# A Interface do Conhecimento sobre Abelhas

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(Organizador)

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# APRESENTAÇÃO

A polinização de pomares de frutas, bem como lavouras de legumes e grãos, e diversas outras espécies vegetais angiospermas, muito se deve à vida das abelhas que é, portanto, crucial para o planeta e para o equilíbrio dos ecossistemas terrestres. Pode-se afirmar que sem os serviços ecológicos ofertados pelas abelhas, a grande maioria das plantas não se reproduziriam. Aproximadamente dois terços dos alimentos que ingerimos são produzidos com a ajuda da polinização das abelhas. Apenas com esse argumento preliminar, podemos apontar, convictos, que esses insetos da ordem Hymenoptera afetam a nossa vida cotidiana, sem que nós sequer nos apercebamos disso. Dessa forma, sem as abelhas, a segurança alimentar da humanidade estaria fortemente ameaçada.

Não obstante, a sociedade civil, bem como diversos outros ramos representativos da população brasileira como os estratos envolvidos com políticas públicas de preservação e mitigação ambiental, bem como a comunidade científica, acadêmica e demais atores envolvidos com o meio ambiente de maneira direta - ou indireta - precisam ser abastecidos continuamente de informações que possam valorizar o papel das abelhas ao planeta, bem como dos produtos por elas derivados.

A presente obra “*A Interface do Conhecimento sobre Abelhas*” é a mais recente iniciativa da Editora Atena no sentido de difusão de conhecimento, demonstração de aprimoramentos e divulgação de ideias, em forma de e-book, na área de Apicultura. A importância prática da própolis, subproduto oriundo das atividades comportamentais das abelhas, bem como a compreensão dos requerimentos nutricionais desses insetos; a composição físico-química, incluindo aminoácidos e minerais, além de análises qualitativas de amostras de méis oriundas da região Norte e Nordeste do Brasil com foco em abelhas sem ferrão são temas de caráter prático e aplicado abordados na presente obra. Além disso, estudos sobre a diversidade de espécies e o número total de indivíduos em áreas restauradas do bioma Cerrado, com ênfase na conservação e restabelecimento das populações de abelhas em paisagens agrícolas, incluindo a diversidade de análises polínicas de espécies florais polinizadas pela espécie *Bombus morio* são apresentadas. Por fim, um estudo sobre a influência de fatores ambientais no fluxo de entrada de grãos de pólen e sua coloração em colmeias de abelhas do gênero *Apis mellifera* finaliza a presente obra tratando de contribuições sobre o entendimento da complexa relação entre o meio ambiente e as atividades forrageadoras das abelhas.

Esperamos que o presente e-book, de publicação da Atena Editora, possa representar como legado, a oferta de conhecimento para capacitação de mão-de-obra através da aquisição de conhecimentos técnico-científicos de vanguarda praticados por diversas instituições em âmbito nacional; instigando professores, pesquisadores, estudantes, profissionais (envolvidos direta e indiretamente) com atividades apícolas frente ao acúmulo constante de conhecimento com potencial de transpor o conhecimento atual acerca dos processos envolvidos com a produção mel, atrelada à conservação das atividades ecológicas das abelhas: seres vivos de relevante importância a diversos sistemas naturais, bem como agroecossistemas terrestres.

Alexandre Igor de Azevedo Pereira

# SUMÁRIO

# CAPÍTULO 5

# DIVERSITY OF BEES IN RESTORED FORESTS LOCATED IN AGRICULTURAL LANDSCAPES

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**ABSTRACT:** Bees play an important role as pollinators in natural areas and provide important ecosystem services for agricultural production. We studied bee diversity in restored sites immersed in fragmented agricultural landscapes in Southeastern Brazil, which is, to our knowledge, the first study of its kind. We evaluated species diversity in restored areas at least five-year-old located in three sites within the Cerrado biome (savannah) in São Paulo, Brazil. We collected data through four methods (active search, spot observations, transect walks and trapping with colored pantraps) and assessed the total number of individuals and species found in each site. We performed spatial analyses to calculate the connectivity indexes for each area and related this bee diversity. We recorded 61 species of bees, 69% of which were solitary and 31% social. *Apis mellifera* was the only non-native species found and was the most abundant one in all sites. We found more species of bees in areas with higher Integral Connectivity Index. Even landscapes with very low natural vegetation cover can support a considerably high proportion of native bee community. Landscape connectivity together with tree diversity are important factors for the number of bee species supported in a given agricultural area. For this reason, we believe that ecological restoration can be a good way to support the conservation and reestablishment of bee populations in highly fragmented agricultural landscapes. We recommend that restoration projects contemplate an array of suitable plant species to provide resources for bees throughout the year.

**KEYWORDS:** Landscape connectivity; biodiversity conservation; pollinators; ecological interactions.

## DIVERSIDADE DE ABELHAS EM FLORESTAS RESTAURADAS LOCALIZADAS EM PAISAGENS AGRÍCOLAS.

**RESUMO:** As abelhas desempenham importante papel como polinizadores em áreas naturais e na produção agrícola. Estudamos a diversidade de abelhas em florestas restauradas, inseridas em paisagens agrícolas no sudeste do Brasil, que é, no nosso conhecimento, o primeiro estudo do gênero. Avaliamos a diversidade de espécies e o número total de indivíduos em áreas restauradas com pelo menos cinco anos de idade, localizadas em três locais dentro do bioma Cerrado (savana) em São Paulo, Brasil. Coletamos dados através de quatro métodos (busca ativa, observações pontuais, transectos e armadilhas coloridas). Realizamos análises espaciais para calcular os índices de conectividade de cada área e relacionamos isso com a diversidade de abelhas. Registramos 61 espécies de abelhas, 69% das quais eram solitárias e 31% sociais. *Apis mellifera* foi a única espécie não nativa encontrada e foi a mais abundante em todos os locais. Encontramos mais espécies de abelhas em áreas com maior índice de conectividade. Mesmo as paisagens com cobertura vegetal muito baixa podem suportar uma proporção consideravelmente alta da comunidade de abelhas nativas. A conectividade da paisagem junto com a diversidade de árvores são fatores importantes para o número de espécies de abelhas apoiadas em uma dada área agrícola. Por essa razão, acreditamos que a restauração ecológica pode ser uma boa maneira de apoiar a conservação e o restabelecimento das populações de abelhas em paisagens agrícolas. Recomendamos que os projetos de restauração contemplem uma variedade de espécies de plantas adequadas para fornecer recursos para as abelhas ao longo do ano.
**PALAVRAS-CHAVE:** Conectividade da paisagem; conservação da Biodiversidade; polinizadores; interações ecológicas.

## 1 I INTRODUCTION

The basic premise for an area to be considered a restored area is the restoration of ecological processes responsible for reconstruction and maintenance of a functional community (Ruiz-Jaen & Aide 2005). One of the most important ecological processes is cross-pollination, because it is essential for sexual reproduction of plants and, in their absence, the maintenance of genetic variability between plants does not occur, can lead to poor fruit and seed formation, fruit abortion and consequent non-formation of seed bank with propagules of these species (Castro et al. 2007).

Several restoration models were developed for restoration of ecosystems with different levels of disturbance. Recommendations to restore degraded areas in low resilience landscapes include planting seedlings of regional native tree species with high diversity (Gandolfi & Rorigues 2007). This restoration methodology helps to rebuild of forest and promotes the connection in the landscape between isolated remnants (Brancalion et al. 2013). Projects to restore degraded areas in low resilient landscapes it is common in São Paulo State - Brazil. Usually these projects are realized on the banks of rivers that in the past were old pastures, formed by grasses that are self-pollinated. However, this promotes the reintroduction of tree species and it is not known, if restored areas within the reported above context contribute to restoration of fauna groups, since due to the habitat loss and degradation process many species may have disappeared locally.

Pinheiro-Machado et al. (2002) cite about 52 studies of bee communities in Brazil, and most of them were made predominantly in natural areas and few in urban or agriculture areas. In addition, given the fragmentation and degradation of natural areas and land use conversion to agriculture and / or urbanization, it cannot be inferred if bee populations that remain in these areas are representative of what may have existed or, if they are only a small part of the existing potential. This makes it difficult to establish a baseline reference to have an expectation of the diversity of bees that can be found in certain localities (Silveira et al. 2002). In this way, the knowledge of communities of bees and their association with specific habitats, such as restored areas inserted in the agricultural landscape, is a large knowledge gap.

This study aims to identify the diversity of bee species in restored areas within a landscape with low percentage of native vegetation cover, high forest fragmentation and land use occupied by intensive farming for many years.

## METHODS

### *Study site*

We evaluated the richness and abundance of bee species from December 2013 to November 2014 in restored areas, for at least 5 years, in three farms located in the state of São Paulo: Ouro Verde Farm in Araraquara (coordinate 21º46'S and 48º20'W) with a restored area of 3.75 hectares, São José Farm in Nuporanga (coordinate 20º45'S and 47º45'W), with a restored area of 15 hectares and Santa Julia Farm in Bebedouro (coordinate 21º00'S and 48º34'W) with a restoration area of 12.25 hectares. In the three areas, the restoration strategy was the planting of native tree seedlings using high diversity of species (80+ species), in a 3 x 2 m spacing (1,667 trees/hectare and 6 $m^2$ per tree). These three municipalities are inserted within a phytogeographical context of Cerrado biomes (Figura 1). The historical occupation of land use in this region is based on convertion of most of the native vegetation into agricultural fields, and today only 5 to 8% of these municipalities' territory is covered by degraded native vegetation (São Paulo 2009).

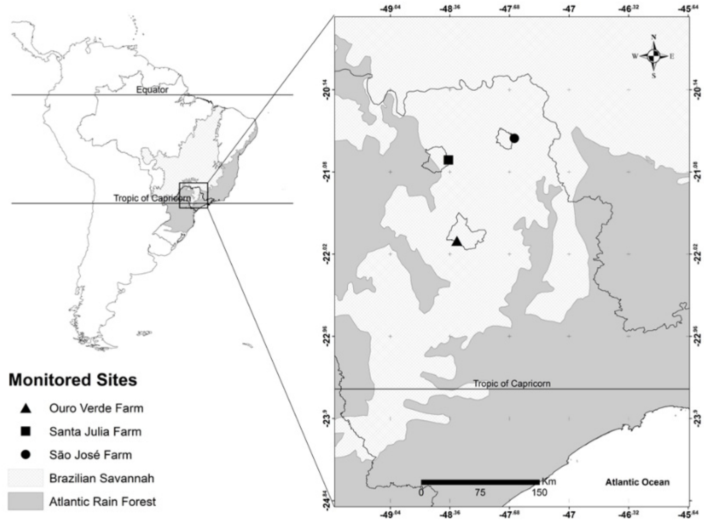


Figure 1. Location of the three forest restoration programs evaluated in São Paulo State, Brazil.

## Characteristics of Restored Areas

In 2014, we assessed native tree species richness in all sites. For species richness, we counted planted seedlings or wildlings (natural regeneration) (inclusion criterion was height > 50 cm).

## Survey of data

The individuals of the bee species were sampled throughout the 4 seasons of the year (summer, autumn, winter and spring). The evaluations were carried out mainly in the morning, due to the greater activities of the insects in the first hours of the day.

## Evaluation of richness of species and abundance of individuals

Due to the wide range of existing behaviors in bees the use of different capture methods is recommended to obtain a more reliable sample of the species richness in each location, therefore, in this study we used four assessment methodologies as described below:

- Visual assessment of flight intensity in transects - Transects were covered, passing the borders (between 0-10 m – agriculture area - restored area) and inside the restored areas (reforestation area with at least 10 m of agricultural area) in trails which had larger quantity of flowery tree species.

- Visual assessment of flight intensity in single location (spot observations) - three fixed points were chosen in stretches of borders and another three in stretches in the central area of reforestation for each of the restored areas.

The active collecting consisted in the capture and observation of bees on the flowers with the help of entomological nets throughout the restored area.

Colored pantraps (yellow, blue and white) were used for capturing of pollinators by visual attraction. Each pantrap was filled with soap water to avoid the escape of the trapped insects. The traps were randomly arranged within the restored areas with a minimum distance of 10 m from the agricultural area and 5 m between traps. The traps remained in place for 24 hours in the area, inspected every 4 hours. The trapped insects collected were stored in vials containing alcohol.

## Identification of bee species

For identification of the sampled species dichotomous keys containing the systematic descriptions of different taxa were used or was requested help of specialists. The specimens collected were transferred to bottles containing 70% alcohol, screened in laboratory and subsequently pinched and oven dried, labeled and deposited in the entomological collection of the Center of Studies of Social Insects, Department of Biology, Institute of Biosciences, UNESP campus of Rio Claro.

## Diversity Index

To evaluate the diversity of the studied sites we obtained the indicators of Maximum Richness (*S´*) which was defined as the number of species found in the restored areas studied, by the Shannon-Weaver index (*H'*) which was obtained from formula:

$$H' = \sum_{i=1}^{S} pi.Ln(pi) \quad (1)$$

pi = Abundance (proportion) of species i in the sample $(pi = ni/N)$

ni = number of individuals of species i

N= total number of individuals in the sample

and by the Pielou Equability index (J ‘) which was calculated using the formula:

$$J' = H'/Hmax \quad (2)$$

J = Pielou Equability

H’ = Shannon diversity index

Hmáx= ln(S).

The Shannon-Weaver diversity index expresses both species richness and uniformity, to consider the weight of rare and abundant species. The greater value of *H’*, the greater the diversity of the community under study (Magurran 1988). The index of Pielou Equability belongs to the interval [0,1], it allows to represent the uniformity of the distribution of individuals among the existing species (Pielou 1966). Its value ranges from 0 (minimum uniformity) to 1 (maximum uniformity - the probability of all species having the same abundance).

## Similarity Indexes

The species composition similarity was calculated between the different seasons of the year using the Jaccard index. The Jaccard index considers the number of common species between two areas (a) and the number of species unique to each area (b, c) (Mueller-Dombois & Ellenberg 1974):

$$Jac = 100a / (a + b + c) \quad (3)$$

Based on this index, a dendrogram based on the group average (UPGMA) was elaborated, in which the grouping is done from the arithmetic mean of the elements, generating a dendrogram, in which the ordinate values express the similarity relations between the objects indicated in the abscissa (Sneath & Sokal 1973). Similarity analysis was performed using Vegan package from software R (Oksanen et al., 2016).

### Integral Connectivity Index

The connectivity of the landscape is understood in this study as the capacity of faunistic elements to move throughout the landscape (JOHNSON et al., 1992). The Integral Connectivity Index (IIC), a measure of connectivity based on the graph theory proposed by Pascual-Hortal and Saura (2006), can vary from 0 to 1, increasing as the landscape becomes more connected. It is calculated for a given part of the landscape and considers not only the value of the remaining vegetation area but also the number of connections between the fragments for a given dispersion capacity of an organism according to the following formula:

$$IIC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i a_j \big/ (1 + nl_{ij})}{A_L^2} \quad (4)$$

where:

$a_i$ is the area of the forest fragment $i$;

$a_j$ is the area of the forest fragment $j$;

$nl_{ij}$ is the number of connections between forest fragments $i$ e $j$;

$A_L$ is the total area of landscape.

We evaluated the IIC considering the moment before and after the restoration activities were carried out in the three areas studied. The areas of the forest fragments in the previous moment of restoration activities were obtained from the Forest Inventory of the Natural Vegetation of São Paulo State (Kronka et al., 2005) and at the later moment, the fragments resulting from the restoration activities were added to perform the calculations. In order to analyze connectivity of the forest fragments, six pre-determined distances (500, 1000, 1500, 2000, 2500 and 3000 meters) were considered, which were based on the flight capacity of native social bees contained in ARAUJO et. al. (2004). Then the values obtained for the IIC were compared using the t-test to assess if there was a difference in landscape connectivity (ZAR 1999). The delimitation of the total area of the landscape was obtained by the buffer of 3 kilometers from the boundaries of the three farms. This analysis was performed using the sofwares Arc Gis 10.6 and Sensinode 2.5.8.

## RESULTS

We collected 11,721 individuals from 61 species of bees. A total of 24 species (40%) were common to all sites; 12 (20%) were found in two farms; and 25 (40%) were exclusive to one study area. The abundance of bees was greatest in Winter and in Spring (4,193 in Spring; 1,249 in Summer; 3,134 in Fall ; and 3,144 in Winter)  (Table 1).

| Classification | habit of life | Ouro Verde Farm | | | | Santa Julia Farm | | | | São José Farm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sp | Su | Au | Wi | Sp | Su | Au | Wi | Sp | Su | Au | Wi |
| APIDAE | | | | | | | | | | | | | |
| *Anthophorinae* | | | | | | | | | | | | | |
| *Anthophorini* | | | | | | | | | | | | | |
| *indeterminada* | Solitary | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| *Centridini* | | | | | | | | | | | | | |
| *Centris sp. Fabricius, 1804* | Solitary | 0 | 0 | 1 | 0 | 3 | 1 | 6 | 0 | 18 | 1 | 2 | 0 |
| *Epicharis sp.Klug, 1807* | Solitary | 1 | 2 | 2 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 1 | 0 |
| *Emphorini* | | | | | | | | | | | | | |
| *Melitoma sp. Lepeletier & Serville, 1828* | Solitary | 1 | 1 | 0 | 0 | 26 | 19 | 27 | 5 | 4 | 0 | 0 | 0 |
| *Melitoma segmentaria (Fabricius, 1804)* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| *Ptilothrix sp. Smith, 1853* | Solitary | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Eucerini* | | | | | | | | | | | | | |
| *Indeterminada* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Melissodes sp. Latreille, 1829* | Solitary | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| *Melissoptila sp. Holmberg, 1884* | Solitary | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Thygater sp. Holmberg, 1884* | Solitary | 3 | 2 | 5 | 0 | 1 | 0 | 0 | 0 | 2 | 5 | 0 | 3 |
| *Peponapis sp. Robertson, 1902* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| *Apinae* | | | | | | | | | | | | | |
| *Apini* | | | | | | | | | | | | | |
| *Apis mellifera Linnaeus, 1758* | Social | 1734 | 190 | 717 | 318 | 668 | 329 | 714 | 1466 | 408 | 103 | 482 | 722 |
| *Indeterminada* | NC | 3 | 0 | 2 | 0 | 20 | 4 | 19 | 2 | 0 | 17 | 6 | 0 |
| *Euglossini* | | | | | | | | | | | | | |
| *Indeterminada* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Euglossa sp. Latreille, 1802* | Solitary | 0 | 0 | 0 | 0 | 4 | 5 | 2 | 0 | 14 | 0 | 0 | 1 |
| *Eulaema sp. Lepeletier, 1841* | Solitary | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 2 | 0 | 0 | 1 | 0 |
| *Eulaema (Apeulaema) nigrita Lepeletier, 1841* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 0 | 0 | 0 |
| *Exomalopsini* | | | | | | | | | | | | | |
| *Indeterminada* | Solitary | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Exomalopsis (Exomalopsis) auropilosa Spinola, 1853* | Solitary | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| *Exomalopsis sp. Spinola, 1853* | Solitary | 3 | 2 | 8 | 0 | 51 | 4 | 59 | 7 | 46 | 4 | 57 | 0 |
| *Tetrapediini* | | | | | | | | | | | | | |
| *Tetrapedia sp. Klug, 1810* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| *Bombinae* | | | | | | | | | | | | | |
| *Bombini* | | | | | | | | | | | | | |
| *Bombus sp. Latreille, 1802* | Social | 0 | 0 | 5 | 1 | 2 | 18 | 28 | 1 | 24 | 0 | 5 | 36 |
| *Bombus (Fervidobombus) morio (Swederus, 1787)* | Social | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| *Meliponinae* | | | | | | | | | | | | | |
| *Meliponini* | | | | | | | | | | | | | |
| *Indeterminada* | Social | 0 | 0 | 11 | 24 | 1 | 0 | 0 | 0 | 6 | 0 | 0 | 0 |
| *Camargoia sp.Moure, 1989* | Social | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Geotrigona sp. Moure, 1943* | Social | 0 | 1 | 7 | 0 | 0 | 2 | 6 | 0 | 1 | 0 | 0 | 0 |
| *Geotrigona subterranea (Friese, 1901)* | Social | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| *Melipona quadrifasciata Lepeletier, 1836* | Social | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
| *Oxytrigona sp. Cockerell, 1917* | Social | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Paratrigona sp. Schwarz, 1938* | Social | 12 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 8 | 29 |
| *Paratrigona lineata (Lepeletier, 1836)* | Social | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| *Scaptotrigona sp. Moure, 1942* | Social | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tetragona sp. Lepeletier & Serville, 1828* | Social | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 |
| *Tetragonisca sp. Moure, 1946* | Social | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tetragonisca angustula (Latreille, 1811)* | Social | 3 | 0 | 12 | 0 | 21 | 4 | 45 | 0 | 10 | 0 | 0 | 12 |
| *Trigona sp. Jurine, 1807* | Social | 8 | 12 | 0 | 0 | 2 | 25 | 19 | 2 | 1 | 0 | 0 | 0 |
| *Trigona hyalinata (Lepeletier, 1836)* | Social | 3 | 9 | 75 | 0 | 11 | 69 | 58 | 12 | 3 | 2 | 3 | 43 |
| *Trigona spinipes (Fabricius, 1793)* | Social | 161 | 8 | 58 | 39 | 66 | 103 | 226 | 31 | 39 | 29 | 58 | 186 |
| *Trigonisca sp. Moure, 1950* | Social | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Xylocopinae* | | | | | | | | | | | | | |
| *Ceratinini* | | | | | | | | | | | | | |
| *Ceratina sp. Latreille, 1802* | Solitary | 2 | 2 | 1 | 0 | 34 | 3 | 8 | 7 | 5 | 0 | 0 | 1 |
| *Xylocopini* | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Xylocopa sp. Latreille, 1802 sp* | Solitary | 16 | 31 | 5 | 3 | 20 | 59 | 18 | 1 | 29 | 17 | 0 | 5 |
| | *Xylocopa (Neoxylocopa) suspecta Moure & Camargo, 1988* | Solitary | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| HALICTIDAE | | | | | | | | | | | | | | |
| | *Halictinae* | | | | | | | | | | | | | |
| | *Indeterminada* | Solitary | 94 | 14 | 137 | 13 | 265 | 30 | 51 | 19 | 79 | 14 | 31 | 29 |
| | *Augochlorini* | | | | | | | | | | | | | |
| | *Indeterminada* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | *Augochlora sp. Smith, 1853* | Solitary | 12 | 9 | 3 | 6 | 26 | 13 | 12 | 24 | 22 | 5 | 8 | 19 |
| | *Augochlorella Sandhouse, 1937* | Solitary | 17 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| | *Augochloropsis sp. Cockerell, 1897* | Solitary | 13 | 1 | 1 | 0 | 27 | 6 | 1 | 22 | 6 | 5 | 3 | 0 |
| | *Paroxystoglossa sp. Moure, 1941* | Solitary | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Pseudaugochlora sp. Michener, 1954* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 11 | 5 | 0 | 0 | 1 |
| | *Temnosoma sp. Smith, 1853* | Solitary | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Halictini* | | | | | | | | | | | | | |
| | *Indeterminada* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| | *Agapostemon sp. Guerin-Meneville, 1844* | Solitary | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | *Dialictus sp. Robertson, 1902* | Solitary | 24 | 1 | 27 | 7 | 8 | 4 | 4 | 11 | 16 | 0 | 21 | 3 |
| | *Habralictus sp. Moure, 1941* | Solitary | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MEGACHILIDAE | | | | | | | | | | | | | | |
| | *Megachilinae* | | | | | | | | | | | | | |
| | *Megachilini* | | | | | | | | | | | | | |
| | *Megachile sp. Latreille, 1802* | Solitary | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| COLLETIDAE | | | | | | | | | | | | | | |
| | *Colletinae* | | | | | | | | | | | | | |
| | *Colletini* | | | | | | | | | | | | | |
| | *Colletes sp. Latreille, 1802* | Solitary | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | *Diphaglossinae* | | | | | | | | | | | | | |
| | *Diphaglossini* | | | | | | | | | | | | | |
| | *Ptiloglossa sp. Smith, 1853* | Solitary | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ANDRENIDAE | | | | | | | | | | | | | | |
| | *Oxaeinae* | | | | | | | | | | | | | |
| | *Indeterminada* | Solitary | 3 | 2 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| | *Oxaea flavescens Klug, 1807* | Solitary | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 2 | 0 |
| | *Oxaea sp. Klug, 1807* | Solitary | 7 | 0 | 8 | 1 | 0 | 3 | 13 | 0 | 5 | 6 | 6 | 4 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Chaeturginus sp. Lucas de Oliveira & Moure, 1963* | Solitary | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 |
| Total | | 2129 | 289 | 1101 | 412 | 1276 | 745 | 1333 | 1631 | 789 | 215 | 700 | 1101 |

Table 1. Diversity and abundance of bees, separated by season, found in the three farms evaluated. (Sp = Spring, Su = Summer, Au = Autumn, Wi = Winter).

The largest number of species was in the São José Farm, but lower abundance of individuals. The Shannon-Weaver and Pielou equability indexes were higher in the São José Farm, followed by Santa Julia and Ouro verde farms (J = 0.44, 0.42, 0.32 Pielou equability) and (H’ = 1.64, 1.61, 1.13 Shannon-Weaver index). The cover of native vegetation was higher in Fazenda São José, but the number of tree species found in the restored areas was the lowest. (Table -2).

| Site | Ouro Verde | Santa Julia | São José | Total | Average |
|---|---|---|---|---|---|
| Individuals | 3,931 | 4,985 | 2,805 | 11,721 | 3,907 |
| Bee species | 35 | 45 | 44 | 61 | |
| Shannon Diversity Index (H’ ) | 1.13 | 1.61 | 1.64 | | |
| Pielou Equability Index (J’ ) | 0.32 | 0.42 | 0.44 | | |
| Total native vegetation cover (%) | 2.30% | 4.50% | 6.90% | | 4.50% |
| Tree diversity of restored forests | 66 | 94 | 43 | | 68 |

The species richness showed great variation throughout the different seasons of the year. The records were larger during spring and autumn (43 during spring, 39 in autumn, 34 in summer and 30 in winter). The cluster analysis showed that only for São José and Ouro Verde there was formation of a group for summer season, and São José farm was the only one had a group to two seasons (Figure 3).

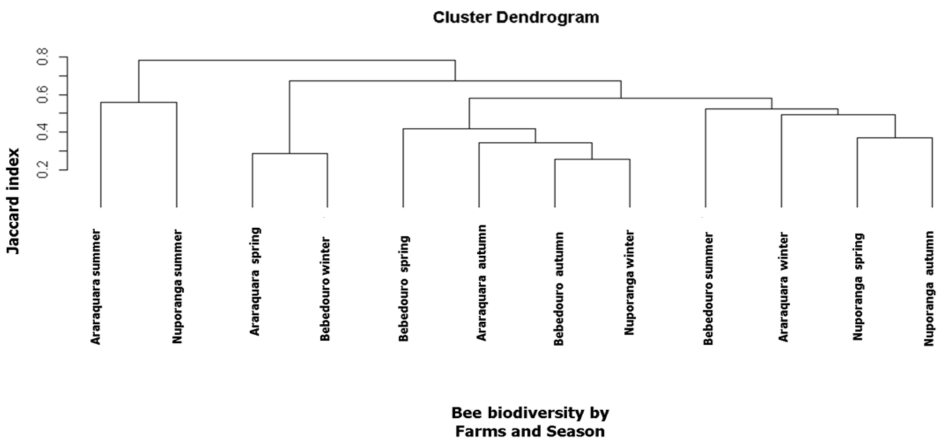


Figure 3. Cluster analysis dendrogram (UPGMA), based upon Jaccard’s Similarity Index, considering the bee biodiversity over the 4 seasons (Summer, Autumn, Winter and Spring) to the three farms evaluated.

### *Landscape Connectivity*

Restoration activities resulted in significant modifications in landscape connectivity for the three study areas. However, the values obtained for the IIC were low and did not exceed 0.001, even considering the possibility of landscape connectivity to a distance of 3,000m. The two sites with higher connectivity were also the sites that hosted the highest diversity of bees. (Table 3). These values are consistent with a landscape with few remnants of native vegetation, a reality found in the three study areas mainly for the Ouro Verde farm located in the municipality of Araraquara (Figure 4).

| Ouro Verde Farm | | São José Farm | | Santa Julia Farm | | Connectivity Distance (m) |
|---|---|---|---|---|---|---|
| IIC Before Restoration | IIC After Restoration | IIC Before Restoration | IIC After Restoration | IIC Before Restoration | IIC After Restoration | |
| 0,0000018 | 0,0000125 | 0,0007136 | 0,0010767 | 0,0001115 | 0,0003928 | 3000 |
| 0,0000018 | 0,000011 | 0,0006498 | 0,0009925 | 0,0000712 | 0,0003841 | 2500 |
| 0,0000018 | 0,0000109 | 0,0005799 | 0,0009369 | 0,0000599 | 0,0003548 | 2000 |
| 0,0000013 | 0,0000089 | 0,0004581 | 0,0007394 | 0,0000598 | 0,0003497 | 1500 |
| 0,0000013 | 0,0000087 | 0,0001459 | 0,0002956 | 0,0000466 | 0,0002657 | 1000 |
| 0,0000013 | 0,0000052 | 0,0001108 | 0,0002267 | 0,0000372 | 0,0001763 | 500 |
| 0,0000015 ± 0,0000003 | 0,000009 ± 0,00003 | 0,0004 ± 0,00026 | 0,0007± 0,00037 | 0,00006± 0,00005 | 0,0003 ± 0,00008 | |
| p<0,0001 | | p<0,002 | | p<0,0001 | | |

Table 3. Comparation of Connectivity Integral Index (IIC) for the three farms (Ouro Verde, Santa Julia and São Jose) using t-test, considering the moment before and after restoration activities, for six scenarios of connectivity distance.

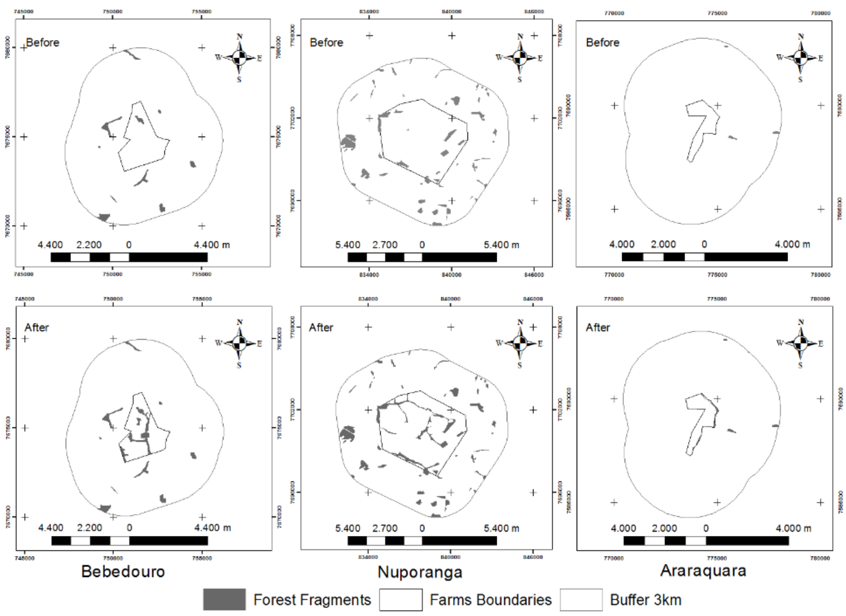


Figure 4. Remnants of native vegetation before and after restoration activities in three farms evaluated (Ouro Verde, Santa Julia and São José Farms). Datas on the remnants of native vegetation before restoration activities were obtained from Kronka et al., (2005)

## Discussion

The diversity of bees we found (61 species) corresponds to approximately 58% of what is known for the Cerrado in the State of São Paulo (Imperatriz-Fonseca et al., 2010) and to 9% of the species that occur in the State as a whole (Pedro & Camargo 1999). This is a surprising result, considering that our study areas had only an average 4.5% natural vegetation cover. These results highlight the importance of natural remnants and restored sites within fragmented agricultural landscapes.

Two thirds of the recorded species were solitary bees. The percentage of social species (29%) was considered high, since 95% of the species catalogued in the world are known for their solitary life history traits (Imperatriz-Fonseca et al. 2007). This result may help to understand how bees with different life history can colonize the restored areas in landscapes with low percentage of native vegetation cover, because many species have limited flight radius and, depending on the distance, would not be able to reach the restored areas alone due to fragmentation, while others with longer flight radius, particularly solitary bees, could.

The life cycle of the solitary bees can have great influence on their distribution areas, because many species nest in the ground, in bounds, dead trunks, fence post and even in holes in walls. As they produce fewer offspring, the need for food is smaller, which can be supplied by a few plants nearby while maintaining a small pool of bees in the area and, therefore, when the restoration project is installed, they benefit and settle rapidly.

In the case of the social bees, the food demand to keep the colony is larger. Bees nest in tree trunks, especially of older and even dead trees, which does not occur in restored environment in the early years of project establishment. Thus, many species are not able to colonize the restored areas at first, but can use the area in search of food at times when there is availability of floral resource.

There are few inventories of bee communities in remnants of native vegetation (Steiner et al., 2006; Alves-Dos-Santos 2007; Mouga & Krug 2010). In these studies the species richness found is quite distinct (32 - 292), possibly because each of them has been developed in different localities, with different aims, methods and sample effort. It is common to obtain more than 100 bee species in the surveys conducted in environments of natural vegetation in areas of the interior of Brazil (Pinheiro-Machado et al., 2002). Silveira et al., (1993) found more than 140 species in an inventory carried out in an abandoned pasture area undergoing regeneration process, inserted in landscape with high resilience.

There are only few publications that present score values for biodiversity index. Pinheiro-Machado et al. (2002) for inventories made up to one year, the value found for the Shannon-Weaver index varied between 2,11 and 4,48 nat/ind-1 and equability between 0,5 and 0,8. Our values were lower than those mentioned, however, we reinforce that we included in the index value Apis mellifera computation that was to species with greater number of individuals for the three surveys and this reflected in the values found, since these indexes are sensitive to the value of abundance of species.

Despite the increase in connectivity in the landscape, the values found for IIC in the three study areas were low. The restoration of degraded areas increased the connectivity of our study sites and we found greater bee diversity in areas with greater connectivity indexes. However, we observed that in Santa Julia and São José Farm that had higher IIC values, the number of species found was higher than in the Ouro Verde farm with less forest fragments. The São José Farm has the most area of native vegetation and Santa Julia farm has most species in restored areas. Comparatively 30% of the species found were restricted to only one study area, which may indicate that many bee populations are isolated because of the fragmentation effect and lack of landscape connectivity. Poor connectivity can affect mainly those species that move at close range. This reinforces the importance of stimulating forest restoration activities to promote the increase of areas covered by native vegetation, diversity of flora and connectivity of the landscape for it to be permeable to the displacement of the fauna. This also strengthens the importance of conserving native vegetation remnants existing in the landscape, regardless of their size or conservation status, because they may be refuges of bee populations that have been isolated due to the habitat loss process.

This study can be considered as a first step to understand the presence of bees in restored areas in locations with intensive agricultural activity. We understand that restored areas, especially in landscapes occupied predominantly by agriculture and high forest fragmentation, can be important for the conservation of bee fauna. According to Garcia et al., (2015), restored areas take a long time to achieve functional diversity equivalent to natural forests including flowering aspects. However, much can still be improved to enable these spaces to be recolonized by the different populations of bees, for example: more studies that classify/catalog bee community in restored areas; New models of restoration considering the introduction of herbaceous species and providing improvement for nesting conditions of social bees; Set of plant species provider of nectar, pollen and vegetable oils, used by different species of bees at best all year around; Understanding the network of interactions of bees with different agricultural crops - agricultural area, restored area, native vegetation and anthropized areas.

## CONCLUSION

Fragmented agricultural landscapes are very important for the conservation of native bees in the Brazilian Cerrado. Small restored areas can increase greatly landscape connectivity. In these landscapes, both natural vegetation remnants and restored areas contribute to support bee species. Even landscapes with very low natural vegetation cover can support a considerably high proportion of native bee community. Landscape connectivity together with tree diversity of restored sites are important factors to increase the number of bee species supported in a given agricultural area. Lastly, we recommend that restoration projects contemplate an array of suitable plant species that can provide resources for bees throughout the year. To our knowledge, this is the first study on native bees in restored tropical areas.

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