Research Article

Richness of Wild Bees (Hymenoptera: Apidae) in a Forest Remnant in a Transition Region of Eastern Amazonia

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Eastern Amazonia is an area with great biological diversity that has suffered rapid deforestation and forest fragmentation over the years. Because of the scarcity of data on the fauna and flora, the northwest of the state of Maranhão has become a priority area for studies that seek to gain a better understanding of bee fauna. Between August 2013 and December 2014, in collections at two-month intervals, a total of 1047 bees belonging to 70 species were collected using two methods (an insect net and scent-baited traps). Apinae was the most abundant subfamily and had the greatest species richness (63 species and 1039 individuals); the most notable tribes in this subfamily were Meliponini (20 species and 445 individuals) and Euglossini (24 species and 452 individuals). In all, 62.8% of the total richness was sampled with an insect net and 34.2% with bait traps. Bees were present in every collection month, and August and December were the months with the greatest richness and abundance, respectively. Although the species accumulation curve did not stabilize, the results were positive as three new species were recorded for the Maranhão state: *Bombus transversalis* (Olivier, 1789); *Xylocopa suspecta* Moure and Camargo, 1988; and *Xylocopa macrops* Lepeletier, 1841, and eleven for the Amazonian region of the state.

1. Introduction

Bees are insects that have a very close relationship with plant species and are undoubtedly the most important pollinators in the majority of biomes where angiosperms are found. They are noteworthy for their species diversity and varied size and behavior [1].

There are estimated to be more than 4,000 genera and around 25,000 species of bees distributed in different regions of the world [2]. Apoidea is currently organized in nine subfamilies, of which five are found in Brazil: Andreninae, Apinae, Colletinae, Halictinae, and Megachilinae [3].

Moure et al. [4] estimated that there are 640 bee species in the state of Maranhão although only 153 recognized species (23%) are registered in biological collections [5]. This estimate is based primarily on systematic studies that have

been carried out in different ecosystems in the state, including flooded fields (Baixada Maranhense) [6], *Cerrado* (savanna-like grasslands) [7–13], open rainforest [14, 15], dense rainforest [16], and *restinga* (sandy coastal strips and their characteristic vegetation) [17–20].

The Amazonian region of the state of Maranhão, in the west of the state, has suffered severe environmental impacts over the years that have adversely affected its ecosystem functions and led to a consequent reduction in biological diversity [21]. Currently, less than 25% of the original vegetation is left [22]. Soares Filho [23] estimated that 97% of the forest remnants would be lost in the coming 50 years, leading to the complete elimination of the ecological functionality of the region.

Although it has suffered considerable deforestation and forest fragmentation, the Amazonian region of the state of

Maranhão still has enormous biological richness and aquatic and terrestrial physiognomic habitat types [24, 25]. Nevertheless, the pollinator fauna in the region remains largely unknown [26].

In this context, the speed with which negative impacts are being exerted on natural systems in the Amazonian region of the state of Maranhão and the lack of data on the fauna and flora in the region make this a priority area for studies that seek to gain a better understanding of the bee community in the region [27, 28].

One approach that can be adopted for this type of study is a structured inventory. In this type of inventory, periodic samples are taken and used for a variety of analyses of community composition [29, 30]. Taxonomic identification of bees and identification of their diversity patterns constitute the first steps in the definition of strategies for rational exploitation and conservation of the resources needed by these pollinators [31, 32].

In light of the above, the present study sought to analyze the composition of bee fauna in an area of the Amazon forest with the aid of the diversity metrics richness, abundance, and relative frequency.

2. Materials and Methods

2.1. Study Area. The study was carried out in easternmost Amazonia on private property extending over 120 ha (Prata Farm, 1°15′0.94″S 46°0′39.94″W) in the municipality of Carutapera in the far northwest of the state of Maranhão (Figure 1).

The predominant local vegetation is dense alluvial rainforest, according to the classification of Veloso et al. [33], with forest formations such as mangroves and alluvial communities (riparian forest) along water courses as well as vines and palm trees on the plains.

Prata Farm is at a low altitude and does not have any steep slopes. The highest points on the farm are around 20 m above the sea level. The climate is a tropical monsoon climate and is characterized by temperatures that vary little throughout the year [34]. There are two well-defined seasons: the dry season, from July to December, and the rainy season, from January to June. Mean annual temperature and mean annual rainfall are 26.6°C and 2100 mm, respectively [35].

The study area is part of the western northeast Atlantic Basin (Gurupi subbasin) and has two permanent water bodies: the Xavier river and the source of the Prata river. It lies within a 15 ha, predominantly closed, native forest fragment considered part of the nonimpacted forest in the region [25], which has undergone widespread deforestation and fragmentation as a result of agricultural and livestock-farming activities.

Collections were performed between August 2013 and December 2014 at two-month intervals, giving a total of eight collections. Two methods were used: active searches with an insect net and scent-baited traps.

2.2. Insect Net. An insect net was used to perform active searches for bees, mainly when they were visiting flowers but also when they were at rest, in flight, or attracted by perspiration [36]. This collection method was used mainly in open areas, where the vegetation consists primarily of bushes, as trees inside the forest fragments are very tall, and most of the flowers are only exposed in the canopy, making them very difficult to reach [37]. Sampling effort with the insect net was 18 h per collection, from 8 AM to 5 PM over two consecutive days, or a total of 144 h.

2.3. Scent-Baited Traps. For the scent-bait method, traps were made from PET (polyethylene terephthalate) bottles, as proposed by Ramalho et al. [38]. Each trap had three entrances, where bees could get access to methyl cinnamate, eugenol, and eucalyptol, scents widely used in studies on Euglossini bee communities [39, 40]. The scent was placed in small wads of cotton, which were then put inside the traps (one per trap), and the traps were replenished every hour with two drops of the respective essence. The traps were left in the closed forest approximately 8 m from each other and 1.5 m above the ground from 8 AM to 5 PM on two consecutive days, giving a sampling effort of 18 h per trap per collection, or a total of 432 h.

The bees collected were sacrificed and then transferred to individual paper bags identified with the time, date, collection method, and georeference. Specimens were mounted in the Bee Studies Laboratory (LEA) and deposited in the laboratory collection (LEACOL) at the Federal University of Maranhão (UFMA) for subsequent species-level identification.

2.4. Data Analysis. Bee community patterns were characterized with the Shannon–Wiener (H') and Simpson (D) diversity indices. Equitability was characterized with the Pielou index (J'). The calculations for these analyses were performed with vegan [41] in R version 3.5.0 [42].

The Whittaker abundance distribution model (rank-abundance curve) was used to analyze species evenness visually [43].

Occurrence frequency (OF) and dominance (DM) were calculated according to Palma [44], where OF = the number of samples containing species i/the number of samples ×100. If OF ≥50%, the species is considered very frequent (VF); if 25% > OF < 50%, it is considered frequent (F); and if OF ≤ 25%, it is considered infrequent (IF). Dominance was calculated as DM = abundance of species i/overall abundance ×100, where DM >5% corresponds to a dominant species (D), 2.5% > DM ≤ 5% to an accessory species (A), and DM ≤ 2.5% to an occasional species (OC).

According to Buschini [45] and Aguiar and Gaglianone [46], OF and DM can be used together to classify a species into one of three categories: common (very frequent or frequent + dominant), rare (infrequent + occasional), and intermediate (other combinations).

To determine sampling sufficiency, a species accumulation curve was plotted (collector's curve) with EstimateS version 8.2.0 [47]. Nonparametric richness estimators were calculated based on 1000 permutations to determine whether the sampling effort was sufficient to reach the total number of species in the community. The chosen estimators were Chao 1 and jackknife 1 as the former is based on the
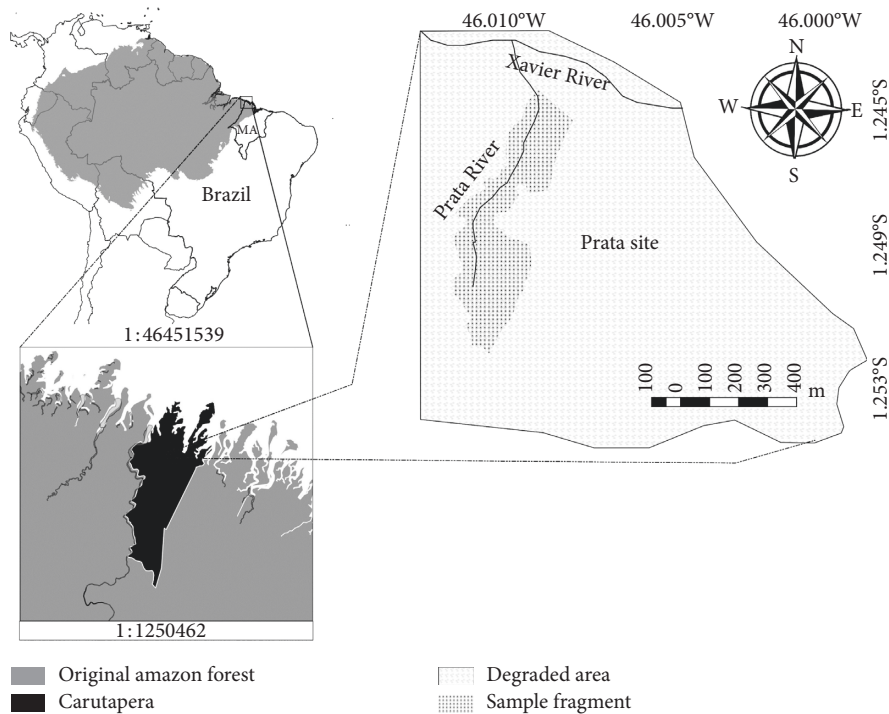
FIGURE 1: Geographic location of the study area in the municipality of Carutapera, Maranhão, Brazil.

abundance of the sampled species, while the latter considers the number of rare species [43].

Spearman's correlation was used to determine whether there was a correlation between rainy/dry periods and the number of species collected in the samples. The results of this test vary between +1 and −1. The analysis was performed with ISwR [48] in R version 3.5.0 [42].

Climate data were collected from the National Meteorology Institute (INMET) online database for World Meteorological Organization station no. 82198 (Turiaçu, MA), which is approximately 85 km from the study area and therefore the closest station.

3. Results

A total of 1047 individuals from 70 species in 35 genera, 15 tribes, and 3 subfamilies were collected (Table 1). The subfamilies with the greatest abundance and richness were, in decreasing order, Apinae (1039 individuals, 63 species), Halictinae (6 individuals, 5 species), and Megachilinae (2 individuals, 2 species). In the distribution by tribe, Euglossini stood out, with 34.2% of the species, and was followed by Meliponini (28.5%), Augochlorini and Xylocopini (7.14%), and Centridini (5.71%). The remaining tribes were represented by only one or two species.

The genera with the greatest number of species were *Euglossa* (17 species, or 24.2%), *Trigona* and *Xylocopa* (5 species each, or 7.14%), and *Eulaema* (4 species, or 5.71%). In terms of abundance, the following genera were noteworthy: *Trigona* (329 individuals, or 31.4%), *Euglossa* (321 individuals, or 30.6%), *Eulaema* (115 individuals, or 10.9%), *Apis* (71 individuals, or 6.78%), *Melipona* (65 individuals, or 6.2%), and *Bombus* and *Tetragona* (32 individuals, or 3.05%

each). A list of the species showing their abundance and frequency is given in Table 1.

3.1. Captures with an Insect Net. When the insect net was used, a total of 590 individuals from 15 tribes, 31 genera, and 47 species were collected (Table 1). Of these species, 44 were collected exclusively with this method and accounted for 62.8% of the community richness.

Subfamilies Halictinae and Megachilinae were also collected exclusively when this method was used and accounted for 10% of total richness but only 0.7% of total abundance. In Apinae, all the tribes apart from Euglossini (i.e., Apini, Bombini, Centridini, Emphorini, Eucerini, Exomalopsini, Meliponini, Tapinotaspidini, Tetrapedini, and Xylocopini) were mostly captured with a net.

In the tribe Meliponini, 20 species were identified, all collected exclusively with a net (Table 1). Of these, the most represented were *Trigona branneri* Cockerell, 1912 ($n = 237$), *Trigona pallens* (Fabricius, 1798) ($n = 49$), *Melipona fasciculata* Smith, 1854 ($n = 40$), *Melipona* gr. *rufiventris* sp. ($n = 25$), *Trigona lacteipennis* Friese, 1900 ($n = 25$), *Trigona fulviventris* Guérin, 1844 ($n = 16$), and *Tetragona clavipes* (Fabricius, 1804) ($n = 16$).

3.2. Captures with Scent-Baited Traps. When scent baits were used, a total of 451 specimens of Euglossini corresponding to 24 species in five genera were collected (Table 1): *Euglossa* (17 species), *Eulaema* (4 species), *Eufriesea* (1 species), *Exaerete* (1 species), and *Aglae* (1 species). These accounted for 43.1% of the abundance and 34.2% of the richness of the bees sampled.

The most represented species was *Euglossa cordata* (Linnaeus, 1758) ($n = 88$), followed by *Eulaema cingulata* (Fabricius,

Table 1: Bee species recorded in Carutapera (MA).

Subfamily/tribe/species	No. of individuals per collection method				Total	Classes		
			Bait traps					
	N	EU	EG	CM	n (%)	DM	OF	SC
Apinae								
Apini								
Apis mellifera Linnaeus, 1758	71				71 (6.78)	D	MF	C
Bombini								
Bombus (*Fervidobombus*) *brevivillus* Franklin, 1913	22	3		2	27 (2.58)	A	MF	I
Bombus (*Fervidobombus*) *transversalis* (Olivier, 1789)	5				5 (0.48)	OC	PF	R
Centridini								
Centris (*Hemisiella*) *trigonoides* Lepeletier, 1841	2				2 (0.19)	OC	F	I
Centris (*Trachina*) aff. *fuscata* Lepeletier, 1841	7				7 (0.67)	OC	F	I
Centris (*Trachina*) *longimana* Fabricius, 1804	1				1 (0.10)	OC	PF	R
Epicharis sp.	1				1 (0.10)	OC	PF	R
Emphorini								
Diadasina sp.	3				3 (0.29)	OC	F	I
Melitoma segmentaria (Fabricius, 1804)	1				1 (0.10)	OC	PF	R
Eucerini								
Florilegus (*Florilegus*) sp.	1				1 (0.10)	OC	PF	R
Euglossini								
Aglae caerulea Lepeletier and Serville, 1825				1	1 (0.10)	OC	PF	R
Eufriesea surinamensis (Linnaeus, 1758)		3			3 (0.29)	OC	PF	R
Euglossa (*Euglossa*) *amazonica* Dressler, 1982		11	5	1	17 (1.62)	OC	MF	I
Euglossa (*Euglossa*) *cordata* (Linnaeus, 1758)	1	56	10	21	88 (8.40)	D	MF	C
Euglossa (*Euglossa*) *despecta* Moure, 1968		14	3		17 (1.62)	OC	MF	I
Euglossa (*Euglossa*) *hemichlora* Cockerell, 1917		2	1		3 (0.29)	OC	F	I
Euglossa (*Euglossa*) *liopoda* Dressler, 1982		1			1 (0.10)	OC	PF	R
Euglossa (*Euglossa*) *modestior* Dressler, 1982		30	4	6	40 (3.82)	A	MF	I
Euglossa (*Euglossa*) *platymera* Dressler, 1982		1			1 (0.10)	OC	PF	R
Euglossa (*Euglossa*) *securigera* Dressler, 1982		8	2	1	11 (1.05)	OC	MF	I
Euglossa (*Euglossa*) *townsendi* Cockerell, 1904		1			1 (0.10)	OC	PF	R
Euglossa (*Euglossa*) *truncata* Rebêlo and Moure, 1996		3			3 (0.29)	OC	F	I
Euglossa (*Euglossella*) *viridis* (Perty, 1833)		1			1 (0.10)	OC	PF	R
Euglossa (*Glossura*) *chalybeata* Friese, 1925		1			1 (0.10)	OC	PF	R
Euglossa (*Glossura*) *ignita* Smith, 1874		45	1	8	54 (5.16)	D	MF	C
Euglossa (*Glossura*) *piliventris* Guérin, 1844		2	1	25	28 (2.67)	A	MF	I
Euglossa (*Glossurella*) *augaspis* Dressler, 1982				1	1 (0.10)	OC	PF	R
Euglossa (*Glossurella*) *bursigera* Moure, 1970		1			1 (0.10)	OC	PF	R
Euglossa (*Glossuropoda*) *intersecta* Latreille, 1817		53			53 (5.06)	D	MF	C
Eulaema (*Apeulaema*) *cingulata* (Fabricius, 1804)			71	1	72 (6.88)	D	MF	C
Eulaema (*Apeulaema*) *nigrita* Lepeletier, 1841		34			34 (3.25)	A	MF	I
Eulaema (*Eulaema*) *bombiformis* (Packard, 1869)				4	4 (0.38)	OC	MF	I
Eulaema (*Eulaema*) *meriana* (Olivier, 1789)		4	1		5 (0.48)	OC	F	I
Exaerete smaragdina (Guérin, 1844)		8	4		12 (1.15)	OC	MF	I
Exomalopsini								
Exomalopsis (*Exomalopsis*) *analis* Spinola, 1853	2				2 (0.19)	OC	PF	R
Meliponini								
Aparatrigona impunctata (Ducke, 1916)	3				3 (0.29)	OC	F	I
Frieseomelitta flavicornis (Fabricius, 1798)	1				1 (0.10)	OC	PF	R
Lestrimelitta limao (Smith, 1863)	3				3 (0.29)	OC	PF	R
Melipona (*Melikerria*) *fasciculata* Smith, 1854	40				40 (3.82)	A	F	I
Melipona (*Michmelia*) gr. *rufiventris* sp.	25				25 (2.39)	OC	F	I
Nannotrigona punctata (Smith, 1854)	1				1 (0.10)	OC	PF	R
Oxytrigona ignis Camargo, 1984	2				2 (0.19)	OC	PF	R
Partamona (*Partamona*) *ailyae* Camargo, 1980	1				1 (0.10)	OC	PF	R
Partamona chapadicola Pedro and Camargo, 2003	4				4 (0.38)	OC	PF	R
Plebeia sp.	2				2 (0.19)	OC	PF	R
Scaura latitarsis (Friese, 1900)	1				1 (0.10)	OC	PF	R

TABLE 1: Continued.

Subfamily/tribe/species	No. of individuals per collection method				Total	Classes		
	N	Bait traps			n (%)	DM	OF	SC
		EU	EG	CM				
Tetragona clavipes (Fabricius, 1804)	16				16 (1.53)	OC	F	I
Tetragona dorsalis (Smith, 1854)	14				14 (1.34)	OC	PF	R
Tetragona sp.	2				2 (0.19)	OC	PF	R
Trigona branneri Cockerell, 1912	237				237 (22.64)	D	MF	C
Trigona fulviventris Guérin, 1844	16				16 (1.53)	OC	F	I
Trigona lacteipennis Friese, 1900	25				25 (2.39)	OC	PF	R
Trigona pallens (Fabricius, 1798)	49				49 (4.68)	A	PF	I
Trigona spinipes (Fabricius, 1793)	2				2 (0.19)	OC	F	I
Trigonisca meridionalis Albuquerque and Camargo, 2007	1				1 (0.10)	OC	PF	R
Nomadini								
Thalestria spinosa (Fabricius, 1804)	2				2 (0.19)	OC	PF	R
Tapinotaspidini								
Paratetrapedia leucostoma (Cockerell, 1923)	1				1 (0.10)	OC	PF	R
Tetrapedini								
Tetrapedia diversipes Klug, 1810	2				2 (0.19)	OC	PF	R
Xylocopini	1				1 (0.10)	OC	PF	R
Xylocopa (*Neoxylocopa*) *aurulenta* (Fabricius, 1804)								
Xylocopa (*Neoxylocopa*) *frontalis* (Olivier, 1789)	7				7 (0.67)	OC	F	I
Xylocopa (*Neoxylocopa*) *suspecta* Moure and Camargo, 1988	3				3 (0.29)	OC	PF	R
Xylocopa (*Schonnherria*) *macrops* Lepeletier, 1841	1				1 (0.10)	OC	PF	R
Xylocopa (*Schonnherria*) *muscaria* (Fabricius, 1775)	3	1			4 (0.38)	OC	PF	R
Halictinae								
Augochlorini								
Auglochora sp.	1				1 (0.10)	OC	PF	R
Augochlorella sp.	2				2 (0.19)	OC	F	R
Augochloropsis sp. 1	1				1 (0.10)	OC	PF	R
Augochloropsis sp. 2	1				1 (0.10)	OC	PF	R
Pseudaugochlora pandora Smith, 1853	1				1 (0.10)	OC	PF	R
Megachilinae								
Anthidini								
Hypanthidium maranhense Urban, 1998	1				1 (0.10)	OC	PF	R
Megachilini								
Megachile sp.	1				1 (0.10)	OC	PF	R
Total	590	283	103	71	1047			

N = insect net; scent-baited traps: EU = eucalyptol, EG = eugenol, and MC = methyl cinnamate; n (%) = total (relative) abundance; DM = dominance (D = dominant, A = accessory, and OC = occasional); OF = occurrence frequency (VF = very frequent, F = frequent, and IF = infrequent); SC = species classification (C = common, I = intermediate, and R = rare).

1804) ($n = 72$), *Euglossa ignita* Smith, 1874 ($n = 54$), *Euglossa intersecta* Latreille, 1817 ($n = 53$), *Euglossa modestior* Dressler, 1982 ($n = 40$), *Eulaema nigrita* Lepeletier, 1841 ($n = 34$), and *Euglossa piliventris* Guérin, 1844 ($n = 28$).

The most attractive bait was eucalyptol, and traps with this scent accounted for 283 individuals from 22 species. The species most attracted to this scent was *E. cordata* and *E. intersecta* (males), *E. nigrita*, *Eufriesea surinamensis* (Linnaeus, 1758), *Euglossa truncata* Rebêlo and Moure, 1996, *Euglossa liopoda* Dressler, 1982, *Euglossa chalybeata* Friese, 1925, and other five species were attracted exclusively by this substance and accounted for 14.2% of the sampled richness in the study location.

Eugenol was the second most attractive substance and accounted for 103 individuals from 11 species (15.7% of the

richness). It was the most attractive scent for *E. cingulata* and no exclusive species in the sample. Methyl cinnamate attracted 71 individuals from 11 species and was the only scent that attracted *Aglae caerulea* Lepeletier and Serville, 1825, *Euglossa augaspis* Dressler, 1982, and *Eulaema bombiformis* (Packard, 1869) (4.3% of the richness).

Euglossa amazonica Dressler, 1982, *E. cordata*, *E. modestior*, *Euglossa securigera* Dressler, 1982, *E. ignita,* and *E. piliventris* were attracted by all three scents.

3.3. Community Fluctuation. The month with the greatest bee richness was August 2014, at the end of the rainy season (30 species) (Figure 2). Although December 2013 and December 2014 had the greatest bee abundance (187 and 176
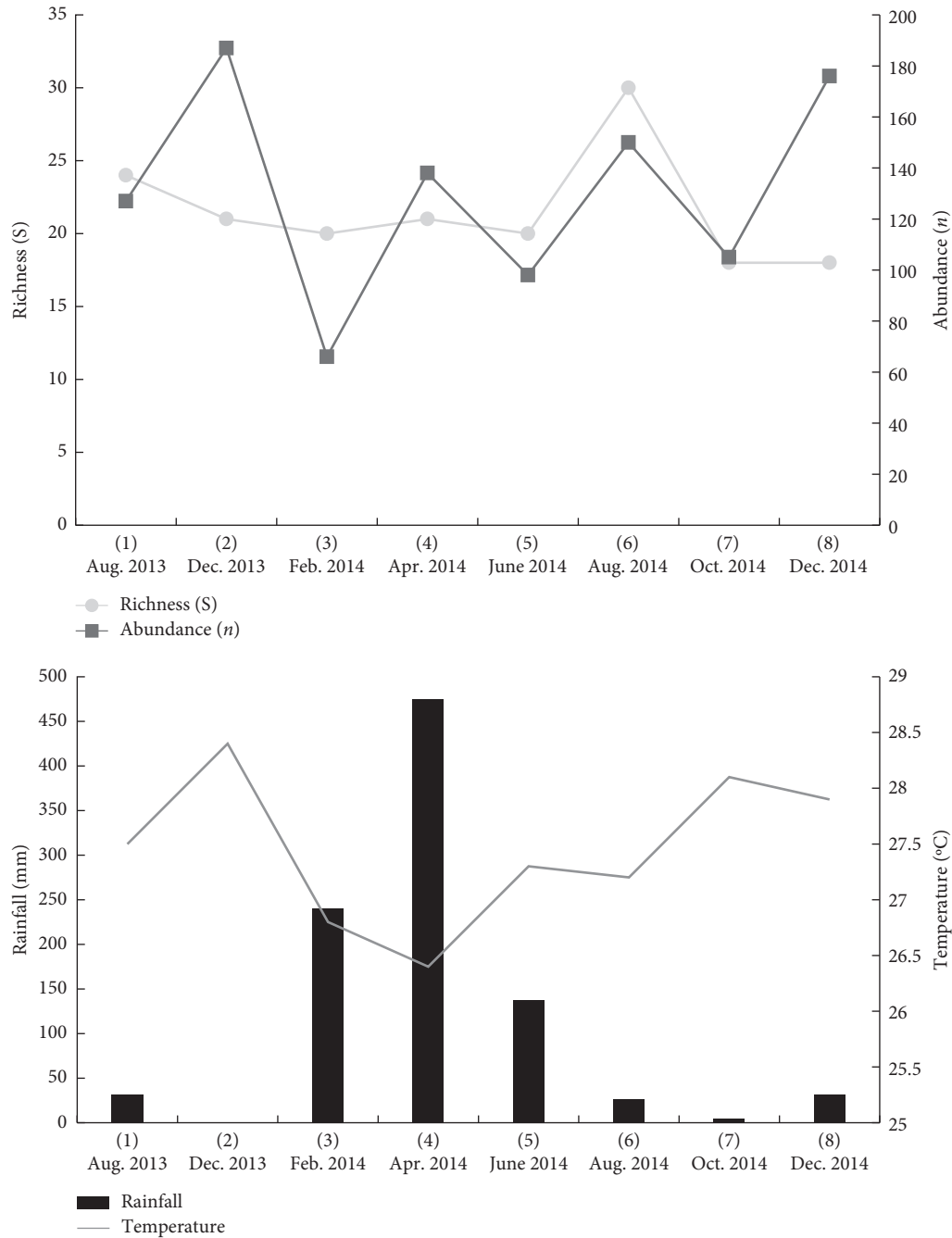
Figure 2: Distribution of bee sample richness and abundance and climate data between August 2013 and December 2014 in Carutapera, MA, Brazil.

individuals, respectively), no significant correlation between climate patterns and diversity patterns was observed ($r = -0.109$; $p = 0.797$).

Based on the annual distribution, 22.9% of the species was considered very frequent, 20% frequent, and 57.1% infrequent, of which 26 were solitary species (Table 1). *E. cordata* was the only species present in every collection month. Of all the specimens, 8.57% were dominant, 8.57% accessory, and 82.8% occasional. When dominance and frequency were combined, six species were classified as common, 24 as intermediate, and 40 as rare (Table 1).

3.4. Sampling Sufficiency. The bee community in this forest environment proved relatively uniform ($J' = 0.72$), an indication that most species were represented by only a few individuals (Figure 3).

The species accumulation curve did not level off (Figure 4), showing that the expected number of species was greater than the number actually collected. Because of this, nonparametric total richness estimators were used.

The results with these were Jackknife $1 = 102.6$ and Chao $1 = 145.5$. Overall, bee diversity in Carutapera was relatively high ($H' = 3.08$), and species dominance was low ($D = 0.08$).
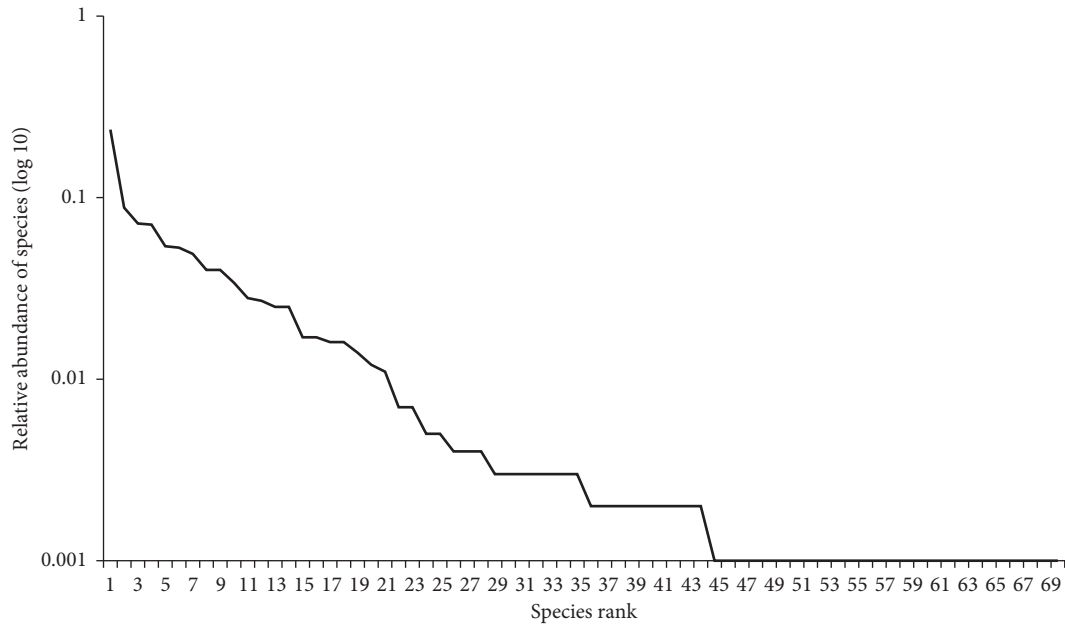
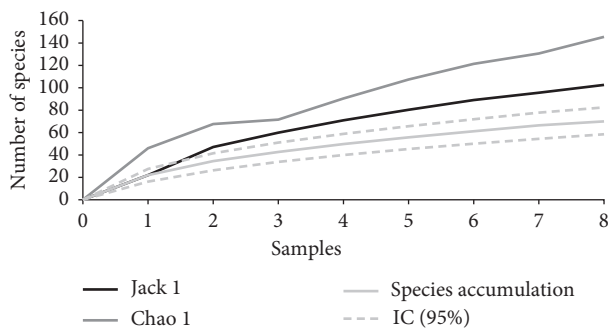Figure 3: Rank-abundance curve for bee species between August 2013 and December 2014 in Carutapera, MA.

Figure 4: Nonparametric richness estimators (Chao 1 and Jack-knife 1) and species accumulation curve (collector's curve) for bees in Carutapera, MA, between August 2013 and December 2014.

4. Discussion

The bee diversity observed in Carutapera was greater than that reported in other studies and ecosystems using more than one collection technique, such as those by Pereira [49] in *Cerrado*, Kamke et al. [18] in *restinga*, Batalha-filho et al. [50] in *caatinga* (an area with xerophilous spiny trees and shrubs) and Krug and Alves-dos-Santos [32] and Gruchowski et al. [51] in the Atlantic forest. Comparisons of fauna in different locations are important for an understanding of communities and ecosystems but are made difficult by the existence of many variables, such as differences between collectors and sampling effort [52], capture modes [32, 53], and climate/geographic variations [54–56].

Venturieri and Contrera [57] discuss the great dearth of standardized surveys of Apoidea in the Amazon biome, the last having been carried out over 100 years ago by Ducke [58]. Since then, few studies of Apoidea in this biome have been published, and the majority of these has been surveys of the tribe Euglossini [49, 59–62]. In eastern Amazonia, where

the state of Maranhão is, four surveys have been carried out [6, 14, 16, 22], although only one of them, which was carried out in the Baixada Maranhense environmental protection area [6], used more than one sampling method.

In the present study, with only half the sampling period and the same collection methods as Albuquerque et al. [6], we recorded similar abundances yet twice the richness. However, the richness was lower than that reported by Poveda-Coronel et al. [63] in a study also carried out in a degraded region of the Amazon; a possible explanation for this is that Poveda-Coronel et al. [63] used two types of trap (trap nest and malaise) in addition to the type of trap used here.

For the remaining studies in which only one sampling method was used, whether an insect net [7, 17, 19, 22] or scent-baited traps [8–11, 14, 16, 64, 65], comparisons in terms of species richness will be presented for the relevant method.

If we consider the data presented here for collections with an insect net, the richness was higher than that reported in any of the studies in the state of Maranhão identified in the literature. This method therefore proved to be the most efficient, as already mentioned in other studies [18, 32] since it alone accounted for 62.8% of the species sampled in the study area.

Subfamily Apinae was notable in the present study, reflecting the known tendency for the species richness of this subfamily to increase at lower latitudes [17, 19, 66], while Andreninae and Colletinae are known to be poorly represented in the neotropical realm [67], explaining the possible absence of these two subfamilies in the community studied.

The tribe Meliponini was noteworthy primarily for its abundance, a consequence of the social nature of the species in this tribe, which have many nests near each other. According to Roubik [68], the evolutionary success of this group is associated with eusocial behavior, perennial colonies, and Catholic foraging habits. Worker bees in these species have a highly developed ability to communicate

information about the location of food sources to other workers [69] and have large colonies [51, 70], so that many individuals from a single colony may be observed on flowers [71].

The stingless bee *T. branneri* was dominant throughout the sampling period and therefore was very frequent; this finding disagrees with the results of most other studies in the state of Maranhão, in which this species was absent [5, 12, 26, 72]. Presumably, this species is better adapted to forests even if they are degraded, as observed by Oliveira et al. [73] for other species of the same genus in continuous and fragmented areas in central Amazonia.

The exotic species *Apis mellifera* Linnaeus, 1758, was also very abundant throughout the sampling period, a finding similar to that reported by Poveda-Coronel et al. [63], who discusses this species resistance not only to the effects of habitat fragmentation but also to climate change, which is increasingly noticeable in tropical regions of the planet.

In the case of solitary bees, there was a general pattern of low abundance, which is probably related to their seasonal lifecycle and the fact that nestbuilding generally occurs in the summer [74, 75].

Turning to scent baits, the tribe Euglossini was most notable and accounted for a significant percentage of the community (34.2%); species richness for this tribe was higher than that reported in other studies in the Amazonian region [14, 59, 72] and in a transition area between *Cerrado* and the Amazon forest [76]. However, the species richness observed for the forest fragment in Carutapera was similar to that reported in other studies in areas with the same type of plant formation that are also under threat from human activity, such as the study by Brito et al. [61] in oil palm plantations in the state of Pará. This result is probably related to the adverse conditions in the study area, which is subjected to constant degradative pressures due to burning, clearing, and logging in neighboring areas [77], a situation reflected in our data by the presence of species such as *E. cordata* and *E. nigrita*. These are generally associated with open areas and areas subjected to stresses caused by human activity [78] and were classified as very frequent in the present study.

It is also possible that these findings simply reflect the sampling method chosen as the only most common baits in orchid bee studies [39, 49, 79] that were used here. For Bezerra and Martins [80], the use of different types of baits is an efficient way of sampling the tribe Euglossini as some species have preferences for particular baits [37, 81].

In the present study, eucalyptol was the most attractive scent both in terms of number of individuals and number of species. This is a pattern that has been observed in many studies [11, 14, 49, 82]. Sofia and Suzuki [79] found that the greater attractiveness of eucalyptol baits was due to the greater volatility of this essential oil compared with other scents. This greater attractiveness resulted in *Eulaema nigrita* and *Euglossa intersecta* mainly visiting baits containing eucalyptol, a pattern also observed in other studies [14, 83].

Eugenol was the second most attractive bait, especially for *E. cingulata* because of its low volatility [84, 85]. Although methyl cinnamate was the least attractive essence, it was the only one that attracted *A. caerulea*, which was considered endemic only to the northern Amazon region prior to the study by Anjos-Silva et al. [81]. Recently, Martins et al. [39] also collected specimens of this species using methyl cinnamate and reported its presence in Maranhão for the first time.

In our study, a pattern of a few species with many individuals and many intermediate and rare species was observed. In spite of this, the equitability index was high. Although the data collected were insufficient to determine whether there was a seasonal distribution of individuals, as collections were only performed in eight months, we observed two abundance peaks (December 2013 and December 2014), corresponding to the dry period, and abundance was lowest in February 2014.

The abundance peaks corresponded to the periods when the greatest number of species from Meliponini were collected. According to Pedro and Camargo [86], the activity of stingless bees is related more to the availability of resources than to climate variations. The richness peak in August 2014 is probably related to the blooming period at the beginning of spring, when various botanical species produce abundant floral resources [87].

Unsampled species, indicated by the richness estimators (Chao 1 = 51.8% and Jackknife 1 = 31.7%), highlight the importance of carrying out further long-term standardized studies in transition areas on the edge of the Amazon region, especially because this is an environment whose diversity has been underestimated in terms of its complexity [88].

However, our data show a high level of diversity, demonstrating, as other authors have [18, 32, 89, 90], that complementary methods can help to assess the bee community structure in a particular environment.

We have added three new records for the state of Maranhão: *Bombus transversalis* (Olivier, 1789), *Xylocopa suspecta* Moure and Camargo, 1988, and *Xylocopa macrops* Lepeletier, 1841. In addition, 11 new species were recorded for the first time in the Amazonian region of the state: *A. caerulea*, *E. amazonica*, *Euglossa despecta* Moure, 1968, *E. bombiformis*, *Aparatrigona impunctata* (Ducke, 1916), *Frieseomelitta flavicornis* (Fabricius, 1798), *Lestrimelitta limao* (Smith, 1863), *Partamona chapadicola* Pedro and Camargo, 2003, *Trigonisca meridionalis* Albuquerque and Camargo, 2007, *Paratetrapedia leucostoma* (Cockerell, 1923), and *Tetrapedia diversipes* Klug, 1810.

5. Conclusions

Bee diversity in the study region was the highest yet recorded in the state of Maranhão. This can be attributed to the particularities of this transition region and the combined use of two collection methods known to be the most effective for bees. Although we did not find any statistically significant correlation with climate patterns, we observed abundance peaks in months corresponding to the dry period. The results presented here help to gain an understanding of bee composition and distribution in northernmost Maranhão. Eleven new occurrences were recorded for the Amazonian region of the state and three for the whole state.

Data Availability

All data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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