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ORIGINAL ARTICLE

Bees (Hymenoptera: Anthophila) in an agroecosystem conducted under Agroecological bases

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Abstract

Bees provide a fundamental ecosystem service as pollinators, playing a central role in agrobiodiversity. Pollinator decline harms higher plant populations, directly impacting modern agricultural production. Bee disappearance is related to excessive changes in natural landscapes, brought about in agroecosystems via excessive floral simplification, intensive agrochemical use, and inadequate soil management. Agricultural management changes can mitigate bee population declines and promote sustainable development. Thus, inventorying potential pollinators in an agroecological area helps to provide primary data for comparing agroecosystem management schemes. Two bee collection campaigns in an agroecological field in western Brazil were conducted using complementary capture methods (passive and active) to optimize individual sampling. A total of 673 specimens, constituting 57 species, belonging to the five bee families occurring in Brazil, were collected. Within the sample, the presence of individuals sensitive to landscape changes and threatened by extinction may indicate that agroecological management sustains agrobiodiversity as it promotes greater floral diversity, involves less intensive soil management, and forbids pesticide use. Knowing this apifauna is essential for scientific research that seeks to understand this group as bioindicators of sustainability, comparing different types of management.

Keywords: Agrobiodiversity; Apifauna; Floral visitors; Neotropics; Pollination; Sustainable agroecosystems.

1. Introduction

Bees (Hymenoptera: Anthophila) comprise around 21 000 species and are distributed worldwide [1, 2]. These insects reach their highest diversity in xeric and temperate areas [1]. In addition to its high taxonomic diversity, Anthophila boasts ethological variability, expressing solitary (∼85 %) and social (∼15 %) habits. Furthermore, 13 % of the bee species are cleptoparasites/parasites [3, 4]. As for their nesting behavior, bees are classified as communal, parasocial, primitively social, semisocial, or subsocial, among others [4, 5].

Seven bee families are recognized: Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, Mellitidae, and Stenotritidae [5]. Of these, five families occur in Brazil (Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae [5, 6]), comprising about 2 000 of all valid bee species [2]. However, estimates suggest that this number is closer to at least 3 000 species [6].

Bees are essential for maintaining the balance of terrestrial ecosystems, since they are responsible for pollinating 90% of all angiosperms [7] and nearly 88% of all plant species of agricultural value [7–9]. This group stands out for providing this pivotal ecosystem service, as the vast majority of its species feed exclusively on floral resources throughout their life cycles [10]. The disappearance and decline of bee species, with the consequent drop in pollination rates, could result in plant population collapse (*i.e.*, the basal component of the food chain) [9, 11, 12], destabilizing several ecosystems and socio-economic dynamics.

Climate change, habitat loss, inadequate soil management, herbicide and pesticide use, the introduction of exotic species, the reduction of floral diversity, and the expansion of areas destined for monocultures, stand out as the main factors leading to bee population decline, undermining food security, human well-being and the modern way of life [13–16]. Proper soil management and minimal or no pesticide use stand at the core of proposed solutions to mitigate the decline of pollinator populations. Thus, maintaining pollinator diversity locally and promoting a sustainable agricultural production [17, 18].

In these studies, agricultural ecosystems, built on agroecological principles, implement a set of practices that combine sustainable production, food security, a conscious use of the soil, an increase of mixed crops areas, and the abolition of pesticide use, promoting an environment with greater floral and, therefore, bee diversity [19, 20]. Thus, high bee diversity directly and indirectly reflects economic gains (increased productivity and quality of fruits and seeds [21–24]), social gain (increased value of the food produced [25]), and environmental gain (the maintenance of biodiversity in these environments and fundamental ecosystem services [9, 11, 24]). As such, this study aimed to analyze the bee species present in an agroecosystem managed under the guidelines and principles of agroecology in an ecotone area between the Atlantic Rainforest and the semi-arid Caatinga, in the state of Bahia, providing additional information about the bee fauna of agroecosystem environments.

2. Material and methods

2.1. Study area

The Centro de Agroecologia Rio Seco - CEARIS, currently managed by Universidade Estadual de Feira de Santana - UEFS, that your former name was Estação Experimental Rio Seco, which belonged to the extinct Empresa Baiana de Desenvolvimento Agrícola - EBDA, was transferred to the UEFS in early 2016, lies along the Salvador-Feira de Santana highway (BR324) within the municipality of Amélia Rodrigues-Bahia (between coordinates 12º22’58S - 12º23’22S and 38º47’76W - 38º47’59W), and covers a rectangular area of approximately 25 hectares, entailing a transition region between the Atlantic Rainforest and Caatinga biomes. Currently, its landscape is composed of forest fragments and agricultural plots managed under agroecology guidelines. The species being grown include cassava (*Manihot esculenta*), corn (*Zea mays*), beans (*Phaseolus vulgaris*), orange (*Citrus sp.*), guava (*Psidium guajava*), acerola (*Malpighia emarginata*), pau-pombo (*Tapirira guianensis*), Aroeira-vermelha (*Schinus terebinthifolius*), and Pau Ferro (*Libidibia ferrea*) (**Fig. 1**).

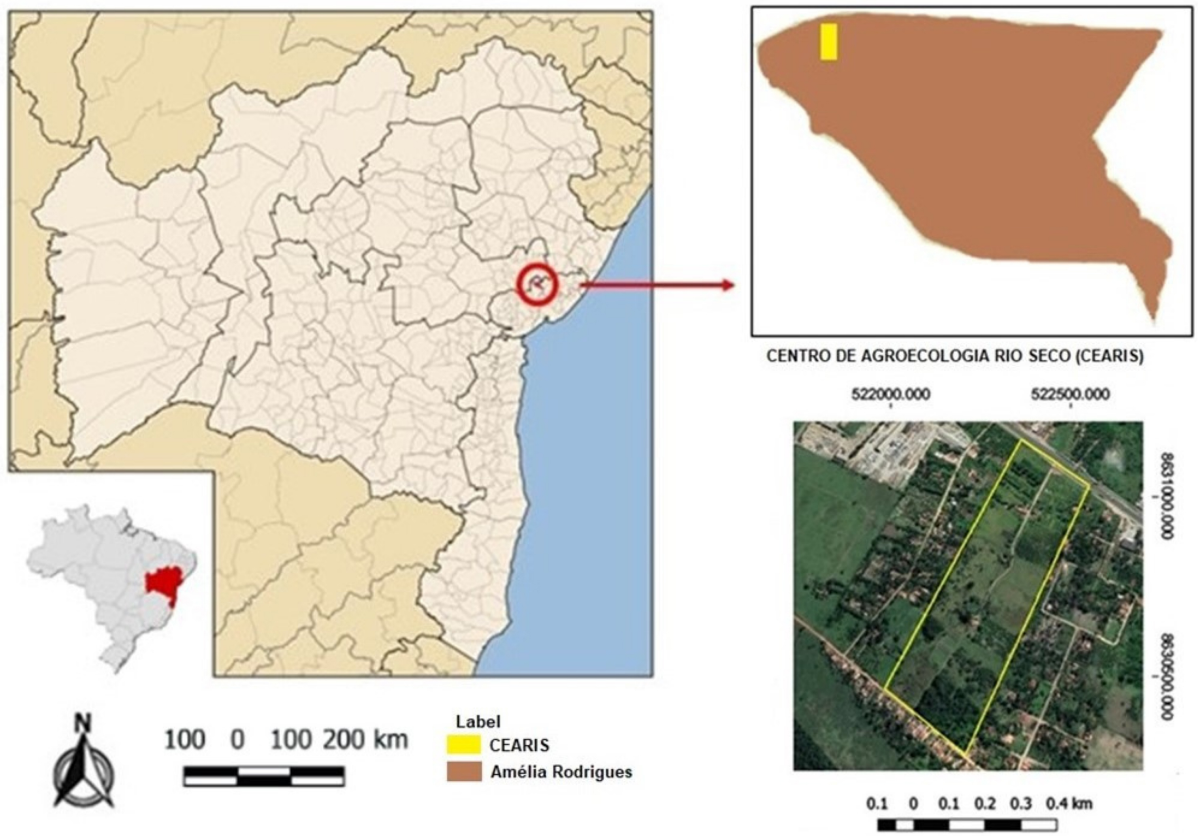

Figure 1. Map of Bahia highlighting the Municipality of Amélia Rodrigues. Perimeter in yellow: Aerial view of the Rio Reco Agroecology Center (CEARIS).

2.2. Bee sampling

Bee collections were carried out in September 2014 and 2021, preferably within areas with flowering plants (**Fig. 2**). Complementary sampling methods were employed, as suggested by [26] involving passive and active approaches. Passive collection involved placing 24 colored water traps (ARCAs or pantraps) arranged in triads of the same color, which were equally distributed in blocks exposed for 120 hours (**Fig. 3**). In parallel, 16 scent traps containing four different artificial essences (eucalyptol, vanillin, eugenol, benzyl benzoate) were set and exposed for 48 hours. Active bee collection took place between sunrise and sunset for 15 minutes every two hours for five consecutive days. In the 2021 collection, only active sampling was performed for two consecutive days.

This sampling took place under the permanent collection license 16777, within the Sistema de Autorização e Informação em Biodiversidade (SISBIO), granted by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), which is part of the Brazilian Ministry of Environment (MMA).

All collected bee specimens were stored in flasks with field labeling and subsequently mounted on entomological pins, dried in drying ovens, and labeled. Bee classification followed that proposed by [5], with minor modifications proposed by [27] (*e.g.*, tribe Oxaeini). For specimen identification at genus and species levels, specialized taxonomic keys were used [6, 28–41].

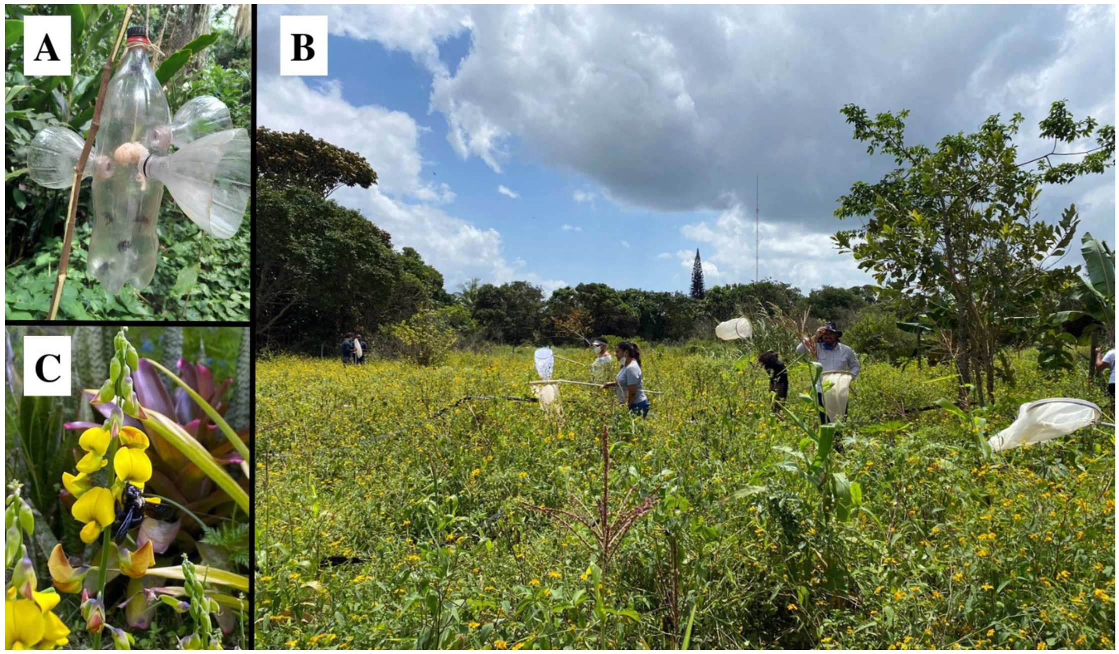

Figure 2. **A)** Odor trap (with some captured Euglossini); **B)** Team performing active collection with the aid of the entomological network; **C)** *Xylocopa* (*Megaxylocopa*) *frontalis* (Olivier, 1789) foraging a *Crotalaria* sp. in the study area.

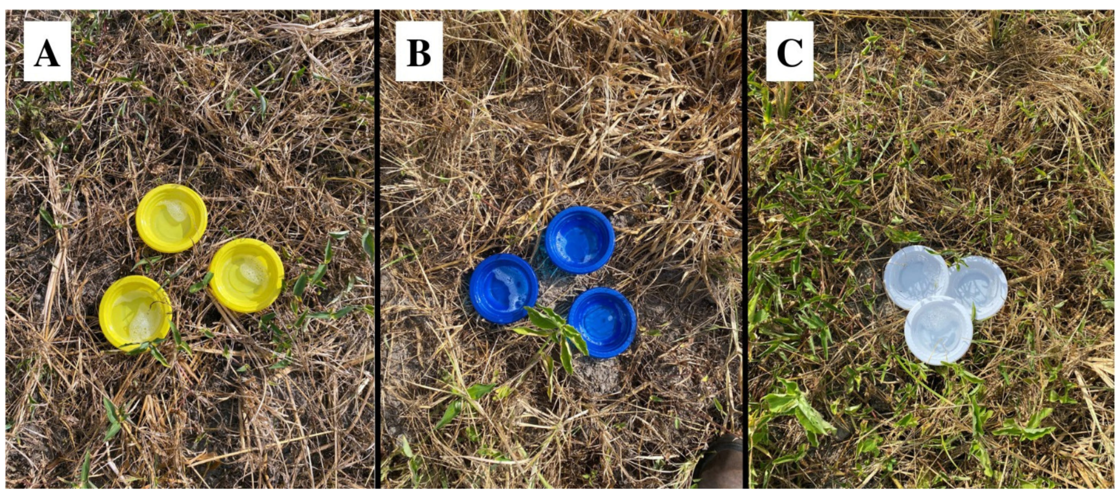

Figure 3. Set of colored water traps (ARCAs or pantraps) exposed in the field. **A)** Yellow pantraps; **B)** Blue pantraps; **C)** White pantraps.

For groups without species-level identification keys, species' original descriptions served as guides, and occasional comparisons were made with type specimen images provided by type-holding Natural History Museums. Following identification, all specimens were deposited in the Entomological Collection of the Zoology Sector of the Museu de História Natural da Bahia (MHNBA-ZOO/UFBA).

2.3. Statistical analysis

The data obtained during field collections were stored in an Excel spreadsheet database. A collector curve was built using the accumulation of species during the collection period. To determine the sample sufficiency of the community, Jackknife1 and Chao1 richness estimators were used, calculated using the Past program version 4.16c [42]. This method helped in the analysis of the efficiency of the collections.

3. Results

A total of 673 specimens were collected, with representatives from the five bee families occurring in Brazil, distributed across 31 genera, and 57 species/morphospecies (**Table 1**). The most abundant and richest family was Apidae with ten tribes (22 genera, 41 species/morphospecies, and 636 specimens), followed by Halictidae with two tribes (four genera, nine species/morphospecies, and 18 specimens), and Megachilidae with two tribes (three genera, five species/morphospecies, and 13 specimens). The families Andrenidae, with one tribe (one genus, one species, and five specimens), and Colletidae, with one tribe (one genus, one species, and one specimen), were the least represented in this sampling.

Across the total sampling time (2014 and 2021 periods), bee species richness estimation curves revealed a stabilizing trend (**Fig. 4**). The Jacknife1 estimator predicted 69 species, whereas the Chao1 estimator predicted 61 species. The collection-derived (*i.e.*, observed) bee species richness reached 82 % and 93 % of these two diversity predictor values, respectively.

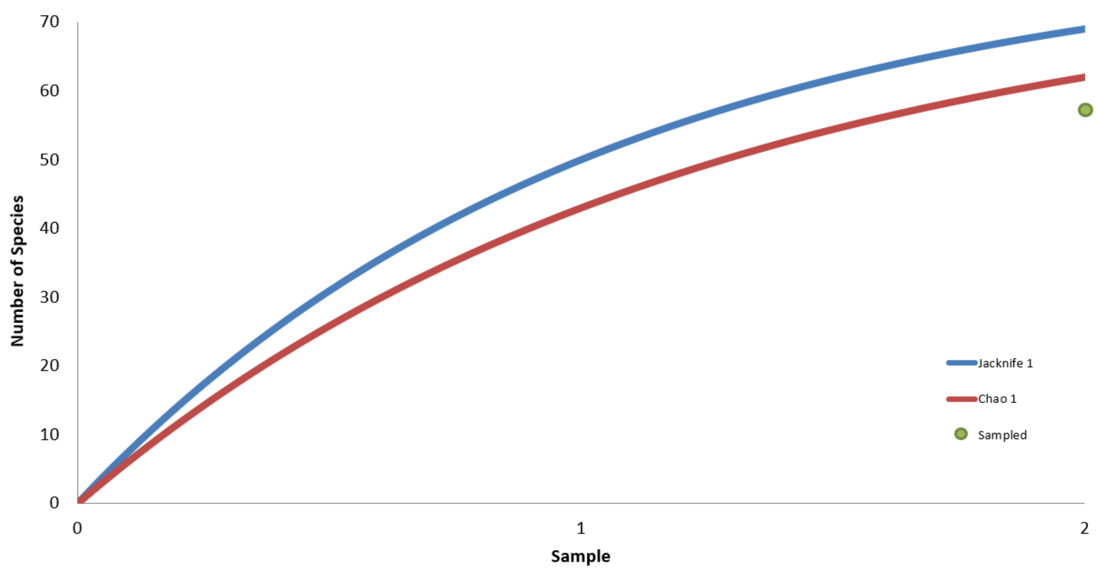

Figure 4. Bee species richness estimation curves for the sampling in Centro de Agroecologia Rio Seco (CEARIS). Sample (x-axis) corresponds to the samples collected in 2014 (1) and 2021 (2) grouped together.

Table 1. List of species/morphospecies collected in Centro de Agroecologia Rio Seco (CEARIS), Amélia Rodrigues, Bahia, Brazil.

Family	Tribe	Genus	Species/Morphospecies	N
Apidae	Apini	*Apis*	*A. mellifera* Linnaeus, 1758	53
	Bombini	*Bombus*	*B.* (*Thoracobombus*) *brevivillus* Franklin, 1913	8
	Centridini	*Centris*	*C.* (*Centris*) *aenea* Lepeletier, 1841	22
			C. (*Centris*) *caxiensis* Ducke, 1907	2
			C. (*Centris*) *decolorata* Lepeletier, 1841	4
			C. (*Centris*) *flavifrons* (Fabricius, 1775)	2
			C. (*Centris*) *nitens* Lepeletier, 1841	6
			C. (*Centris*) *spilopoda* Moure, 1969	11
			C. (*Hemisiella*) *tarsata* Smith, 1874	1
			C. (*Hemisiella*) *trigonoides* Lepeletier, 1841	5
			C. (*Trachina*) *fuscata* Lepeletier, 1841	2
	Ericrocidini	*Mesoplia*	*M. regalis* (Smith, 1854)	3
	Eucerini	*Florilegus*	*F.* (*Euflorilegus*) *similis* Urban, 1970	5
		Gaesischia	*Gaesischia* sp. 1	1
		Thygater	*T.* (*Thygater*) *analis* (Lepeletier, 1841)	2
	Euglossini	*Euglossa*	*Eg.* (*Euglossa*) *aratingae* Nemésio, 2009	17
			Eg. (*Euglossa*) *carolina* Nemésio, 2009	211
			Eg. (*Euglossa*) *securigera* Dressler, 1982	9
		Eulaema	*El.* (*Apeulaema*) *nigrita* Lepeletier, 1841	115
			El. (*Eulaema*) *atleticana* Nemésio, 2009	27
			El. (*Eulaema*) *niveofasciata* (Friese, 1899)	1
	Exomalopsini	*Exomalopsis*	*E.* (*Exomalopsis*) *auropilosa* Spinola, 1853	1
			E. (*Exomalopsis*) *fulvofasciata* Smith, 1879	1
	Meliponini	*Frieseomelitta*	*F. doederleini* Friese, 1900	1
		Geotrigona	*G.* (*Geotrigona*) *mombuca* (Smith, 1863)	2
		Melipona	*M.* (*Michmelia*) *scutellaris* Latreille, 1811	5
		Nannotrigona	*N. testaceicornis* (Lepeletier, 1836)	9
		Oxytrigona	*O. cagafogo* (Müller, 1874)	2
		Paratrigona	*Pr. incerta* Camargo & Moure, 1994	2
		Partamona	*Pt. helleri* (Friese, 1900)	1
		Scaptotrigona	*S.* (*Baryorygma*) *bipunctata* (Lepeletier, 1836)	1
			S. (*Scaptotrigona*) *xanthotricha* Moure, 1950	4
		Tetragonisca	*Te. angustula* (Latreille, 1811)	8
		Trigona	*Tr.* (*Trigona*) *spinipes* (Fabricius, 1793)	12
			Trigona sp. 1	29
	Tapinotaspidini	*Tapinotaspoides*	*T. rufescens* (Friese, 1899)	3
	Xylocopini	*Xylocopa*	*X.* (*Neoxylocopa*) *grisescens* Lepeletier, 1841	1
			X. (*Neoxylocopa*) *suspecta* Moure & Camargo, 1988	3
			X. (*Neoxylocopa*) *cearensis* Ducke, 1910	7
			X. (*Megaxylocopa*) *frontalis* (Olivier, 1789)	12
			X. (*Schonnherria*) *subcyanea* Pérez, 1901	25
Halictidae	Augochlorini	*Augochlora*	*A.* (*Augochlora*) *braziliensis* (Vachal, 1911)	2
			Augochlora sp. 1	1
			Augochlora sp. 2	2
			Augochlora sp. 3	1
		Augochlorella	*Augochlorella* sp. 1	2
		Pseudaugochlora	*P. pandora* (Smith, 1853)	2
			P. graminea (Fabricius, 1804)	1
	Halictini	*Dialictus*	*D. opacus* (Moure, 1940)	5
			Dialictus sp. 1	2
Megachilidae	Anthidiini	*Larocanthidium*	*L. emarginatum* Urban, 1997	6
		Hypanthidium	*H.* aff. *beniense* Cockerell, 1927	1
	Megachilini	*Megachile*	*M.* (*Pseudocentron*) sp. 1	1
			M. (*Pseudocentron*) sp. 2	4
			M. (*Acentron*) sp. 1	1
Andrenidae	Oxaeini	*Oxaea*	*O. flavescens* Klug, 1807	5
Colletidae	Colletini	*Colletes*	*C. rufipes* Smith, 1879	1
TOTAL				**673**

4. Discussion

Members of the *Euglossini* tribe (56 % of the individuals collected) predominated in this collection. The species *Euglossa carolina* Nemésio, 2009 (211 specimens) and *Eulaema nigrita* Lepeletier, 1841 (115 specimens) were the leading *Euglossini* in this collection. Such predominance is primarily associated with the effective use of a passive trap with an attractant [35], as the pheromone used in the collection lure is a potent attractant for two species, successfully triggering their ability to travel long distances when this tapping method is used [26, 35].

The presence of generalist species, such as *Apis mellifera* Linnaeus, 1758 (53 specimens) and *Trigona spinipes* (Fabricius, 1793) (29 specimens), highlights their high adaptability to anthropogenic environments and their ability to nest in exposed locations—particularly in the case of the Africanized honeybee. According to [43], the generalist behavior of these species favors the pollination of both cultivated and wild plants, positively impacting overall biodiversity and agricultural productivity. However, their dominance may have counteractive effects on more sensitive and specialized plant species, potentially disrupting ecological interactions and the stability of given ecosystems [44].

The identification of a nest of *Paratrigona incerta* Camargo & Moure, 1994 (**Fig. 5** A-B) and the presence of *Geotrigona mombuca* (Smith, 1863) (Fig. 5 C-D) and several *Centris* spp. individuals (*e.g.*, Fig. 5 E-F) in this sampling at CEARIS demonstrate that the landscape of this agroecosystem is more favorable to sensitive bee groups. CEARIS experiences a reduced use of heavy machinery, less intensive mechanical soil management, and the prohibition of pesticide use, all of which may contribute to the reestablishment of such bee species, given that the soil is not constantly compacted and much of the spontaneous herbaceous flora acts as companion plants to crops.

Another indication that agroecological farming areas are significantly more favorable to pollinators than conventional agricultural areas is the fact that *Melipona* (*Michmelia*) *scutellaris* Latreille, 1811 (**Fig. 6** A-B) was sampled in the study area. This species is of high environmental and socio-economic importance and is highly sensitive to environmental changes—especially deforestation. *M. scutellaris* is currently listed on the national Red List of threatened fauna (as EN – Endangered) (MMA ORDINANCE No. 148, JUNE 7, 2022), and on the red list of the state of Bahia, it appears as VU – Vulnerable (SEMA ORDINANCE No. 37, AUGUST 15, 2017).

Regarding the ecotone area, *Tapinotaspoides rufescens* (Friese, 1899) (Fig. 6 C-D) commonly occurs in Caatinga regions. The presence of many species with low sampling frequencies may indicate that the floral diversity and vegetation cover at CEARIS support a high richness of floral visitors, given the ample variety of pollen and nectar sources, benefiting a larger number of bee species.

Thus, the use of complementary collection methods in floral visitor sampling increases sampling efficiency by allowing for the recording of a broader diversity of groups. Another relevant aspect is that integrating agricultural areas and natural remnants, managing them in more conscious and less impactful manners [45, 46], benefits both generalist bee species, such as *Apis mellifera* and *Trigona spinipes*, and specialists such as *Melipona scutellaris*. Ultimately, ecosystems with greater structural complexity contribute to the maintenance of ecological functionality and resilience, making them more capable of withstanding environmental pressures [47, 48].

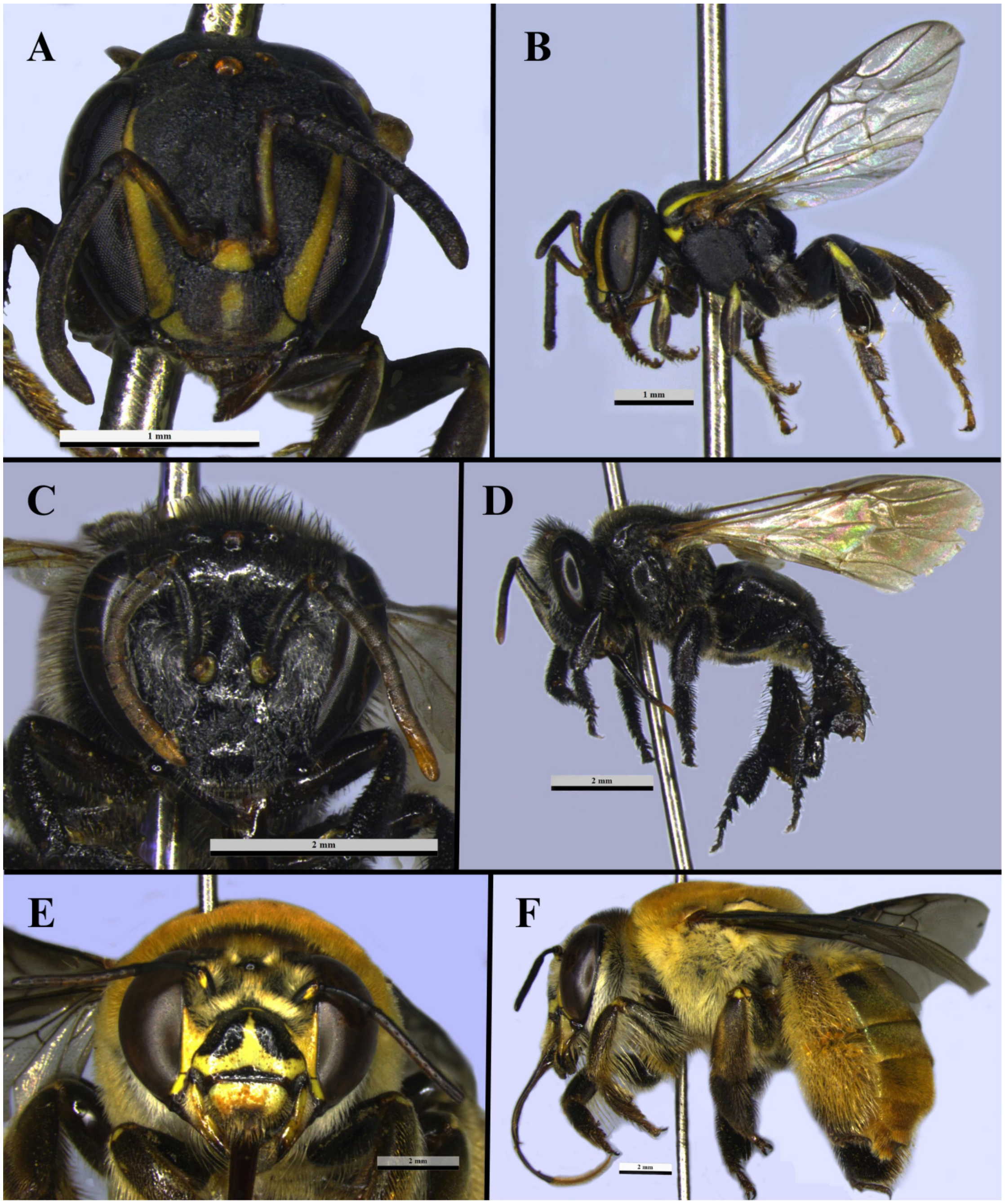

Figure 5. A, C, E: Collected bee's head frontal views; **B, D, F**: Habitus lateral. Species: A and B) *Paratrigona incerta* Camargo & Moure, 1994; **C** and **D**) *Geotrigona mombuca* (Smith, 1863); **E** and **F**) *Centris* (*Centris*) *aenea* Lepeletier, 1841.

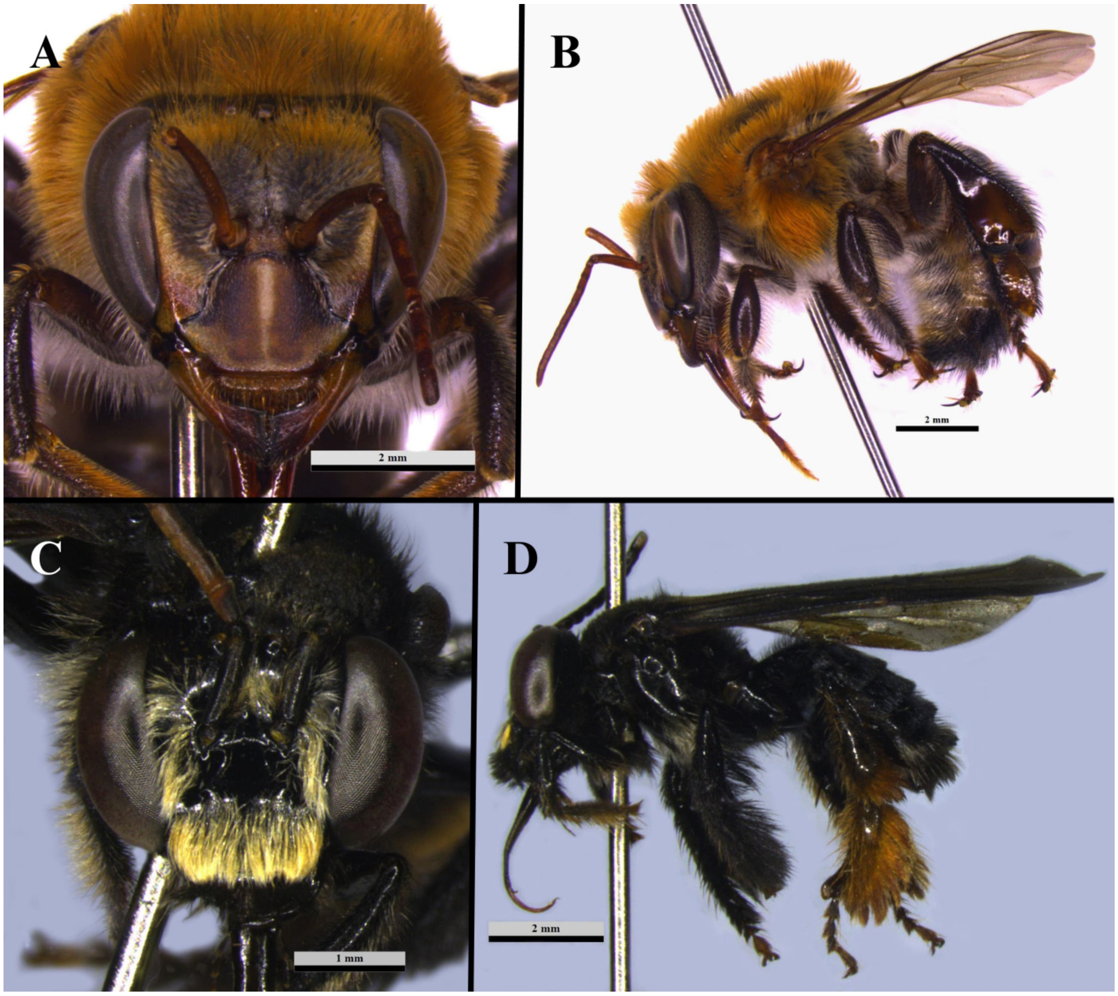

Figure 6. **A, C**: Collected bee's head frontal views; **B, D**: Habitus lateral. Species: **A** and **B**) *Melipona* (*Michmelia*) *scutellaris* Latreille, 1811; **C** and **D**) *Tapinotaspoides rufescens* (Friese, 1899).

5. Conclusions

A priori knowledge of the apifauna of an agroecological agroecosystem can aid future studies that use these groups as bioindicators of agricultural environments. This information is central to assessing the degree of conservation, resilience, and the capacities for environmental recovery and reestablishment of functional agrobiodiversity brought about by bee services in ecosystems.

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7. Conflict of interest

The authors declare no conflicts of interest.

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Abejas (Hymenoptera: Anthophila) en un agroecosistema manejado con bases agroecológicas

Resumen: Las abejas prestan un servicio ecosistémico fundamental como polinizadoras, desempeñando un papel central en la agrobiodiversidad. La disminución de los polinizadores afecta a las poblaciones de plantas superiores, impactando de manera directa la producción agrícola moderna. El declive de las abejas está vinculado a cambios drásticos en los paisajes naturales, originados en los agroecosistemas por la simplificación floral, el uso intensivo de agroquímicos y el manejo inadecuado del suelo. Los cambios en el manejo agrícola pueden mitigar la reducción de las poblaciones de abejas y promover el desarrollo sostenible. Por lo tanto, realizar inventarios de potenciales polinizadores en un área agroecológica permite generar datos primarios para comparar diferentes esquemas de manejo agroecosistémico. Se llevaron a cabo dos campañas de recolección de abejas en un campo agroecológico del occidente de Brasil. Las campañas emplearon métodos complementarios de captura (pasivos y activos) para optimizar el muestreo de individuos. En total se recolectaron 673 especímenes, correspondientes a 57 especies pertenecientes a las cinco familias de abejas presentes en Brasil. La presencia de individuos sensibles a los cambios en el paisaje y amenazados de extinción dentro de la muestra puede indicar que el manejo agroecológico favorece la agrobiodiversidad al promover una mayor diversidad floral, un manejo del suelo menos intensivo y la ausencia de pesticidas. Conocer la apifauna es esencial para la investigación científica que busca comprender a este grupo como bioindicador de sostenibilidad, comparando distintos tipos de manejo.

Palabras Clave: Agrobiodiversidad; Agroecosistemas sostenibles; Apifauna; Neotrópico; Polinización; Visitantes florales.

Abelhas (Hymenoptera: Anthophila) em um agroecossistema conduzido sob bases agroecológicas

Resumo: As abelhas prestam um serviço ecossistêmico fundamental como polinizadoras, desempenhando um papel central na agrobiodiversidade. A redução dos polinizadores afeta as populações de plantas superiores, impactando diretamente a produção agrícola moderna. O declínio das populações de abelhas está associado a transformações intensas nas paisagens naturais, provocadas nos agroecossistemas pela simplificação floral, pelo uso intensivo de agroquímicos e pelo manejo inadequado do solo. Alterações nas práticas agrícolas podem mitigar a redução das populações de abelhas e promover o desenvolvimento sustentável. Portanto, realizar inventários de potenciais polinizadores em uma área agroecológica permite gerar dados primários para comparar diferentes esquemas de manejo agroecossistêmico. Foram realizadas duas campanhas de coleta de abelhas em um campo agroecológico no oeste do Brasil. As campanhas utilizaram métodos complementares de captura (passivos e ativos) para otimizar a amostragem de indivíduos. No total, foram coletados 673 espécimes, correspondentes a 57 espécies pertencentes às cinco famílias de abelhas presentes no Brasil. A presença de indivíduos sensíveis às mudanças na paisagem e ameaçados de extinção dentro da amostra pode indicar que o manejo agroecológico favorece a agrobiodiversidade ao promover maior diversidade floral, manejo menos intensivo do solo e ausência de pesticidas. Conhecer a apifauna é essencial para a pesquisa científica que busca compreender esse grupo como bioindicador de sustentabilidade, comparando diferentes tipos de manejo.

Palavras-chave: Agrobiodiversidade; Agroecossistemas sustentáveis; Apifauna; Neotrópico; Polinização; Visitantes florais.

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