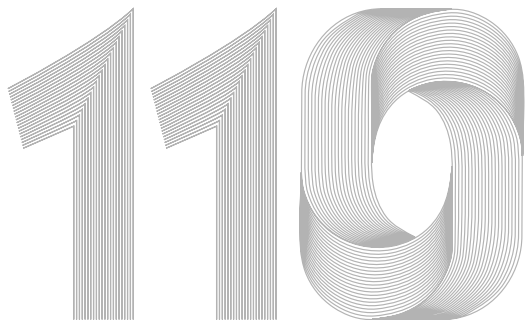




ECOSYSTEMS

Overcoming the Linnean and Wallacean shortfalls in the northeast of Atlantic Forest: The community of bees (Hymenoptera, Apidae) in a potentially threatened area

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Abstract: The Atlantic Forest is one of the most threatened biomes with a complex evolutive history compounded by subunits and local endemism. Despite that, many taxa, such as bees, is still poorly known in some regions, including several protected areas. These gaps in diversity and distribution represent an impediment in the knowledge of these important pollinators. In this context, faunistic surveys are valuable tools to explore regional diversity, to decrease the Linnean and Wallacean shortfalls. For this, we conducted an inventory of bees in the largest Atlantic Forest remnant north of São Francisco River. We collected typical bee fauna of Atlantic Forest as *Ariphanarthra* Moure and other species typical of Amazonian fauna. We also registered a new species of Meliponini and first specimens of *Geotrigona xanthopoda* Camargo & Moure outside of Caatinga biome. Our data demonstrated that bees in this portion of Atlantic Forest possesses unique elements, reinforcing its heterogenous composition and, the importance of actions to conserving this area as an environmental refuge. Therefore, it is necessary to reassess current government proposals for the implementation of public infrastructure and private developments in the region, which threaten to irreversibly impact the fauna and flora of this portion of the Atlantic Forest.

Ke ywords: Alpha diversity, Endemism, Sampling, Species conservation, South America.

INTRODUCTION

The Atlantic Forest is one of the most biodiverse tropical ecosystems in the world, result of a complex evolutionary history (Myers et al. 2000, Galindo-Leal & Câmara 2003, Ewers & Didham 2006). Biogeographical studies pointed out that this biome is not a unique component, possessing elements that corroborate our division into at least two large partitions - north and south (Fiaschi & Pirani 2009). The northern portion of the Atlantic Forest is currently reduced to small fragments, with few regions of original characteristics due to human exploration and

occupation over centuries (Lobo et al. 2011, Tabarelli & Santos 2004a).

The biota of this portion of the biome is compounded by species with a diverse evolutionary origin, arising of past connections with the Amazonian Forest and the south partition of Atlantic Forest (Ledo & Colli 2017, Tabarelli et al. 2005). The northern partition has a high heterogeneity vegetation with endemic species distributed in specific regions, such as the Pernambuco Endemism Center (PEC). The PEC is defined as a biogeographical unit of the Atlantic Forest to the north of the São Francisco

River, that encompasses lowland coastal Atlantic Forests of the states of Alagoas, Pernambuco, Paraíba, and Rio Grande do Norte (Feijó et al. 2023, Tabarelli et al. 2005). This portion is one of the regions of the planet where conservation efforts are most urgent to avoid the local species extinction in the short term (Tabarelli & Santos 2004b).

Despite the advance of deforestation in the PEC, new taxa continue to be described in distinct groups, such as bromeliads, ophids, amphibians and lizards (Freire 1999, Cruz et al. 2006, Ferrarezzi & Freire 2001, Siqueira Filho & Leme 2006). Endemic species are also known to some lineages as birds and reptiles (Roda unpublished data, Hoogmoed et al. 1994, Peixoto et al. 2003). Specifically, about bees, the studies on the PEC are still incipient compared to other taxa, including insects such as butterflies (Freitas et al. 2023), social wasps (Santos & Somavilla 2020), ants (Silva et al. 2023) and termites (Vasconcellos et al. 2023).

Inventories about bees in the PEC were focused only in Euglossini (Bezerra & Martins 2001, Milet-Pinheiro & Schlindwein 2005, Darrault et al. 2006, Moura & Schlindwein 2009, Nemésio 2010, Nemésio & Santos-Júnior 2014, Oliveira et al. 2015). This restriction on the knowledge of the species of bees (Linnean deficit) and its distribution (Wallacean distribution) in this portion of Atlantic Forest, are barriers to its conservation. For this, we conducted the first survey of bee fauna in an area of the PEC using Malaise traps. Our objective was to present a list of species of bees in the region, discuss the local diversity and compare the results with other surveys conducted in the Atlantic Forest with the same methodology. Inventories such this are necessary to decrease gaps of knowledge, to monitor local communities, and to propose policies to protect pollinators and endemism areas.

MATERIALS AND METHODS

This study was carried out in the remnants of Atlantic Forest of Pernambuco Endemism Center (PEC), situated in the Environmental Protection Area (APA) Aldeia-Beberibe (Figure 1). The APA Aldeia-Beberibe covers an area of around 31 thousand hectares distributed in eight municipalities of state of Pernambuco (Governo do Estado de Pernambuco 2012). According to Köppen's classification, the climate is predominantly hot and tropical humid, with rainfall concentrated between March and August and a mean annual temperature of 24 °C (Alvares et al. 2013, Governo do Estado de Pernambuco 2012). The samples were conducted in two municipalities, Paulista and Recife. The area in Paulista is a private property little urbanized, situated in Biodiversity Protection Zone and Environmental Services (ZPBSA) and Subzone of Forest Protection (Governo do Estado de Pernambuco 2012). The second area situated in Recife, is in Parque Estadual de Dois Irmãos. Both areas are composed by a mosaic of Dense Ombrophilous Forest of lowland represented by fragments of secondary forest fragments in medium to advanced regeneration stage, and together constitute the largest forest fragment north of São Francisco River (Lucena 2009).

The bees were collected with Malaise traps model 6-meter long with two collector vials (Gressit & Gressit unpublished data), for 17 months, totaling 22 samples (Supplementary Material - Table SI). Each municipality was considered a sampling unit, with a total of four traps installed in the APA with the following coordinates: Malaise 1 (-8,011783 -34,944223), Malaise 2 (-8,005470 -34,942078), Malaise 3 (-7,919646 -35,019914) and Malaise 4 (-7,923530 -35,015541). The identification of material was made with assistance of taxonomic works for each taxon, compared with reference

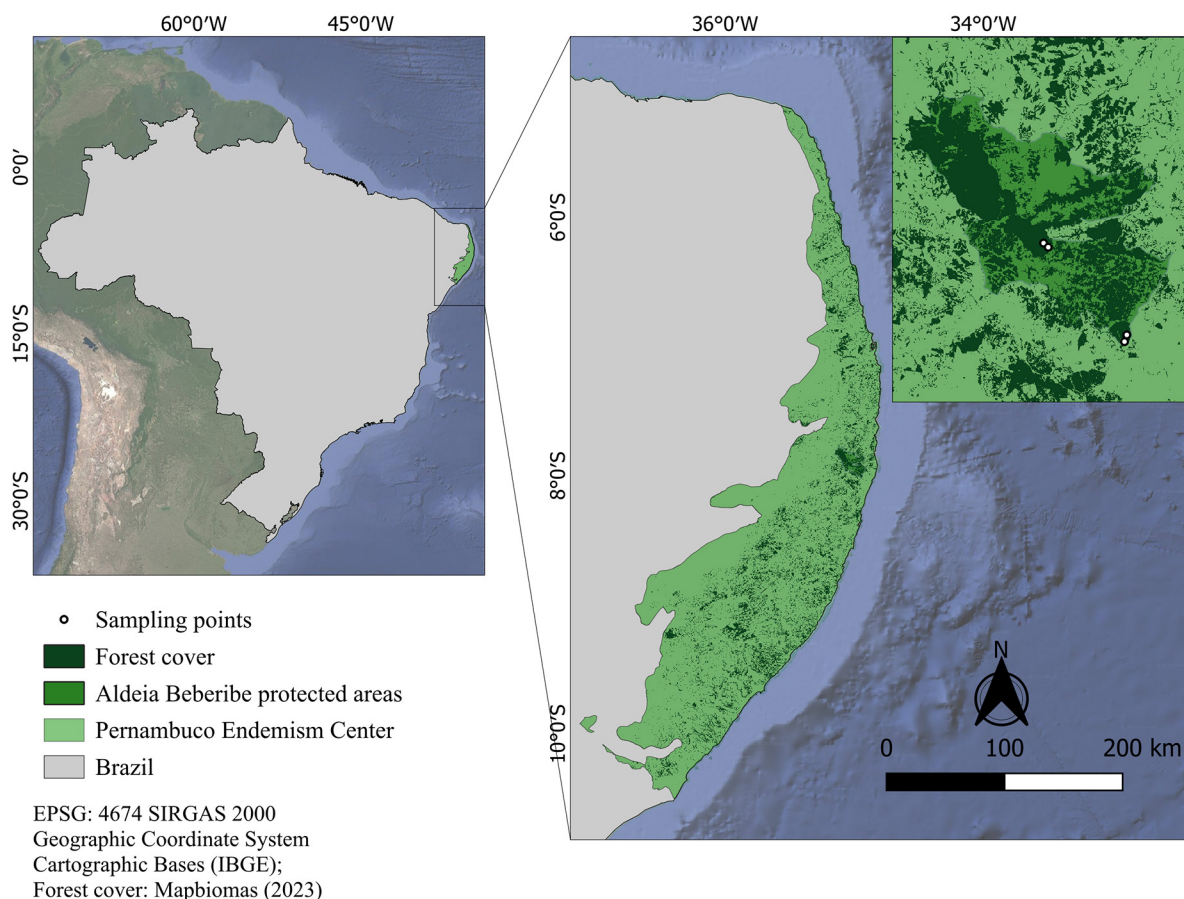


Figure 1. Map of location of sites of collect in the APA Aldeia-Beberibe inserted in Pernambuco Endemism Center (PEC), Pernambuco, Brazil.

material deposited in Coleção Entomológica da Universidade Federal Rural de Pernambuco (CERPE) and, in some cases a specialist was consulted. The bees are herein treated as a unique family - Apidae, according to Melo & Gonçalves (2005).

The data of richness, abundance and diversity (Shannon-Wiener index - H') was performed using EstimateS 9 program and PAST program. The collector curve was calculated based on the number of species collected during the period of study. The richness estimators Chao1, Jackknife 1 and Bootstrap were used to determine sample sufficiency through to EstimateS 9 program.

RESULTS

A total of 1358 bees belonging to 48 species was collected from January 2022 to May 2023. The bees captured are distributed in three subfamilies, 15 tribes and 33 genera (Table I). Apinae and Halictinae were the richest taxa, with 34 and 12 species, respectively. Apinae was the most abundant group, with near 95.1% of the total collected individuals, followed by Halictinae with about 4.8%, and Colletinae with only 0.1%. Meliponini and Euglossini were the tribes with higher richness of species, with 14 and 10 respectively. *Trigona braueri* Friese, 1900 was the most abundant species with 765 individuals, corresponding to about 56% of total of sampled bees.

Table I. List of species of bees (Hymenoptera, Apidae) collected in the APA Aldeia-Beberibe, inserted in Pernambuco Endemism Center (PEC), Pernambuco, Brazil from January 2022 to May 2023 using Malaise traps.

TAXA			Number of individuals	
			Recife	Paulista
APINAE	Ancyloscelidini	<i>Ancyloscelis apiformis</i> (Fabricius, 1793)	1	-
	Epicharitini	<i>Epicharis (Epicharitides) duckei</i> Friese, 1900	-	1
	Ericrocidini	<i>Acanthopus excellens</i> Schrottky, 1902	-	1
	Eucerini	<i>Thygater (Thygater) palliventris</i> (Friese, 1908)	3	14
	Euglossini	<i>Eufriesea surinamensis</i> (Linnaeus, 1758)	-	1
		<i>Euglossa (Euglossa) cordata</i> (Linnaeus, 1758)	1	43
		<i>Euglossa (Euglossa) despecta</i> Moure, 1968	-	1
		<i>Euglossa (Euglossa) gaianii</i> Dressler, 1982	-	3
		<i>Euglossa (Euglossella) perpulchra</i> Moure & Schindwein, 2002	-	19
		<i>Euglossa (Glossurella) clausi</i> Nemésio & Engel, 2012	-	7
		<i>Euglossa (Glossurella) ignita</i> Smith, 1874	1	-
		<i>Euglossa</i> sp.	-	1
		<i>Eulaema (Apeulaema) cingulata</i> (Fabricius, 1804)	1	2
		<i>Eulaema (Apeulaema) nigrita</i> Lepeletier, 1841	5	6
	Exomalopsini	<i>Exomalopsis</i> sp.	1	8
	Meliponini	<i>Frieseomelitta doederleini</i> (Friese, 1900)	3	2
		<i>Geotrigona xanthopoda</i> Camargo & Moure, 1996	-	16
		<i>Melipona (Michmelia) scutellaris</i> Latreille, 1811	31	54
		Meliponini sp. nov.	-	2
		<i>Nannotrigona punctata</i> (Smith, 1854)	3	-
		<i>Nannotrigona testaceicornis</i> (Lepeletier, 1836)	1	1
		<i>Partamona cf. helleri</i> (Friese, 1900)	152	21
		<i>Partamona cf. littoralis</i> Pedro & Camargo, 2003	3	-
		<i>Plebeia flavocincta</i> (Cockerell, 1912)	48	31
		<i>Scaptotrigona cf. tubiba</i> (Smith, 1863)	1	1
		<i>Tetragonisca angustula</i> (Latreille, 1811)	2	1
		<i>Trigona braueri</i> Friese, 1900	18	747
		<i>Trigona fuscipennis</i> Friese, 1900	2	3
		<i>Trigona spinipes</i> (Fabricius, 1793)	1	2

Table I. Continuation.

	Osirini	<i>Osiris</i> sp. 1	-	8
		<i>Osiris</i> sp. 2	-	2
	Rhathymini	<i>Rhathymus</i> sp.	-	1
	Tapinotaspidini	<i>Paratetrapedia bicolor</i> (Smith, 1854)	6	6
	Xylocopini	<i>Xylocopa</i> sp.	1	-
COLLETINAE	Colletini	<i>Colletes petropolitanus</i> Dalla Torre, 1896	-	1
	Hylaeini	<i>Hylaeus</i> sp.	-	1
HALICTINAE	Augochlorini	<i>Ariphanarthra</i> sp.	-	2
		<i>Augochlorella</i> sp.	2	2
		<i>Augochloropsis callichroa</i> (Cockerell, 1900)	1	2
		<i>Augochloropsis</i> sp.1	-	1
		<i>Augochloropsis</i> sp.2	-	2
		<i>Augochloropsis</i> sp.3	2	2
		<i>Megalopta</i> sp.	1	-
		<i>Megaloptina</i> sp.	2	6
		<i>Pereirapis</i> sp.	-	14
		<i>Stilbochlora eickworti</i> (Engel, Brooks & Yanega, 1997)	4	18
	Halictini	<i>Dialictus</i> sp.	-	3
		<i>Habralictus canaliculatus</i> Moure, 1941	1	1
		Total	298	1060

The species accumulation curve did not indicate stabilization (Figure 2), and the richness estimators were: 58,13 (Chao 1), 61,32 (Jackknife 1) and 53,83 (Bootstrap). The number of species samples were lower than results found by Andrade et al. (2021) and Gonçalves & Brandão (2008), while the number of individuals was highest (Table II). The index of diversity (H') to total area was 1.815, being of 1.465 only to Paulista and 1.899 to Recife. In the areas of Recife and Paulista there were registered 26 and 41 species respectively, while the simultaneous occurrence was of 18 species. In the area of Paulista there were registered 19 exclusive species, while in Recife five exclusive species were registered (Table I). *Euglossa perpulchra*

Moure & Schlindwein, 2002, *Euglossa clausii* Nemésio & Engel, 2012, *Euglossa gaianii* Dressler, 1982 and *Euglossa despecta* Moure, 1968 was collected only in Paulista. *Geotrigona xanthopoda* Camargo & Moure, 1996 was registered for the first time outside of Caatinga biome. Additionally, two individuals of a new species of Meliponini were collected (Melo & Parizotto, unpublished data).

DISCUSSION

Our results pointed out that the area houses a diverse and heterogeneous fauna of bees, with species typically of Atlantic Forest and, also elements of Amazonian fauna, reflection

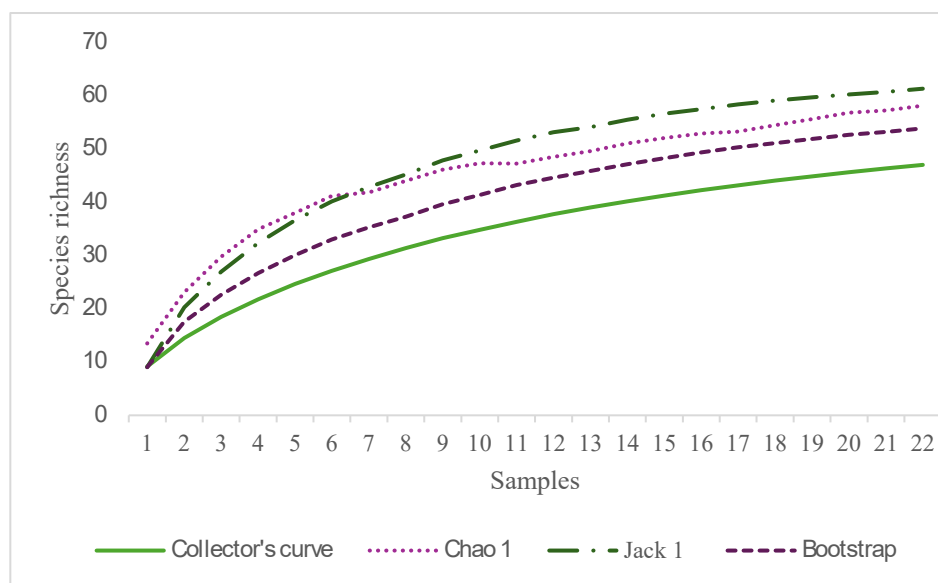


Figure 2. Species accumulation curve and wealth estimators of the bee community richness of fragments of APA Aldeia-Beberibe inserted in Pernambuco Endemism Center (PEC), Pernambuco, Brazil.

Table II. Number of species and individuals of surveys of bee assemblages carried out in Atlantic Forest using Malaise traps.

	Number of species	Number of individuals	Sample period
This study	48	1358	17 months
Andrade et al. (2021)	62	812	15 months
Gonçalves & Brandão (2008)	84	647	13 months

of historical connections. The record of endemic species, a new species of Meliponini and, the register of distribution of *Geotrigona* corroborated this hypothesis and demonstrated the importance of surveys in poor explored areas. These data demonstrate the urgency and relevance of conservation of the largest fragment of Atlantic Forest in the north of São Francisco River (APA Aldeia-Beberibe), even considering the limitations of sampling methodology.

Among bee taxa sampling, Apinae and Halictinae were the richest in number of species. This result follows the pattern found by Andrade et al. (2021) and Gonçalves & Brandão (2008), even as other inventories of bees with other methodology (Gonçalves & Melo 2005, Martins et al. 2013). Additionally, this result reflects the diversity of these taxa, with Apinae representing

the most diverse subfamily (6,000 described species), followed by Halictinae (4,500 described species) (Michener 2007). On the other hand, our results show differences between richness and abundance in comparison to inventories with the same methodology in areas of the Atlantic Forest (Table II). Considering the richness, our results were lower than the two other inventories, even with a similar period of sampling. In relation to the abundance, the greatest abundance found in our data is due to the high number of individuals of *Trigona braueri*, which represented more than 50% of total registered. This result is possibly related to the biology of species of *Trigona* that usually has numerous works in the colonies. The social behavior also can be a factor that influenced the greatest abundance of *T. braueri* like other

species of Meliponini and Euglossini in the samples (Gonçalves et al. 1996, Gonçalves & Brandão 2008, Andrade et al. 2021).

The diversity ($H' = 1,815$) and richness of bees in the study area could be underestimated due the exclusive use of Malaise traps, as already pointed out in studies for other taxa (Fraser et al. 2008). Even so, the use of Malaise can be considered a more efficient method in forest environments as the APA Aldeia-Beberibe (Somavilla et al. 2019, Souza et al. 2015). Additionally, the results cover important Linnean and Wallacean deficits to bee fauna. We highlight the presence of *Euglossa perpulchra*, endemic of PEC and associated with few modified environments (Faria & Melo 2011). Additionally, *Euglossa clausii*, *Euglossa gaianii* and *Euglossa despecta* are species bioindicators of environmental quality (Giangarelli et al. 2009, Mariano et al. 2024). Other important register was *Geotrigona xanthopoda*, a species previously recognized as restrict to Caatinga Domain (Camargo & Moure 1996, Zanella & Martins 2003). This data expands the distribution of the *G. xanthopoda* to the Atlantic Forest biome and the distribution of the genus. We also highlight a new species of Meliponini, that reinforces the importance of surveys in poorly explored areas.

Furthermore, the presence of species such as *Stilbochlora eickworti*, a typically Amazonian species, and *Ariphanarthra*, characteristics from Atlantic Forest, and the endemic *E. perpulchra* suggest that the bee fauna of this portion of the biome is unique, reinforcing a heterogeneous composition. The bee communities of PEC corroborate the recognition of this biogeographic partition of biome as an important endemism center, such as indicated to other taxa (Dubeux et al. 2025, Feijó et al. 2023).

CONCLUSIONS

We emphasize the urgency to break the devastation of this region of Atlantic Forest, which is the region most likely to lose species on a regional and global scale (Silva et al. 2002). The impact of deforestation not only affects the bees and ecosystemic services provided by these insects, but also all fauna and flora that still resist these impacts. For this reason, it is essential to encourage surveys in areas with gaps, promote long-term monitoring studies and involve the local communities in the conservation of remaining natural areas. Therefore, we need that public governance drive actions to programs of restauration, solutions for the maintenance of natural areas and zero deforestation and degradation.

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SUPPLEMENTARY MATERIAL

Table S1.

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Data availability

Data will be made available upon reasonable request.

