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SURVEY OF BEE FAUNA AND CONSERVATION STATUS INDICATORS IN A RESTORED ATLANTIC FOREST FRAGMENT IN ARARAS, SÃO PAULO

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ABSTRACT. The Atlantic Forest is recognized for its high biodiversity and endemism. In Brazil, it has faced severe deforestation, with considerable reduction in its original area and loss of biodiversity; thus it is crucial to prioritize it for restoration and preservation efforts. Given that bees are essential in maintaining plant diversity and that landscape alterations are a major factor responsible for the pollinator's decline, this study aimed to identify the bee fauna of an Atlantic Forest restored fragment. Bees were collected monthly using pan traps and aromatic traps over 12 month. In total, 208 individuals from the Apidae and Halictidae families were collected. *Eulaema nigrita*, the most abundant species (40.86%), was exclusively captured in aromatic traps, whereas *Melitoma segmentaria* (9.61%), predominantly collected in blue pan traps, was the second most abundant species. The species accumulation curve showed that 12 months of sampling period was insufficient to catalog the entire bee community, with an estimated additional 13 months required to reach sample stability. Although the complete bee community was not recorded, the major abundance of *E. nigrita* and *M. segmentaria*, both recognized as a bioindicator of disturbed fragments, indicates that the forest fragment is not in an optimal conservation condition, requiring additional studies to evaluate the real conservation status. Regardless of this, our results underscore the importance of monitoring the ecological health of this restoration fragment, which could provide essential data to inform future research focused on developing management and conservation strategies for pollinators and native or restored forests.

Keywords: Bee fauna; Bioindicator species; Atlantic forest; Pollinator diversity; Restoration ecology; Biodiversity monitoring.

INTRODUCTION

Animals engage in numerous ecological interactions, including pollination, which is essential for the reproductive success of most native and cultivated plants (POTTS *et al.*, 2010). Pollinators are thus fundamental to maintaining biodiversity, with approximately 90% of angiosperms relying on animals for pollination (OLLERTON, WINFREE, TARRANT, 2011).

Insects substantially contribute to the pollination of several plant species and are considered the most important group of pollinators (SCHOONHOVEN, JERMY, VAN-LOON, 1998). Among them, bees are the most specialized, with approximately 20,000 identified species (IPBES, 2017; ORR *et al.*, 2021). Their morphological adaptations allow them to efficiently collect, manipulate, transport, and store pollen despite the varying shapes and sizes of pollen grains (DANFORTH *et al.*, 2006).

Plants and bees have co-evolved over time, with these insects becoming as specialized as the flowering plants they associated with during the evolution, leading to co-dependance (EVERT, EICHHORN, 2014). Consequently, the disappearance of these pollinators would reduce the genetic variability of the associated plants, potentially resulting in the loss of several plant species, and vice versa.

The sharp decline in various bee species in the recent decades has raised concerns among researchers and government officials worldwide, as bee biodiversity is essential for maintaining plant diversity in both natural and human-modified ecosystems (TSCHEULIN *et al.*, 2011). A reduction in pollination services would affect global food production, given the reliance of various cultivated plant species on pollinators. Recognizing their critical role, the International Environmental Organization declared bees the most important organisms on Earth in 2008, highlighting their irreplaceable value (GAMBLE, 2008). The absence of bees, therefore, poses a major threat to national and international food security and could lead to a considerable reduction in fruit and seed production.

Several factors have contributed to the decline in bee species, with the primary drivers being anthropogenic actions, such as the indiscriminate use of pesticides and degradation of natural habitats, which significantly contribute to climate change (BERINGER, MACIEL, TRAMONTINA, 2019; AMARAL, CARNIATTO, 2023). As agriculture intensified, regions of native vegetation were converted into cultivated fields. Initially, diverse crop cultivation practices helped maintain a more varied landscape. However, the later shift to monoculture had a greater impact on the interactions between pollinators and plant species (PATRÍCIO-ROBERTO, CAMPOS, 2014; ST. CLAIR *et al.*, 2020).

A varied food source is essential to support a diverse bee fauna (TSCHARNTKE *et al.*, 2005; ST. CLAIR *et al.*, 2020). Habitat fragmentation, however, disproportionately impacts oligolectic bee species those that forage on specific groups of plants making them more vulnerable to fragmentation than are generalist (polylectic) species, which forage on a wider variety of flowering plants. Overall, forest fragmentation reduces visits by endemic bee species, leading to a decrease in fruit production from native plants (CUNNINGHAM, 2000; MICHENER, 2007).

Given the importance of bees in maintaining plant diversity in both natural and human-modified ecosystems, it is essential to enhance knowledge, monitoring, and biodiversity management of bees, with the aim of developing effective preservation strategies for at-risk species. Accordingly, expanding knowledge about bee fauna requires studies on species organization and distribution, which are conducted through fauna surveys (SILVEIRA, MELO, ALMEIDA, 2002; BARROS *et al.*, 2022).

Furthermore, survey studies can help identify species that serve as bioindicators and aid in assessing the conservation status of ecosystems (BROWN Jr., 1997; CARDOSO, 2010). For example, certain species that rely on dense forests for survival, such as *Melipona* sp., are bioindicators of well-preserved forest environments and are highly vulnerable to deforestation a major anthropogenic threat. Conversely, species such as *Eulaema nigrita*, which adapt well to open areas, are commonly found in degraded regions of the Atlantic Forest, and serve as bioindicators of disturbed or degraded habitats rather than intact forest zones (SILVEIRA, MELO, ALMEIDA, 2002; BARROS *et al.*, 2022).

The Atlantic Forest is a biome that has been substantially impacted by anthropogenic activities since the arrival of the first European explorers on the Brazilian coast. After centuries of deforestation, only approximately 7% of the original forest remains, with 80% of this area consisting of small fragments, and the rest comprising remote, hard-to-access remnants (RIBEIRO *et al.*, 2009; MELLO-THÉRY, 2023; SOUZA *et al.*, 2022). This biome encompasses various physiognomies and diverse forest formations, spanning seventeen states across Brazil. Approximately 70% of the Brazilian population lives within Atlantic Forest regions, intensifying anthropogenic pressures on the remaining forested areas (TONHASCA, 2005; IBGE, 2016).

To address these impacts, it is essential to implement laws and actions aimed at preserving, restoring, and monitoring native areas of the Atlantic Forest. In Brazil, the Brazilian Forest Code serves as the primary legal framework for protecting native vegetation. Originally established by Federal Law 4,771/65, this code was updated in 2012 (Federal Law 12,651/12) and aims to conserve Permanent Preservation Areas (APP) and Legal Reserves (RL) (BRASIL, 2012).

APPs are intended to protect water bodies by conserving riparian forests, thereby ensuring water supply for approximately 122 million inhabitants within the Atlantic Forest region (PINTO *et al.*, 2009; SOS MATA ATLÂNTICA, 2021). RLs, on the other hand, mandate the preservation of a portion of original vegetation within rural areas (SPAROVEK *et al.*, 2010), emphasizing the critical role of native vegetation in maintaining the biodiversity of the biome (PATRÍCIO-ROBERTO, CAMPOS, 2014).

However, the Brazilian Forest Code has been subject to critique by various researchers, as the “New Forest Code” reduced the obligation to conserve territories with native vegetation despite the scarcity of original Atlantic Forest cover in agricultural areas nationwide (SPAROVEK *et al.*, 2010). Furthermore, although the legislation mandates the restoration of native forests and their ecological services in both rural and urban areas and the Atlantic Forest is constitutionally protected this biome continues to experience deforestation, largely driven by agricultural expansion (TONHASCA, 2005).

According to the Brazilian Forest Code (BRASIL, 2012), owners of rural properties are required to maintain 20% of their total land area with the original vegetation of the biome. However, various regions still have a significant deficit in native vegetation cover (SPAROVEK *et al.*, 2010). For example, in the state of São Paulo (SP), 20–90% of the existing native area must be restored to meet the legal minimum forest cover (SOARES FILHO *et al.*, 2014).

To address this deficit, the Pact for the Restoration of the Atlantic Forest in Brazil was initiated in 2009 (RODRIGUES, BRANCALION, ISERNHAGEN, 2009), with the aim of restoring approximately 15 million ha of native vegetation. Additionally, in 2017, the National Plan for the Recovery of Native Vegetation (PLANAVEG) was established by several government ministries, including the Ministry of the Environment, the Civil House of the Presidency of the Republic, the Ministry of Agriculture, Livestock and Supply, and the Ministry of Education. This plan aims to promote and strengthen the technologies and public policies that encourage sustainable agricultural practices alongside measures to restore and preserve native forests (PLANAVEG; MMA 2017).

Environmental restoration is thus fundamental to preventing further loss of species and genetic diversity. Various restoration methods, such as the planting of native species, are currently employed to reestablish the ecological interactions of biomes (FRAGOSO, 2014).

Once restoration is implemented, monitoring and periodic evaluation of the fragment become essential to ensure a continuous analysis of the degraded area and the effectiveness of applied methodologies. This approach helps identify and address any issues that may hinder restoration success. However, in Brazil, monitoring activities often receive limited attention, largely because restoration is frequently viewed as merely a requirement for environmental licensing and certification rather than a genuine effort to restore biodiversity (BRANCALION *et al.*, 2013).

In SP, public policies for restoration and environmental monitoring were established through the Secretariat of the Environment of SP (SMA) Resolution No. 32 (SÃO PAULO, 2014) and the Coordination of Biodiversity and Natural Resources (CBRN) Ordinance 01/2015 (SÃO PAULO, 2015), setting protocols to evaluate site progress based on soil cover by native vegetation, the density of regenerated native individuals, and the number of regenerated native species (SÃO PAULO, 2015). However, these indicators do not fully reflect the actual restoration status of the site, as they do not account for ecological processes indicative of a balanced ecosystem. Therefore, monitoring protocols should include assessments of these ecological processes to ensure the sustainability of restored areas (PENHA *et al.*, 2019).

Although monitoring biodiversity through survey studies does not provide direct data on the reestablishment of ecosystem services in areas undergoing restoration, this method can offer a strong indication of vegetation conservation status through the presence of certain species that serve as bioindicators (CARDOSO, 2010; BATISTA *et al.*, 2020). For instance, survey studies can detect species associated with degraded environments, such as *Eulaema nigrita* (SILVEIRA, MELO, ALMEIDA, 2002). Therefore, fauna surveys studies are valuable in restoration monitoring, providing essential data for the development of additional methodologies for investigating ecological processes within restored areas (DE CAMARGO *et al.*, 2015).

In this context, this study aimed to identify the bee community within a forest restoration fragment of the Atlantic Forest. The specific objectives were to (1) conduct a year-long survey of bee fauna in an Atlantic Forest restoration fragment and (2) compare the species composition found in this fragment with records of the occurrence of endemic species in this biome from previous research.

METHODOLOGY

Study area

This study was conducted in the municipality of Araras, SP, between June 2022 and May 2023. Data collection was carried out in the forest restoration APP at the Federal University of São Carlos (UFSCar) – Araras campus, SP, located between the geographic coordinates 22°18′31″S and 47° 23′13″W (Figure 1).

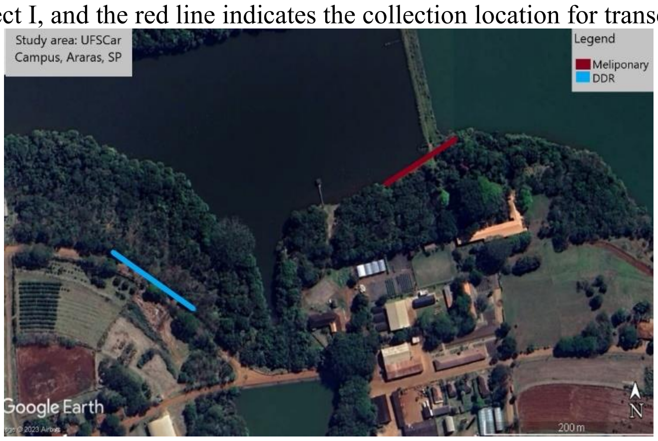
The UFSCar – Araras campus contains forest restoration fragments covering a total area of 26.55 ha, established in 2007 and 2009 along the banks of the campus watercourses (ROCHA *et al.*, 2018). These areas were reforested with plant species typical of the Semideciduous

Seasonal Forest, belonging to the Atlantic Forest biome (SOS MATA ATLÂNTICA; INPE, 2015).

At a landscape scale, the UFSCar – Araras campus is situated within an agricultural matrix dominated by sugar cane cultivation, with smaller patches of various other crops, as well as natural APPs and additional areas undergoing restoration (ROCHA *et al.*, 2018).

The study area has a monsoon-influenced humid subtropical climate (Cwa) climate, according to the Köppen classification system, with two well-defined seasons a rainy season from October to March, and a dry season from April to September. The average annual temperature and rainfall in Araras are 21.6°C and 1,422.8 mm, respectively (KOTTEK *et al.*, 2006).

Figure 1 - Study area within the UFSCar– Araras campus, SP. The blue line indicates the collection location for transect I, and the red line indicates the collection location for transect II.



Source: Prepared by the author.

Identification of bee fauna

The bee fauna was surveyed using two methods (i) pan traps and (ii) scent bait (odoriferous) traps, positioned along two transects. Collections were conducted monthly over a one-year period. Pan traps were prepared and installed in accordance with the protocols established by Leong; Thorp (1999); Aizen; Feinsinger (1994) and Moreti; Marchini (1998). The transects were positioned on opposite edges of the fragment, with traps set at 6:00 am and exposed for 24 hours (AIZEN, FEINSINGER, 1994). During this period, bees were collected at three time points 1:00 pm, 6:00 pm, and 7:00 am the following day and stored individually in plastic bottles containing 70% alcohol.

Scent bait traps were prepared and installed in accordance with the methods outlined by Montoya-Pfeiffer; Rodrigues; Alves-Dos-Santos (2020) and Campos *et al.* (1989). Bees captured in these traps were collected and stored using the same protocols as for pan traps.

Statistical Analysis

The occurrence of identified species was represented in graphs and tables, created using the Microsoft Excel software (Microsoft Corporation, Redmond, EUA). The distribution of species among bee families and the variation in abundance and species richness throughout the year were analyzed.

A rarefaction curve was also established to estimate species richness. Rarefaction (interpolation) determines the expected number of species in each community by standardizing sample sizes across all collections. The analysis was based on the smallest number of individuals sampled per month to ensure standardization. In addition to rarefaction, extrapolations were performed to estimate the potential number of species with increased collection effort. The analysis was conducted using the "iNEXT" package (HSIEH *et al.*, 2022) in RStudio software version 2023.3.1.446 (POSIT TEAM, 2023).

The bees captured in this study were dry-mounted and identified to the lowest possible taxonomic level using an identification key (SILVEIRA, MELO, ALMEIDA, 2002). Specimens that could not be identified through this method were sent to bee taxonomist Dr. Favízia Freitas de Oliveira for identification. All specimens were subsequently deposited in the Bees and Environmental Services (ASA) group collection at the UFSCar – Araras campus, SP.

RESULTS AND DISCUSSION

Over the 12-month collection period, 208 individuals were captured, representing 32 species, 18 genera, and 10 tribes within the Apidae and Halictidae families (TABLE 1).

Table 1 - Bee species collected over a 12-month period.

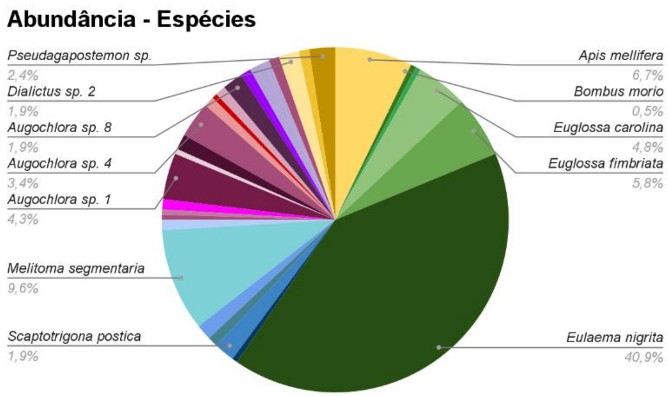
Family	Tribe	Species	Abundance
Apidae	Apini	*Apis mellifera*	14
	Bombini	*Bombus morio*	1
	Euglossini	*Euglossa sp. 1*	1
		Euglossa sp. 2	1
		Euglossa carolina	10
		Euglossa fimbriata	12
		Eulaema nigrita	85
	Meliponini	*Plebeia aff. droryana*	1
		Scaptotrigona postica	4
		Trigona spinipes	2
	Emphorini	*Ancyloscelis sp. 1*	3
		Melitoma segmentaria	20
	Eucerini	*Florilegus festivus*	2
		Thygater analis	1
	Exomalopsini	*Exomalopsis analis*	1
	Ceratinini	*Ceratina* aff. *maculifrons*	2
Halictidae	Augochlorini	*Augochlora sp. 1*	9
		Augochlora sp. 2	1
		Augochlora sp. 3	3
		Augochlora sp. 4	7
		Augochlora sp. 5	2
		Augochlora sp. 6	1
		Augochlora sp. 7	2
		Augochlora sp. 8	4
		Augochlora iphigenia	1
		Augochlorella sp. 1	1
		Augochloropsis sp. 1	3
		Augochloropsis sp. 2	1
	Halictini	*Dialictus sp. 1*	2
		Dialictus sp. 2	4
		Dialictus osmioides	2
		Pseudagapostemon sp. 1	5
TOTAL			208

Source: Prepared by the author.

The most abundant species were *Eulaema nigrita*, with 85 individuals captured (40.86% of collections), including 23 individuals in collected in November alone, followed by *Melitoma segmentaria*, with 20 individuals, representing 9.61% of the species collected (FIGURE 2).

All *Eulaema nigrita* individuals were captured in scent traps baited with eucalyptol. This result aligns with the behavior of male bees in the Euglossini tribe, which habitually visit plants to collect volatile substances that they use to synthesize sexual pheromones and mark their territories. The greater abundance observed from November to January corresponds with *E. nigrita* individuals captured in scent bait traps, a period that coincides with the peak flowering and reproductive season for this species. However, this pattern could be impacted by climate change, as it affects vegetation productivity, which in turn affects food availability (floral resources) and the proliferation of bee populations (PERUQUETTI, 2003).

Figure 2 – Percentage abundance of bee species collected over a 12-month period.



Source: Prepared by the author.

In some solitary bee species, males typically emerge from nests before females and are responsible for attracting or finding females for mating. Additionally, males often patrol flowers that attract females and mark territories with pheromones (CARDOSO, 2010; MEDEIROS, SCHLINDWEIN, 2003). Among Euglossini, males use sexual pheromones to attract females, who likely select mates based on the diversity of volatile compounds the males gather from orchids (CAMERON, 2004).

The high abundance of *E. nigrita* observed in this study may indicate a low conservation status of the restored fragment, as this species is commonly associated with disturbed environments. *E. nigrita* is typically found in areas impacted by environmental degradation and anthropogenic activity, particularly in the Atlantic Forest, making it a reliable bioindicator species of degraded environmental conditions. (AGUIAR, GAGLIANONE, 2008; PERUQUETTI *et al.*, 1999; SANTOS *et al.*, 2019; SILVEIRA, MELO, ALMEIDA, 2002; BATISTA *et al.*, 2020).

Carneiro *et al.* (2022) evaluated the influence of habitat quality on the Euglossini community in a coffee matrix region. They found that large areas of coffee monoculture negatively affected Euglossini species richness and abundance, as monoculture reduces food availability for this group. In this study, *E. nigrita* was the most abundant species, even in areas farthest from forests, where anthropogenic interference was highest. Thus, the Euglossini tribe (orchid bees) has proven effective in studies of forest fragmentation, meeting the essential criteria to be considered as an ecological indicator for both conserved and degraded areas, depending on the target species. Additionally, the tribe is taxonomically well-described compared with other tribes and can be efficiently captured using standard methods such as

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aromatic bait traps (GONÇALVES, FARIA, 2021). Moreover, orchid bees possess high dispersal capabilities, allowing them to travel long distances and adapt to fragmented environments (DA SILVA, MARCO, 2014; BATISTA *et al.*, 2020).

Another indication that the restoration area may not be in a good conservation status is the regular capture of *Melitoma segmentaria*, the second most abundant species in this study. All individuals were captured in blue-colored traps, as this oligolectic species is associated with flowers of the Convolvulaceae family, particularly the genus *Ipomoea*, which includes various species with blue and violet inflorescence (DA PAZ, PIGOZZO, 2013; RAMELLO *et al.*, 2021; SCHALLER, ROIG-ALSINA, 2019; DA SILVA, MOUGA, DEC, 2022). This affinity explains its preference for blue pan traps, which functioned as visual indicators, as these bees are highly sensitivity to the ultraviolet light spectrum. (KEVAN, CHITTKA, DYER, 2001). Additionally, the Convolvulaceae family includes numerous vines and lianas, commonly found in open areas and fragment edges, particularly in locations disturbed by anthropogenic activity (DA PAZ; PIGOZZO, 2013), similar to the current study area.

Most bee specimens were collected in transect II (131 individuals; 63%), while 77 individuals (37%) were captured in fragment I. A total of 16 species were identified across both fragments, with 11 species being common to both, including *Apis mellifera*, *Euglossa carolina*, *Euglossa fimbriata*, *Eulaema nigrita*, *Scaptotrigona postica*, *Trigona spinipes*, *Melitoma segmentaria*, *Augochlora sp. 7*, *Augochloropsis sp. 1*, *Dialictus sp. 1*, *and Dialictus sp. 2.* This result reflects the importance of habitat quality for pollinator presence, as the presence of more preserved habitats with low anthropogenic impact supports pollinator permanence by providing permanent nesting sites. (PERUQUETTI *et al.*, 1999; GAGLIANONE *et al.*, 2018).

Larger, less disturbed forest fragments offer abundant food resources, favorable nesting sites, and fewer environmental stressors such as temperature and humidity fluctuations, resulting in higher bee abundance and richness (PERUQUETTI *et al.*, 1999). Conversely, more anthropized or urbanized habitats, with roads, buildings, and other infrastructure, can negatively impact wild bee richness and abundance (WATSON, WOLF, ACHER, 2011).

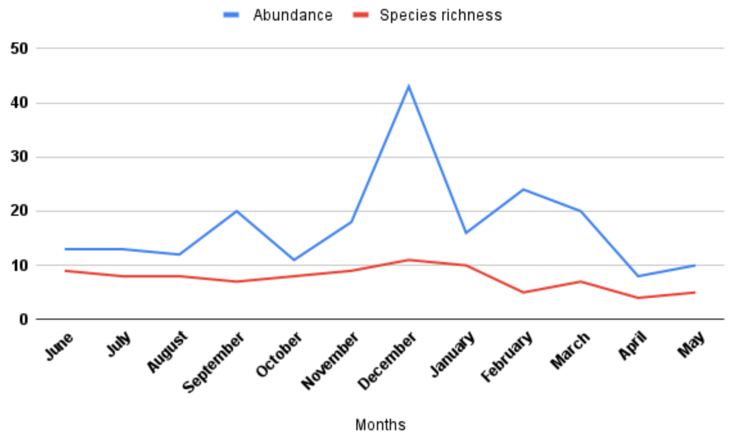
The results of this study align with the literature regarding species abundance, with transect II showing higher abundance than transect I. Transect I is located at the outer edge of the fragment, adjacent to a busy road and very close to buildings, while transect II is located along the inner edge of the fragment, adjacent to the pond on University grounds. This area is less accessible due to the limited pruning maintenance, making it a favorable environment for bee presence.

Across sampling sites, pan traps captured 97 (46.63%) individuals, with 52 (53.60%) in blue traps, 32 (32.98%) in yellow traps, and 13 (13.40%) in the white traps. These results are consistent with those of other studies, wherein blue traps were the most effective (CAMPBELL, HANULA, 2007; KRUG, ALVES-DOS-SANTOS, 2008; MAUÉS *et al.*, 2011; XINGFANG, 2015). This attraction to blue traps is due to the heightened sensitivity of bees to short wavelengths, making them more responsive to ultraviolet and yellow spectra (KEVAN, CHITTKA, DYER, 2001). Additionally, color-based traps are effective in attracting pollinators, as color is a primary visual cue used by plants to attract pollinators (CAMPBELL, HANULA, 2007).

The scent traps captured 111 (53.36%) individuals, including 85 *E. nigrita* and 24 individuals from four species of the genus *Euglossa* (TABLE 1). All specimens collected using this method were males of the Euglossini tribe, known for visiting plants in search of volatile substances (CARDOSO, 2010). Several studies have tested various fragrances in these traps, with eucalyptol consistently proving to be one of the compounds most effective at attracting Euglossini males. In this study, eucalyptol was highly effective for capturing this pollinator guild (MONTOYA-PFEIFFER, RODRIGUES, ALVES-DOS-SANTOS, 2020; SANTOS *et al*., 2019; CARDOSO, 2010).

Over the one-year collection period, species richness remained relatively stable across months, while abundance varied, showing some peaks when more specimens were caught. The highest abundance in 2022 was recorded in September (20 individuals) and December (43 individuals), whereas in 2023, peaks occurred in February (24 individuals) and March (20 individuals). In contrast, the lowest abundance in 2022 was observed in October (11 individuals), and in 2023, in April (8 individuals) and May (10 individuals). Other months had an average abundance of 14 individuals (FIGURE 3).

Figure 3 – Monthly abundance and richness of bee species collected over a 12-month period, represented as a line graph.



Source: Prepared by the author.

The months with the highest bee incidence coincided with the hottest months of the year, while the months with the lowest incidence occurred during the coldest periods, with the exception of October 2022. In October 2022, temperatures reached a yearly high, averaging 27.2°C, while also receiving 11 days of precipitation. On the day of collection, the temperature was 28°C, with rainfall of 4.4 mm of rainfall (INMET, 2022), likely hindering bee activity. As heterothermic animals, bees' body temperature varies with environmental conditions, and temperatures outside their optimal range can inhibit their behavior (MELLANBY, 1931). Studies also indicate that bee flight activity increases at higher temperatures and decreases at lower temperatures (BURRILL, DIETZ, 1981). Notably, the months with the highest species incidence corresponded to spring and summer, when flowering peaks and the abundance of floral resources attracts pollinators (BRANDÃO, MUCHA, PINHEIRO, 2020).

The species accumulation curve indicated that 12 months of surveying was insufficient to catalog the entire bee community in the fragment, as evidenced by the curve's ascending end (FIGURE 4A). Typically, the accumulation curve is calculated based on the study area size to determine if it adequately represents the entire community present. However, Schilling and Batista (2008) found that this approach is unreliable in tropical areas due to the high phytosociological characteristics of these areas, especially the high richness of plant species. The authors proposed adapting this methodology to assess sampling sufficiency through a space-time relationship. Following this approach, the extrapolation curve suggested that an additional 13 months of sampling would be needed to reach sampling stability, totaling 2 years and 1 month of sampling (FIGURE 4B).

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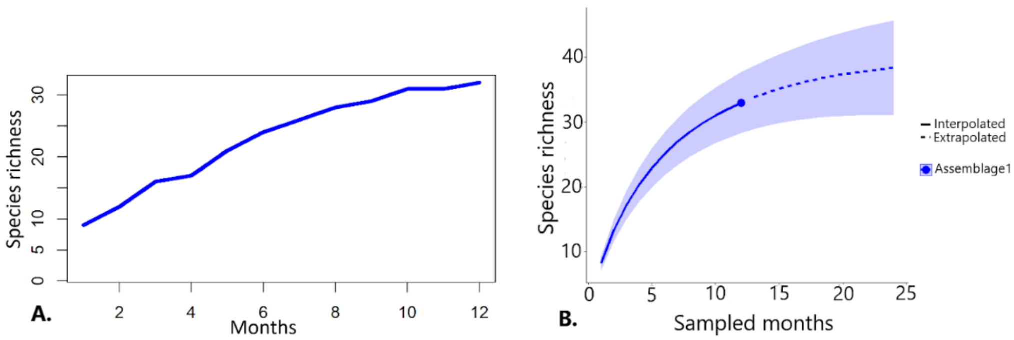
Although the bee community was not sampled in its entirety, this study identified a species richness comparable to similar surveys carried out in Araras, SP (SANTOS, 2012; MONTOYA-PFEIFFER, RODRIGUES, ALVES-DOS-SANTOS, 2020).

In 2012, Santos carried out a survey of bees in the same study area, sampling individuals from the Apidae, Halictidae, and Andrenidae families, although the latter was not observed in this study. Montoya-Pfeiffer, Rodrigues and Alves-dos-Santos (2020) surveyed bee communities across various Atlantic Forest fragments in Araras, identifying bees from all families as classified by Silveira, Melo and Almeida (2002): Apidae, Halictidae, Andrenidae, Megachilidae, and Colletidae. Table 2 lists the bee species common to this study and those recorded by Montoya-Pfeiffer, Rodrigues, and Alves-dos-Santos (2020) and Santos (2012).

Figure 4 - Rarefaction curve. **A** - Species accumulation curve. **B** – Extrapolation curve.



Source: Prepared by Montagnana, P.C.

Table 2 – Bee species common to this study and the studies by Montoya-Pfeiffer, Rodrigues, and Alves-dos-Santos (2020) and Santos (2012).

Species identified in this study	Species identified in Montoya-Pfeiffer, Rodrigues e Alves-dos-Santos (2020)	Species identified in Santos (2012)
Apis mellifera	X	X
Bombus morio		X
Euglossa sp. 1		X
Euglossa sp. 2		
Euglossa carolina		
Euglossa fimbriata	X	
Eulaema nigrita	X	
Plebeia aff. droryana		X
Scaptotrigona postica		
Trigona spinipes	X	X
Ancyloscelis sp. 1		X
Melitoma segmentaria	X	X
Florilegus festivus	X	
Thygater analis	X	
Exomalopsis analis	X	
Ceratina aff. *maculifrons*	X	
Augochlora sp. 1	X	
Augochlora sp. 2	X	
Augochlora sp. 3	X	
Augochlora sp. 4	X	
Augochlora sp. 5	X	
Augochlora sp. 6	X	
Augochlora sp. 7	X	

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Augochlora sp. 8		
Augochlora iphigenia		
Augochlorella sp. 1	X	
Augochloropsis sp. 1	X	X
Augochloropsis sp. 2	X	X
Dialictus sp. 1	X	
Dialictus sp. 2	X	
Dialictus osmioides	X	
Pseudagapostemon sp. 1	X	

Although Santos (2012) sampled bees in the same restoration fragment, the method used was active collection, conducted exclusively on flowering plants. In contrast, our study combined two different methods pan traps and scent bait traps independently of the presence of flowering plant. Using multiple collection methods has proven more efficient for sampling bees, as different species require different capturing methods (KRUG, ALVES-DOS-SANTOS, 2008; O'CONNOR *et al.*, 2018). According to Krug and Alves-dos-Santos (2008), pan traps tend to attract more individuals from the Halictidae and Apidae families, which forage year-round, supporting the findings of this study. Meanwhile, active flower-based collections are more effective for sampling all bee families, particularly Colletidae, Andrenidae, and Megachilidae, which are most active in summer. This makes active collection an effective method depending on the research objectives.

The findings of our study and those of Santos (2012) align with the collection method efficiencies evaluated by Krug and Alves-dos-Santos. In the present study, 32 species were recorded, all within the Apidae and Halictidae families (TABLE 1), whereas Santos (2012) observed only 20 bee species, but across three families (Apidae, Halictidae, and Andrenidae), with only 9 species being common to both studies (TABLE 2). The additional species recorded by Santos (2012) were *Augochloropsis cupreola*, *Centris sp.*, *Cephalotrigona sp.*, *Epicharis rustica*, *Exomalopsis sp.*, *Leurotrigona muelleri*, *Oxaea flavescens*, *Paratrigona lineata*, *Tetragonisca angustula*, *Trigona hyalinata*, *Xylocopa hirsutissima*, and *Xylocopa sp.*

Montoya-Pfeiffer, Rodrigues, and Alves-dos-Santos (2020) used the same collection methods as those used in the present study (pan traps and odor traps). However, their study spanned several Atlantic Rainforest fragments along a conservation gradient, ranging from highly degraded areas to areas having good conservation status, and was conducted over a three-year period. Consequently, they reported much greater bee richness and abundance (84 species and 545 individuals). Notably, two bee species *Scaptotrigona postica* and *Augochlora iphigenia* were unique to the present study and absent in the studies by both Santos (2012) and Montoya-Pfeiffer, Rodrigues, and Alves-dos-Santos (2020). However, the presence of *S. postica* may be attributed to a nearby experimental meliponarium housing colonies of this species.

The presence of *A. iphigenia* aligns with that reported in other studies, having been recorded in the Atlantic Forest Biome (URUSHIMA, CASTRO, MORINI, 2022; GONÇALVES, BRANDÃO, 2008; SOBREIRO, 2018). Lepeco and Gonçalves (2022) suggested that this species of *Augochlora* is abundant across various regions and can occur in different biomes, from Central Brazil to the Argentine Pampas. When comparing the species found in these two studies conducted in Araras, some specimens of *Augochlora* collected by Montoya-Pfeiffer, Rodrigues and Alves-dos-Santos (2020) were not identified to the species level, which suggests that some may potentially be *A. iphigenia*.

The findings of this study highlight the importance of monitoring the conservation status of restored forest fragments and provide a foundation for future research aimed at developing effective management and conservation strategies for pollinators and native or restored forests.

CONCLUSION

All the species observed in this study occur within the Atlantic Forest Biome. The differences in species composition between the present study and two other surveys conducted in Atlantic Forest fragments in Araras may be attributed to the different methodologies and sampling efforts employed.

The predominance of degradation-associated species - *E. nigrita* and *M. segmentaria* - indicates that the forest fragment is not in an optimal conservation condition, necessitating further degradation assessments to guide targeted management strategies.

Fauna survey and monitoring studies are essential first steps in any complex research aimed at conservation or restoration, as they establish baseline biodiversity data for the target group. In addition to providing insights into species richness and abundance throughout the year, such studies help identify key species that can serve as bioindicators of the conservation status of the region (BROWN Jr, 1997).

In the present study, the high abundance of two species recognized as bioindicators of disturbed environments suggests that the restoration fragment on the UFSCar – Araras campus, SP, is not in an optimal conservation condition. Further research is need to both survey the fauna and assess ecosystem service provision at the site. Additionally, the findings of this study would aid in developing improved strategies for the conservation and restoration of native vegetation in Araras and the broader Atlantic Forest Biome.

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