*., 2013). Therefore, euglossine bees are a good indicator not only of the diversity of bee communities, but also of the diversity of flowering plants available (Roubik & Hanson, 2004), being a good general bioindicator of ecological condition of the areas.

The altered area presented higher beta diversity than the preserved area, corroborating our second hypothesis. The modifications caused by subsistence agro-extractivism may have provided small-scale changes in the landscape, altering the floristic composition and increasing habitat complexity at smaller spatial scales (Stein *et al*., 2014), leading to a greater variation in species composition among transects. More complex habitats can favour greater beta diversity mainly due the greater variety of microhabitats and resources (Pierre & Kovalenko, 2014), that together act as environmental filters related to the species sorting paradigm (Leibold *et al*., 2004). A greater variation of tolerant species between sites may also cause an increased beta diversity (Johnson & Angeler, 2014).

In conclusion, our fidings corroborated our first hypothesis, that preserved areas have higher species richness and different composition of Euglossini bees than altered areas, and our second hypothesis, that the altered areas present higher beta diversity than preserved areas. However, we found similar mean abundance between the preserved and altered areas. This may reflect that alfa and beta diversity of Euglossini bees may respond in opposite ways to human alterations at smaller spatial scales, suggesting the existence of distinct tolerances among Euglossini species to anthropogenic disturbances, and distinct responses of the overall community to habitat characteristics. Large-scale landscape changes, such as the construction of dams, mining and agribusiness carried out on large properties, are obviously the main drivers of forest destruction. Still, the results of our study indicate that small-scale activities promoted by traditional populations can have local impacts on the environment and biota. This process should be better understood, once these changes can impair ecosystem services and compromise the economic activities of these populations and their traditional way of life. Our study constitutes the first contribution to the use of Euglossini bees as bioindicators of environmental degradation in eastern Amazon. Despite dealing with a small sample size, our results revealed clear effects of small-scale perturbations in the structure of bee assemblages. Therefore, we highlight the need for more comprehensive studies aiming to elucidate this relationship and to better support biomonitoring and conservation planning of Euglossini bees and the plants pollinized by them.

Supplementary material. The following online material is available for this article: Additional figures.

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