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Plant-bee interactions and pollen flux in restored  
areas of Atlantic Forest

Interações planta-abelha e o fluxo de pólen em  
áreas restauradas de Mata Atlântica

São Paulo

2018

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Tese apresentada ao Instituto de Biociências da Universidade de São Paulo, para a obtenção de Título de Doutor em Ecologia, na Área de concentração: Ecologia de Ecossistemas Terrestres.

EXEMPLAR CORRIGIDO - O original encontra-se disponível no Instituto de Biociências da USP

Orientadora: Isabel Alves dos Santos

São Paulo

2018

## Ficha cartográfica

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Montoya-Pfeiffer, Paula María

Plant-bee interactions and pollen flux  
in restored areas of Atlantic Forest

92 pages

Thesis (Doctoral) - Institute of  
Biosciences of the University of São Paulo.  
Department of Ecology.

1. Apoidea 2. Community Ecology  
3. Pollination. I. University of São Paulo.  
Institute of Biosciences. Department of  
Ecology.

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Prof

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Prof.

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Prof

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Prof.

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Orientadora Prof.

## Acknowledgements

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I would like to thank my adviser, Prof. Isabel Alves dos Santos, for the friendship and advice she has provided throughout my time as her student and for giving me the opportunity to make part of this program. The members of my dissertation committee Ricardo Ribeiro Rodrigues, Jean Paul Metzger, Claudia Inês da Silva, and the professors Oswaldo Baquero and Peter Kevan, for the valuable suggestions they made to this work.

I thank the staff from the BeeLab for the research support, in particular Paulo Cesar Fernandes for his help in field work. I also want to thank the Online Pollen Catalogs Network (RCPol) for the help with pollen analysis, and the secretary from the department of Ecology Vera Lima for the patient guidance in bureaucratic procedures.

I am grateful to the Administrative Department of Science, Technology and Innovation from Colombia (COLCIENCIAS) and the Coordination for the Improvement of Higher Education Personnel from Brazil (CAPES), for providing the funding which allowed me to undertake this research. I also thank the Organizing Committees of the VII World Conference on Ecological Restoration SER 2017 and the XIX International Botanical Congress for giving me the opportunity to attend conferences and share this work.

Finally, I wish to thank my family and friends, especially Sebastian, Dioneval and Julian for the company and providing me with many ways to escape from my studies. I am most thankful and want to apologize to my mom for not being with her, and all the bees I had to kill, to whom I dedicate this work.

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## General Introduction

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Habitat fragmentation on agricultural landscapes reduces the population size of many plant species and increases their spatial isolation. As a result, plant genetic variability is reduced due to a blockage in the gene flow that is carried out by pollinators and seed dispersers (Dick et al. 2008; Aavik & Helm 2018). Within the remaining isolated populations, reproduction between close relatives or genetically similar plants (produced by seeds from the same matrix or matrixes with a certain grade of relatedness) can be problematic as a consequence of genetic self-incompatibility systems that impede seed fecundation, even when pollination (i.e. transference of pollen grains to the stigma) is accomplished (McKay et al. 2005). Thus, plant species success becomes critical because of a seed production decline. High genetically varied populations in conserved areas in contrast, have greater adaptive capacity in the face of environmental changes, since they contain genes from distant relatives adapted to different environmental conditions, which enhance the survival chances for their descendants in the long term (Dick et al. 2008; Aavik & Helm 2018).

As a consequence of fragmentation, the conservation and restoration of pollinators is essential for sustaining viable plant populations, because they promote pollen transport and gene flux among individuals in isolated fragments. As it is expected that populations in remnant and restored plant communities perpetuate with the passing of the years, restoration programs on high fragmented agricultural landscapes should be planned with consideration for achieving this purpose (Montalvo et al 1997; Castro, 2007; Castro et al. 2007). However, little has been done in this regard, as most studies on restoration ecology have been centered in solving problems of shorter term priority, specially related with the initial establishment of plant populations (e.g. seed colonization and germination, seedling survival and so on) (Rodrigues et al. 2009; 2011), while applied pollination studies have

been focused on enhancing the reproductive success and productivity of crop plant species important for human food security (Kremen et al. 2007; Dixon 2009; Menz et al. 2011).

In this work, we evaluate plant-pollinator interactions in restored tropical forests, aiming to establish first, the pollination requirements of plant species in these forests, and secondly, if the pollinator requirements are being fulfilled and the interactions between plants and pollinators are being recovered throughout restoration practices. This work comprises two chapters structured as articles:

**Chapter 1. Are the assemblages of tree pollination modes being recovered by tropical forest restoration?** By doing an extensive literature review about the pollination biology of tree species in primary forests, restoration plantings and naturally regenerated forests, we compare and identify patterns on the functional diversity and the assemblages of plant pollination modes in these communities.

**Chapter 2. Functional responses and effects from bee communities in restored tropical forests.** By sampling bees (i.e. the most important pollinators) and identifying the pollen grains attached to their bodies, we analyze and compare the functional diversity of bee communities and their floral resources, and the structure of plant-bee interactions in primary forests, restoration plantings, disturbed herbaceous areas and sugar cane fields, as well as in response to habitat isolation.

Finally, we discuss the implications of different restoration and landscape design practices on the recovery of plant-pollinator interactions.

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# Chapter 1

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## Are the assemblages of tree pollination modes being recovered by tropical forest restoration?<sup>1</sup>

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### ABSTRACT

**Questions:** Do the assemblages of pollination modes in restored (tree plantings) and secondary (naturally regenerated) forests change in comparison with primary forests, and how do these assemblages relate to species turnover at regional scale?

**Location:** Southeast region of Brazil.

**Methods:** We classified tree species found in a total of 40 forest sites (18 primary, 11 restored, 11 secondary) according to pollination mode, based on the literature. We calculated and compared functional dissimilarity distances, amounts of species and accumulated abundance of pollination modes, and functional indices of richness and evenness between forest types.

**Results:** Functional dissimilarity distances were much smaller than species dissimilarity distances within forest types (mean values, < 20%, > 80%, respectively), indicating a small variation in pollination modes between sites. Functional indices of richness and evenness did not differ between forest types. However, significant changes

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<sup>1</sup> Article published in: Montoya-Pfeiffer, P. M., Rodrigues, R. R., Metzger, J. P., da Silva, C. I., Santos Baquero, O., & Alves dos Santos, I. (2018). Are the assemblages of tree pollination modes being recovered by tropical forest restoration? *Applied Vegetation Science*, 21(1): 156-163. Manuscript attached at the end of this document.

were found in the species and abundance proportions of several pollination modes. Primary forests were characterized by the predominance of generalized insect-pollinated species, followed by secondary proportions of bee, wind, and moth pollination; other pollination modes were underrepresented. In restored forests, reductions were found in generalized insect, moth, wind, fly, pollen-consuming insect, and very-small insect pollination, whereas the species pollinated by bees and bats were more than doubled. Smaller changes were found among secondary forests, including reductions in moth, fly, and fig-wasp pollination, whereas there were incremental changes in bee, beetle, big animal, and small insect pollination.

**Conclusions:** Our results indicated a rather stable assemblage of pollination modes and also high ecological redundancy among trees regardless of the species replacement at the regional scale. Major changes among restored forests are probably in response to larger disturbance effects and/or restoration practices conducted in these sites. In contrast, smaller changes among secondary forests could be in response to smaller disturbance effects and natural selection processes and also seem to suggest that highly resilient degraded areas are more likely to recuperate their functional diversity by natural regeneration alone. In both cases, however, efforts in recovering such patterns should be encouraged to avoid possible negative effects in plant–pollinator interactions.

**Keywords:** Atlantic forest; Brazil; community structure; ecosystem management; forest fragmentation; functional diversity; human disturbance; meta-analysis; natural regeneration; plant-animal interactions; pollination syndromes; reproductive traits; restoration ecology; semi-deciduous forest.

## RESUMO

**Perguntas:** Os sistemas de polinização em florestas restauradas (plantios de árvores) e secundárias (naturalmente regeneradas) diferem daqueles das comunidades de florestas primárias, e como estes se relacionam com a substituição de espécies em escala regional?

**Localização:** Região sudeste do Brasil.

**Métodos:** Classificamos as espécies de árvores encontradas em 40 áreas florestais (18 primárias, 11 restauradas, 11 secundárias) por seu modo de polinização, baseando-nos na informação achada na literatura. Calculamos e comparamos as distâncias de dessemelhança funcional, quantidades de espécies e abundâncias acumuladas dos modos de polinização, e índices funcionais de riqueza e equitatividade entre tipos de florestas.

**Resultados:** A dissimilaridade funcional foi muito menor que a dissimilaridade em espécies entre locais de amostragem (valores médios, < 20%, > 80%, respectivamente). A riqueza e equitatividade funcional não se diferenciaram entre tipos de florestas. Porém, se encontraram diferenças significativas nas proporções de espécies e abundância de vários modos de polinização. As florestas primárias se caracterizaram pela predominância de espécies generalistas polinizadas por insetos, seguidas por proporções secundárias de espécies polinizadas por abelhas, vento e mariposas; outros modos de polinização estiveram sub-representados. Nas florestas restauradas diminui a polinização por insetos (generalistas), mariposas, vento, insetos consumidores de pólen, e insetos muito pequenos, enquanto que as proporções das plantas polinizadas por abelhas e morcegos duplicaram. As diferenças foram menores nas florestas secundárias, incluindo reduções na polinização por mariposas, moscas, vespas das figueiras, enquanto foram incrementadas as proporções das espécies polinizadas por abelhas, besouros, animais grandes e insetos pequenos.

**Conclusões:** Nossos resultados indicam uma assembléia de modos de polinização relativamente estável, além de alta redundância ecológica nas comunidades de árvores em escala regional. As maiores diferenças nas florestas restauradas provavelmente responderam a maiores efeitos de degradação e/ou às práticas de restauração ativa conduzidas nestas áreas. Por sua vez, as menores diferenças nas áreas secundárias poderiam ser explicadas pelos menores efeitos de degradação e os processos de seleção natural, sugerindo que as áreas altamente resilientes são mais propensas a recuperar sua diversidade funcional simplesmente mediante regeneração natural. Nos dois casos, porém, os esforços para recuperar os padrões das florestas primárias devem ser estimulados, para evitar possíveis consequências negativas nas interações planta-polinizador.

**Palavras chave:** floresta atlântica; Brasil; estrutura de comunidades; manutenção de ecossistemas; fragmentação florestal; diversidade funcional; distúrbio antrópico; regeneração natural; interações planta-animal; síndromes de polinização, atributos reprodutivos; ecologia da restauração; floresta semidecidual.

## INTRODUCTION

Tropical forests are rapidly being degraded worldwide, affecting biodiversity, ecosystem functioning, and the provision of ecosystem services. Consequently, their recuperation by means of ecological restoration is becoming a pressing necessity to recreate lost habitats for endangered species, while promoting human welfare and economic development (SER 2004). The success and sustainability of restoration programs depend on not only the retrieval of species diversity but also the diversity of functional traits, i.e., morphological, physiological, behavioral, structural, and phenological characteristics, considered relevant to their response to the environment and/or their effect on ecosystem properties and services (Lugo 1992; Silver 1996; Violle et al. 2007; Rodrigues et al. 2009; Cadotte et al. 2011). These include, for example, traits involved in the ability of a plant to colonize, compete, and regenerate, to establish and persist in a restored community (e.g., seed viability, dispersal strategy, light tolerance, and growth rate) or traits associated with ecosystem services like water purification, carbon sequestration, or wood provision (e.g., nutrient fixation, wood density, and growth rate), from which landholders would benefit.

Plant pollination modes, comprising strategies and adaptations for attracting pollinators, have received little attention in the context of restoration ecology (Girao et al. 2007; Ceccon & Varasin 2014; Garcia et al. 2015; Martins & Antoni 2016). Yet, the restoration of floral source diversity and availability in plant communities guarantees the wellbeing of their pollinators (Heithaus 1974; Carvalheiro et al. 2013; Dicks et al. 2015) and subsequently, the maintenance of the functions and services derived from plant species (Ashman et al. 2004; Fontaine et al. 2006; Kremen et al. 2007). The intraspecific genetic diversity in plants, which is indispensable for the preservation and evolution of restored forests, sometimes relies more on pollen vectors than on seed vectors (e.g., in the case of

autochoric species) (Helsen et al. 2016; Lexer et al. 2016) or may be dissimilarly affected by both when these exhibit different dispersal patterns, occurring at different distances and directions (Beckie et al. 2016; Miller 2016; Wang et al. 2016). Moreover, pollinators may sometimes indirectly benefit seed dispersal and seedling recruitment by the enhancement of seed and fruit set/size (Bond 1994; Lundgren et al. 2016). Pollinator conservation by ecological restoration has also been shown to improve crop pollination services, which could be translated into additional incentives and revenues for the implementation of restoration programs in agricultural regions (Heithaus 1974; Carvalheiro et al. 2013; Dicks et al. 2015).

Different restoration scenarios may lead to variable species assemblages with possible detrimental effects on the diversity of pollination modes. For instance, highly devastated areas that have lost their capacity to auto recuperate and require tree plantings for restoration would probably generate plant communities diverging more from the original ones. In contrast, less disturbed areas that are still highly resilient and capable of auto regenerating naturally, without the necessity to implement active restoration practices, would probably generate plant communities diverging less from the original ones (Rodrigues et al. 2009; Brancalion et al. 2015). The consequences of these possible scenarios have been explored to a small extent (Chazdon et al. 2003; Girão et al. 2009; Lopes et al. 2009; Kimell et al. 2010; Garcia et al. 2015; Martins & Antoni 2016). Hence, in the present study, we compared the diversity of pollination modes in restoration plantings and naturally regenerated forests with that in primary forests in Brazil. Given that species assemblages vary spatially in response to local environmental and landscape conditions and the geographic distribution of species (Torres et al. 1997, Brancalion et al. 2015), we included plant communities from several locations to understand how the diversity of pollination modes relates to species turnover at a regional scale, as well as to search for patterns that could be used as a model for restoration planning in tropical forests.

## METHODS

The present study was based on data from 40 floristic surveys conducted in tree communities within the domain of tropical semi-deciduous forests in the Atlantic forest biome in Brazil (Veloso et al. 1991). These surveys were selected because they used a similar methodology (phytosociological data obtained from trees above 4.5 cm diameter at breast height) and the species importance values (used herein as a proxy for abundance) were available. 18 surveys were conducted in relatively well-conserved primary forest fragments, although some of them were slightly affected by selective logging and livestock grazing (named herein as “remnants”). 11 surveys were conducted in degraded sites restored with tree plantings of various native and exotic species (named herein as “restored”). The remaining 11 surveys were conducted in less degraded areas restored by natural regeneration alone (named herein as “secondary”). The maximum distance between sites was 986 km and the minimum was 100 m (19°26′–23°33′S and 41°13′–50°27′W). The elevation varied between 100 and 1025 masl. The climate of the region was classified as Cwa, Cwb, or Cfa in the Köppen system (1948), with a dry winter from June to September, a rainy summer from December to March, a mean annual temperature of 18°C–22°C, and annual precipitation of 1100–1730 mm. The references are summarized in Appendix 1.1.

The species registered in these surveys were classified into the following pollination modes: “bird”; “bat”; “wasp”; “fly”; “moth”; “beetle”; “small insect” (trips, rove beetles, etc.); “bee”; “mammal” (non-flying); and “wind.” Mixed pollination modes are indicated by the conjunction of two or more of the former, but the most common modes received different names: “insect” (various types); “pollen consumer” (various types of insects excluding nectar consumers like lepidopterans); “big animal” (large bees, birds, lepidopterans, and bats); “long tongue” (bees, lepidopterans, and birds); and “vertebrate” (hummingbirds and bats). These pollination modes were established after conducting an extensive literature review on the pollinators of each species. The species without any information were classified into the category of another in the same genus or family showing similar floral morphology (see Appendix 1.2). We decided not to use the traditional pollination syndromes of Fægri and van der Pijl (1979) that are based on floral-trait combinations alone, given their inability in predicting the pollinators of several species

(Mayfield et al. 2001; Ollerton et al. 2009; Rosas-Guerrero et al. 2014). Likewise, taking into account the recommendations of many authors (Waser et al. 1996; Ollerton et al. 2009, 2015; Rosas-Guerrero et al. 2014), we considered not only the most efficient pollinators but also the secondary or less effective ones because pollinator efficiency can vary in space and time (Waser et al. 1996; Price et al. 2005; Ollerton et al. 2015) and because secondary pollinators represent important selecting forces in the expression and evolution of many flower phenotypes (Sargent and Otto 2006; Strauss and Whittall 2006). In addition, pollination modes represent an ecological function of resource provision from which both primary and secondary pollinators benefit.

Comparisons between sites and forest types (remnants, restored, and secondary) were conducted using Morisita–Horn dissimilarity distances, as suggested by Wolda (1981), for dealing with different sample sizes. Species dissimilarity distances were calculated on a matrix containing the species abundances by site (i.e., importance value\*sample area/100). Functional dissimilarity distances were calculated on two matrices: one containing the species quantities from each pollination mode by site (functional dissimilarity for species) and the other containing the accumulated abundances of pollination modes by site (functional dissimilarity for abundances). Spatial autocorrelations were tested by performing Mantel tests with dissimilarity and geographical distances between sites (significance level = 0.05). Overall differences in the assemblages of species and pollination modes among forest types were tested using multivariate analyses of variance (MANOVA, significance level = 0.05). The functional diversity of each site was estimated using the indices of functional richness and evenness provided by Villéger et al. (2008) and Schleuter et al. (2010). Particular differences in functional indices and pollination modes were tested separately using generalized linear models (GLM). Beta models were fitted to functional indices, Poisson and negative binomial models to species quantities, and Gaussian models to accumulated abundances. Binomial-Gamma hurdle models were fitted to rare pollination modes with zero-inflated data (> 30% zero values). Forest type was included as the explanatory variable with a significance level of 0.05. Sample area was added as an offset variable in Poisson and binomial models and as an explanatory variable in beta and gamma models to control for unequal sampling. Model fitting was measured by  $R^2$  values, the ratio deviance: degrees of freedom, residual

analysis, and AUC values. All analyses were performed using R, packages FD, vegan, lme4, betareg, and ggplot2 (R Foundation for Statistical Computing 2011).

## RESULTS

From a total of 974 tree species registered in the floristic surveys, 660 species were found in remnants, 305 in restored forests, and 452 in secondary forests. The species were spatially structured (Mantel test,  $r = 0.42$ ,  $p < 0.01$ ) and varied greatly between sites (mean dissimilarity distances were higher than 0.8, see Fig. 1) and forest types (MANOVA,  $F = 2.57$ ,  $p < 0.01$ ).

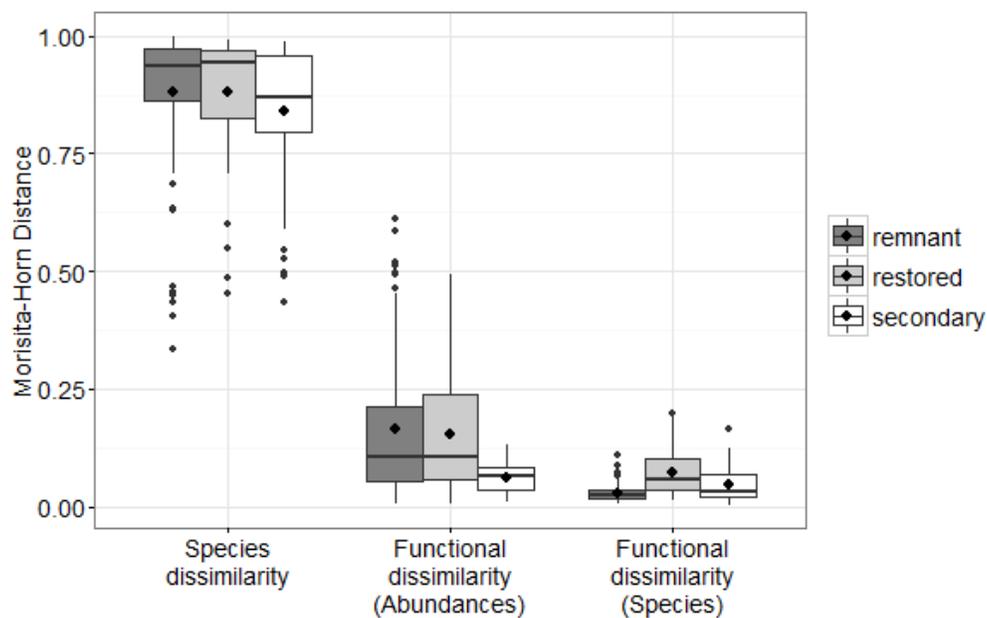


Figure 1.1. Box-plot of species and functional dissimilarities in remnants (primary forest), restored (tree plantings) and secondary (naturally regenerated) tropical semi-deciduous forests. Central boxes span the first quartile to the third quartile (the inter-quartile range or IQR). Segments and points inside the boxes show the median and the mean values respectively, and “whiskers” below and above the boxes show the location of the smallest and the largest values no further than  $1.5 \times \text{IQR}$  from the first and the third quartiles. Small points indicate data beyond the whiskers or “outliers”. Species dissimilarity indicates the differences in the tree species composition among

sites, whereas functional dissimilarity indicates the differences in the abundances and the number of species from different pollination modes among sites. No statistical differences were found among forest types, but the figure indicates much higher dissimilarities in the species composition than in the assemblages of pollination modes in all forest types.

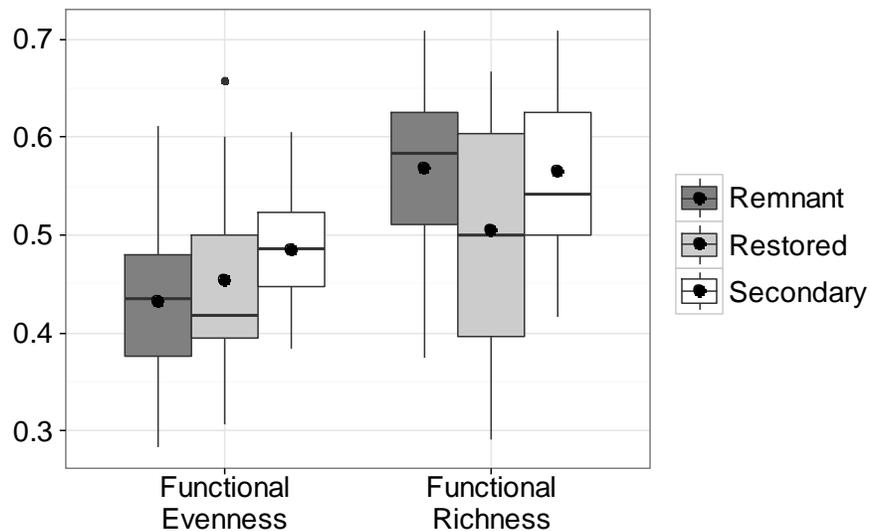


Figure 2. Box-plot of the functional indices of richness and evenness of pollination modes in remnants (primary forests), restored (tree plantings) and secondary (naturally regenerated) tropical semi-deciduous forests. Central boxes span the first quartile to the third quartile (the inter-quartile range or IQR). Segments and points inside the boxes show the median and the mean values respectively, and “whiskers” below and above the boxes show the location of the smallest and the largest values no further than  $1.5 \times \text{IQR}$  from the first and the third quartiles. The small point indicates a datum beyond the whisker or “outlier”. No statistical differences were found among forest types.

Remnant forests were particularly characterized by the predominance of insect-pollinated trees, represented by nearly half the species and individuals in every site (Fig. 3) and by 48 families, among which Lauraceae, Leguminosae (mimosoid species), Sapindaceae, Sapotaceae, and Rutaceae were some of the most important. This pollination

mode was followed by bee pollination, mainly represented by species from the families Leguminosae (sf. Caesalpinoidae, Papilionoidae), Bignoniaceae, Solanaceae, and Melastomataceae; wind pollination, with various common Moraceae, Euphorbiaceae, and Urticaceae species; moth pollination in many Apocynaceae (genera *Aspidosperma*, *Himatanthus*, and *Tabernaemontana*), Meliaceae (*Guarea* and *Cabranea*), Ebenaceae (*Diospyros*), Proteaceae (*Euplassa* and *Roupala*), and Rubiaceae (*Posoqueria*, *Randia*, and *Tocoyena*) species; and pollen-consumer pollination in Myrtaceae. Other pollination modes were found in mean proportions smaller than 0.04.

In restored forests, the prevalent abundance of insect-pollinated trees was maintained, although a significant reduction of about 6% was found in the amount of species (Fig. 3). From a total of 48 families of insect-pollinated species in remnants, only 28 were found in restored forests. Some families with the largest reductions in species included Lauraceae (7/36 spp.), Rubiaceae (1/15 spp.), and Sapotaceae (2/14 spp.). Wind-pollinated species and abundance were reduced by more than one third probably because only three of 15 wind-pollinated euphorbs found in remnants were also found in restored forests. Moth pollinated species diminished by a half, and their abundance by more than a half (11/31 spp.). The Apocynaceae family, which had the most number of moth-pollinated species, was represented here by only five species, compared with 15 species found in remnants. Other families of moth-pollinated species that were absent in restored forests included Rubiaceae (e.g., *Posoqueria* spp.), Ebenaceae (e.g., *Diospyros* spp.), and Proteaceae (e.g., *Roupala montana*). The species and abundances for pollen-consuming insects decreased, mainly because of reductions in Myrtaceae species (7/43 spp.). Flowers specialized in very small insects significantly decreased, probably as a result of the absence of Monimiaceae species (2/8 spp., genera *Mollinedia* and *Siparuna*). The abundance of fly-pollinated species reduced as well, in response to the scarcity of individuals of *Metrodorea nigra*, which was an important species among remnants. These reductions in pollination modes were replaced by much higher abundances and species pollinated by bees (mainly Caesalpinoidae, Papilionoidae, and Bignoniaceae species) and bats (mostly Malvaceae sf. Bombacoideae species). The mean number of bird-pollinated species increased, although not significantly, because of the presence of *Erythrina speciosa* in many restored forests.

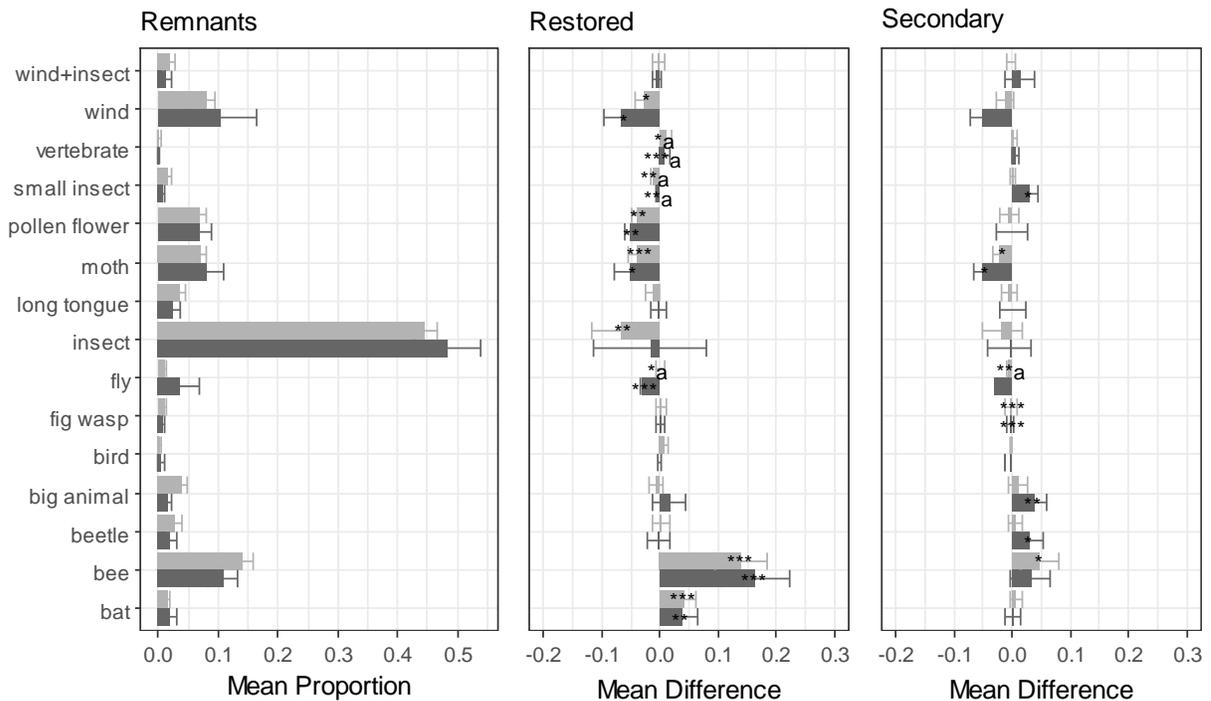


Figure 3. Mean values and confidence intervals (95%) of species (light-gray) and abundance (dark-gray) proportions of pollination modes at remnants (primary forest) and the differences found among restored (tree plantings) and secondary (naturally regenerated) tropical semi-deciduous forests are shown in the figure. The figure shows greater changes among restored forests than secondary forests, compared with primary forests. Asterisks (\*) denote significant differences in generalized linear models: \*0.05, \*\*0.01, \*\*\*0.001. “a” indicates changes in the presence-absence of pollination modes using zero-inflated binomial models.

Secondary forests also differed from remnants but changed to a lesser extent than restored forests (Fig. 3). Bee-pollinated species significantly increased. Moth-pollinated species significantly reduced to one half, and important reductions were found in the abundances of Apocynaceae (e.g., genera *Aspidosperma* and *Tabernaemontana*) and Meliaceae species (particularly *Cabralea canjerana*). The occurrence of fly pollination decreased owing to the absence of *Metrodorea nigra*. Abundances were smaller in fig-wasp pollination (*Ficus* spp.) and wind pollination (various Euphorbiaceae species such as *Actinostemon* spp., *Sebastiania commersoniana*, and *Tetrorchidium rubrivenium*) but

greater in beetle (*Xylopiia sericea* and other Annonaceae species), small insect (higher frequency of *Siparuna guianensis* trees), and big animal pollination (*Inga* spp.).

## DISCUSSION

We observed several patterns that are helpful in understanding the processes governing the assemblage of pollination modes among species, as well as in the decision-making processes aimed at restoring functional diverse ecosystems.

First, species dissimilarity was much higher than functional dissimilarity among forest locations (Fig. 1). High species dissimilarity could be explained by the great distances between some of our study areas; however, the restricted geographic distribution of many species responding to specific environmental requirements (i.e., topography, soil types, and pluviometric regimes), in conjunction with possible stochastic events, can also contribute to a high species turnover between communities on a minor scale (Torres et al. 1997; Brancalion et al. 2015). Small degrading effects in our remnants relating to fragmentation, border effects, or other human pressures could be additional causes of variation in species composition. However, the significant differences between the three forest types demonstrated that the major causes of differentiation reside in the processes of total deforestation, land use practices, and subsequent restoration.

In contrast, the smaller functional dissimilarity indicates a rather stable functional assemblage of pollination modes and also a high ecological redundancy among communities (Petchey et al. 2007; Pillar et al. 2013), regardless of the species replacement. The lack of spatial autocorrelation confirms this result because the variations in pollination modes were not related to the differences in species composition (and its spatial autocorrelation) among locations. Comparable studies support our findings and suggest that, among communities, differentiation for particular traits can be relatively small because of habitat-filtering forces selecting species with similar adaptations from the regional pool, as opposed to within communities, where the interactions between coexisting species are supposed to augment functional diversity by niche segregation (Pavoine and Dolédec 2005; de Bello et al. 2009).

Second, pollination systems were characterized by the high predominance of generalist insect pollination and the secondary incidences of bee, wind, moth, and pollen-consuming insect pollination, whereas many other specialized and mixed modes were underrepresented. This fairly low functional diversity of tree communities could possibly be ascribed to an environmental filtering mechanism where several selecting forces, perhaps including both pollinator and nonpollinator agents (i.e., herbivores, pathogens, and abiotic stressors), may be interacting (Sargent and Otto 2006; Strauss and Whittall 2006). Underrepresented modes such as beetle, bat, and bird pollination seem to be more common in understory plants (Bawa 1990; Frankie et al. 1990; Schatz 1990; Sazima et al. 1999; Buzato et al. 2000; Fleming and Muchhala 2008; Diogo et al. 2016), for example, in many herbaceous monocots (Costaceae and Heliconiaceae by hummingbirds and bats and Cyclantaceae by beetles) and epiphytes (Araceae by beetles and bromeliads by hummingbirds and bats). Such great trait divergence among plant growth forms is expected and seems to be a pattern for various functional traits (de Bello et al. 2009). In the context of ecological restoration, this issue is of high concern and highlights the importance of encouraging projects aimed at reintroducing plants with different habits into restored and secondary forests (e.g., Duarte and Gandolfi 2013; Le Bourlegat et al. 2013) to fully recover functional diversity.

Third, restored forests showed more accentuated and variable changes on the assemblages of pollination modes than secondary forests, as was expected. One of the possible causes could be the artificial selection of species for plantings, which is generally performed to recover functional traits more relevant during the initial establishment of seedlings (e.g., light requirements) and/or which depends on the cost and availability of seedlings in nurseries; hence, it sometimes includes both native and exotic species (Brancalion et al. 2015). As a result, many functional traits essential for the stability of the ecosystem in the long term (e.g., reproductive traits) could remain neglected. Other causes could be the major disturbance impacts associated with these areas, causing alterations, for example, in soil seed banks, soil properties, and the loss of connectivity with the surrounding forests that facilitates propagule arrival. The smaller changes found among secondary forests, in turn, seem to be reflected in the minor disturbance impacts and the lack of human intervention in these areas. In the present study, we could not test how

specific restoration practices, ages of restoration, and other local environmental variables explain variations in pollination modes within forest types because of the small number of sites and a lack of detailed information. However, our results suggest that highly resilient degraded sites could easily recuperate their functional diversity by natural regeneration alone, whereas at more disturbed sites, selecting better species for plantings and monitoring natural regenerants is recommended to better reassemble functional diversity.

Despite the changes found in several pollination modes, the functional richness among restored and secondary forests did not significantly differ from remnants, although we found lower values among several restored sites. Similarly, the functional evenness did not significantly differ among forest types, probably because the predominance of the most important pollination modes, as well as the underrepresentation of the less common ones, was still maintained. This lack of variation seems to be concordant with the suggestion of Schleuter et al. (2010) that states that functional diversity indices are not so reliable when using categorical data because they were specially developed for numerical traits. In this case, the variation in functional diversity indices alone would probably not be able to detect significant changes in particular functional attributes that may have important implications for biodiversity conservation.

Some of the changes we found in pollination modes are reinforced by previous studies, such as the negative effect of forest fragmentation on moth pollination found by Girão et al. (2009) and the greater representation of beetle-pollinated species (i.e., *X. aromatica*) in secondary areas found by Martins and Antoni (2016). However, divergent results appear when comparing our findings with those of studies that include different plant growth forms and strata. For example, Chazdon et al. (2003) and Lopes et al. (2009) have found major proportions of generalized insect pollination among secondary wet forests in Costa Rica and Brazil, but in the present study, we found it was predominant even among primary forests. Other specialized modes, such as bird, bat, and non-flying mammal pollination, have been reported to be intensely reduced by human disturbances in other tropical wet forests (Girão et al. 2009; Lopes et al. 2009; Kimell et al. 2010; Chazdon et al. 2003). In the present study, such pollination modes were underrepresented in general among tree species and did not significantly change in secondary areas.

Conflicting results may also occur as a consequence of ambiguous methods for plant classification. In previous studies conducted in semi-deciduous (Kinoshita et al. 2006; Yamamoto et al. 2007) and other tropical forests (Kress and Beach 1994; van Dulmen 2001; Girão et al. 2007; Araujo et al. 2009; Diogo et al. 2016), there was a predominance of bee pollination instead of generalized insect pollination because the authors used the traditional pollination syndromes (i.e., Fægri and van der Pijl 1979) or just included the most efficient pollinators during plant species classification. We do not deny that bees are the preponderant pollinators of tropical wild species (i.e., according to these studies, bees pollinate more than 50% of species), but this does not necessarily mean that bee-pollinated plants are particularly adapted to bee pollination or that these plants prevent visits from other types of pollinators (e.g., Mayfield et al. 2001). Similarly, Kimell et al. (2010) have found an overrepresentation of moth pollination in two secondary fragments because of the high dominance of *Inga ingoides* and *Albizia saman* trees. In the present study, we found an increase in the abundance of various *Inga* species among secondary forests, but we classified them as big-animal pollinated trees because they are secondarily pollinated by birds, bats, and butterflies (Koptur 1983; Amorim et al. 2013).

## **Conclusions**

In conclusion, we found that the assemblages of pollination modes in these tropical forests describe a pattern which is maintained at regional scale, and can be recovered throughout natural regeneration after low disturbance, but could remain altered after high disturbance and subsequent restoration practices. Several effects resulting from alterations in these assemblages may be expected. Reductions among specialized pollination modes (principally moth, fly, and small insect) are likely to cause major competition between animal vectors. Pollinators have been seen to change their foraging behavior to more generalized visitation patterns in less diverse plant communities (Heithaus 1974). Under the former conditions, plant pollination would be negatively affected by smaller visitation frequency and the arrival of alien pollen to the stigmas. At the community level, less stable and robust interaction networks would be anticipated as well as mismatches in flowering periods (Miller-Rushing et al. 2010). Increases in the species and abundance proportions of

pollination modes (particularly bees and bats in our case) are expected to be advantageous for their pollinators because of major resource availability (Carvalho et al. 2013; Dicks et al. 2015). Plant species having such pollination modes would be enhanced by means of facilitation and by greater attraction of their pollinators (Ghazoul 2006). Still, plant species could be negatively affected as well because of major competition for pollination (Mitchell et al. 2009).

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## Chapter 2

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### Functional responses and effects from bee communities in restored tropical forests

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#### **ABSTRACT**

Wild pollinators are necessary not only to enhance the production of many crop species but also for ensuring plant reproduction among remnant and restored ecosystems. Therefore, restoration activities should lead to their recovery by improving their connectivity and habitat requirements. We assessed the functional responses and effects from bee communities in restoration plantings (restoration corridors) and compared them with habitats in a perturbation gradient from conserved to degraded fragments of primary forest, to disturbed herbaceous areas in wetlands (secondary corridors), to sugarcane fields, and in response to habitat isolation.

We characterized bee species and the pollen grains transported on their bodies using functional traits (bees: body size, nesting location, sociality and foraging strategy; plants: habit, successional class, geographic origin and pollination mode), evaluated changes in bee abundances and pollen frequencies between habitat types and in relation to fragment cover areas in 1km-radius buffers, and created interaction networks between functional groups of bees and plants, aiming to test differences in network topology and identify modules in the overall community.

We found that the bee communities and their plant interactions were not still fully recovered in restoration plantings, although these areas were better than secondary

corridors in enhancing the recuperation of pollinators, as they played an important role in floral resource provisioning. The effect of habitat isolation was negative in general and highlighted the importance of preserving remnant fragments in providing pollinators to restored areas. Larger bee species with more restricted nesting and floral requirements seemed to be the most affected, while the smaller bees that nest below ground and are more related to herbaceous ruderal plants, were practically unaffected by habitat changes or isolation. The structure of interaction networks was little affected, but the composition and diversity of functional groups significantly changed, showing more negative consequences on the woody species that represent the basis for restored and remnant ecosystems, as they were more strongly associated to the most vulnerable bee species.

**Keywords:** biodiversity conservation; community assemblage; connectivity; ecosystem degradation; functional diversity; habitat restoration; interaction networks; land-use change; modularity; pollen transport; pollination.

## **RESUMO**

Os polinizadores silvestres são necessários não somente para melhorar a produção das plantas cultivadas, mas também para garantir a continuidade na reprodução das espécies vegetais nos ecossistemas remanescentes e restaurados. Desta forma as atividades de restauração ecológica devem ser planejadas considerando também a recuperação dos polinizadores, através da melhoria da conectividade da paisagem e da presença de seus requerimentos de habitat. Neste trabalho avaliamos as respostas e os efeitos funcionais das comunidades de abelhas em plantios de restauração (corredores em restauração), e comparamos com habitats representados num gradiente de perturbação, desde fragmentos conservados e degradados de floresta primária, até áreas alagadas e degradadas dominadas por herbáceas (corredores secundários), e cultivos de cana-de-açúcar, assim como em resposta ao isolamento de habitat.

Caracterizamos as espécies de abelhas e dos grãos de pólen transportados no seu corpo mediante atributos funcionais (abelhas: tamanho do corpo, local de nidificação, socialidade e estratégia de forrageamento; plantas: hábito, classe sucessional, origem

geográfica e modo de polinização), avaliamos as variações na abundância de abelhas e a frequência de pólen entre os tipos de habitat, e em relação às área de cobertura de fragmentos calculadas em buffers de 1km de raio, e construímos redes de interação entre grupos funcionais de abelhas e plantas, objetivando avaliar as diferenças na topologia das redes e identificar módulos de interação na comunidade em geral.

Encontramos que as comunidades de abelhas e suas interações com as plantas não estavam totalmente recuperadas nos plantios de restauração, porém, estas áreas representaram um papel muito melhor que os corredores secundários, no que se refere ao provisionamento de recursos florais para as abelhas. O efeito do isolamento de habitat, que foi negativo de maneira geral, destaca a importância de preservar os remanescentes de floresta primária para o fornecimento de polinizadores para as áreas em restauração. As abelhas de maior porte e com mais restrições de nidificação e forrageamento foram as mais afetadas, enquanto que as abelhas menores que nidificam no solo e estão mais relacionadas com plantas herbáceas ruderais, não foram muito afetadas pelas mudanças ou isolamento do habitat. A estrutura das redes de interação variou pouco, mas a composição e diversidade de grupos funcionais mudaram significativamente. As plantas lenhosas que são base dos ecossistemas florestais remanescentes e restaurados foram as mais afetadas, pois estão mais fortemente ligadas as espécies de abelhas mais vulneráveis.

**Palavras chave:** conservação da biodiversidade; degradação ecossistêmica; diversidade funcional; estrutura de comunidades; modularidade; mudanças no uso da terra; polinização; redes de interações; restauração de habitat; transporte de pólen.

## INTRODUCTION

The conservation and restoration of wild pollinator communities are necessary not only to enhance the production of many crop species important on human food security (Kremen et al. 2007), but also for ensuring the reproduction and resilience of wild plant species among remnant and restored ecosystems. For this reason, restoration activities should lead to the recovery of pollinators and their functionality, specifically, through the spatial integration of habitat areas to facilitate their movement and dispersal within the

landscape, as well as by fulfilling all the habitat requirements for their survival (Dixon 2009; Menz et al. 2011). According to the pollinator necessities and the level of environmental degradation in the region, restoration activities may vary from small and passive interventions like maintaining vegetated areas as linear landscape elements (e.g. ditches, hedgerows) or “stepping stone” patches between habitat areas, for guiding pollinator movement through the inhospitable matrix (e.g. Dicks et al. 2010; Van Rossum & Triest 2012; Kormann et al. 2016), to more complex and active actions that include the increase of habitat areas or the reintroduction of specific requirements (e.g. nesting materials, floral resources) (Falcy & Estades 2007; Dixon 2009; Menz et al. 2011). The way how pollinators and their functional processes respond to these possible actions should be evaluated and considered for guiding the decisions to be made during restoration planning.

The responses of pollinators can be assessed by their “response traits”, i.e. morphological, physiological and behavioral characteristics among species that mediate their tolerance to environmental changes (Violle et al. 2007). In the case of bees, which are the main pollinators of flowering plants (Kremen et al. 2007), traits related with dispersal capacity, sociality, nesting and foraging are indicated as the principal predictors of species occurrence and abundance in disturbed (Williams et al. 2010; de Palma et al. 2015; Coutinho et al. 2018) and restored habitats (Kremen & M'Gonigle 2015; Öckinger et al. 2017). The effects on the pollination function are generally studied by following a network approach, where it is possible to visualize the structure of the dynamics between plants and pollinator species, so that the consequences of species additions or losses in the face of restoration and other environmental changes can be predicted (Forup et al. 2008; Williams 2011; Kaiser-Bumbury et al. 2017). However, a challenge still remains in understanding how these ecological networks could be scaled to a functional trait level instead of focusing on the taxonomical diversity, so as to enable the identification of general patterns that work for species with similar phenotypes, and could better serve as a basis for biodiversity and ecosystem management, at the same time that other evolutionary and phylogenetic processes can be explored (Suding et al. 2008; Menz et al. 2011; Raimundo et al. 2018).

In this work, we assessed the trait responses of bee communities and their effect on pollen transportation as a proxy for pollination, in restoration plantings aimed to recreate highly diverse sustainable forests in a sugarcane producing region in Brazil (Rodrigues et al. 2011). Firstly, we compared the abundance of bees with different functional traits in restoration plantings, with those in “reference” fragments of undisturbed and disturbed primary forest, as well as with more disturbed herbaceous areas in wetlands -which may also play a role in providing habitat and connectivity-, and the sugarcane matrix. We hypothesized that bee trait assemblages in restoration plantings would differ less from reference communities than those in the more disturbed areas, being the species with higher restrictions on mobility, nesting and foraging the most affected (Kremen & M'Gonigle 2015; Öckinger et al. 2017). Additionally, we compared bee functional traits in sampling sites with different surrounding cover areas of reference fragments with the expectation to find a negative effect of habitat isolation on the functional responses of bee pollinators (Öckinger et al. 2017).

In a second part of this paper, we assessed the bee community effect on pollen transportation by identifying the pollen grains on bee bodies, and analyzing changes in the pollen frequency from plants with different functional traits that were consider relevant to restoration ecology and pollination (i.e. habit, geographic origin, successional class and pollination mode). We expect old successional, native and woody plants to be more affected by losses on bee functional diversity, due to their correlation with specialized bee pollination modes (Chazdon et al. 2003; Ghazoul 2006; Montoya-Pfeiffer et al. 2018). Afterwards, we created interaction networks between functional groups of bees and plants, aiming to establish first, if the network structure differs between the different habitat types and in response to habitat isolation, and secondly, if more strengthen links (i.e. modules) between certain functional groups of bees and plants exist. For the first objective, we predict smaller network complexity and robustness in restoration plantings than in reference forests but higher than in disturbed habitats, as well as a negative effect of habitat isolation, in consequence to functional diversity losses on bee communities (Forup et al. 2008; Williams 2011; Kaiser-Bumbury et al. 2017; Öckinger et al. 2017). For the second objective, our prediction is to find tightly linked functional groups, because bee species

with similar functional traits could select for plant species with also similar traits as a result of coevolutionary processes (Olesen et al. 2007).

## **METHODOLOGY**

### **Study area**

We conducted fieldwork in an agricultural area located within the domain of the Atlantic forest in southeast Brazil (municipality of Araras, Sao Paulo state) (22°25'46.95"S, 47°20'36.80"W) (Veloso et al. 1991). The area is greatly devastated with about 7% of its original vegetation and dominated by a matrix of sugarcane fields (Fig. 2.1). The small forest fragments that still remain are highly degraded and characterized by a discontinuous canopy covered by superabundant native lianas, and borders heavily colonized by invasive non-native grasses (hereafter degraded fragments). Two still remaining bigger fragments showing less degradation (i.e. continuous forest canopy without aggressive lianas, presence of epiphytes, understory shaded and natural regeneration taking place) were taken as reference ecosystems in our data analysis (hereafter conserved fragments). Some fragments are connected by highly diverse (i.e. ~80 spp.) tree restoration plantings that were initiated between the years of 2001-2005, with the intention to protect the water bodies from the area while increasing forest cover and connectance between fragments (hereafter restored corridors) (Naves 2013; Rodrigues et al. 2011). Other fragments remain linked by anthropogenic wetlands created after siltation of water courses, which are now dominated by herbaceous vegetation with very low potential of autogenic restoration (hereafter secondary corridors). (Naves 2013; Rodrigues et al. 2011).

### **Sampling design and data collection**

We established sampling sites in reference fragments (4), disturbed fragments (5), restored corridors (15), secondary corridors (12) and sugarcane fields (16). Sampling sites in restored and secondary corridors, and sugarcane fields were placed at distances from fragments ranging from 100 to 2500m and separated from each other by at least 100m.

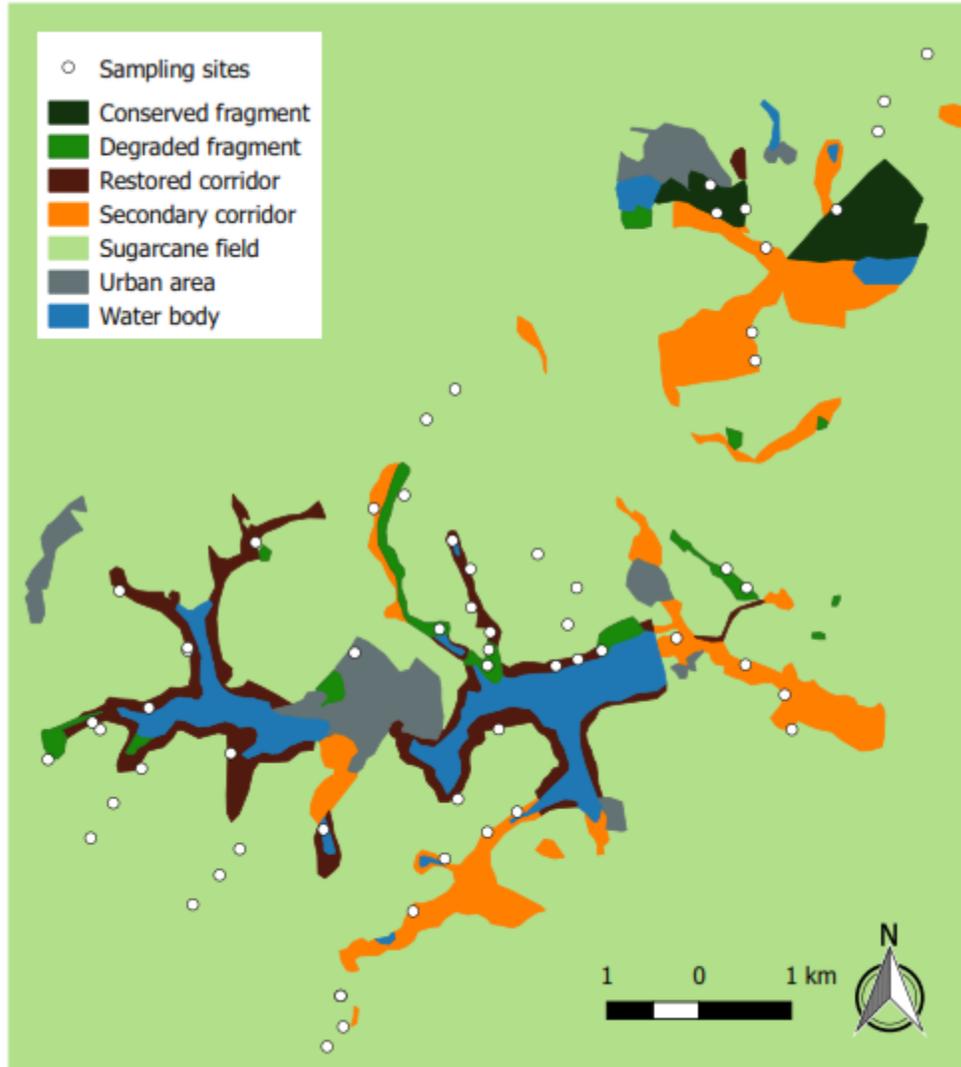


Figure 2.1. Map of the study area indicating vegetation cover types and sampling sites.

Given the close proximity of various fragments that may affect the occurrence and behavior of bee species in several sites, we calculated the total fragment cover area (i.e. conserved and disturbed fragments) in buffers of 1000 m around each sampling site according to the mean foraging distances of many bee species (Kremen et al. 2004), and used this measurement as an explanatory variable for analyzing the effect of habitat isolation. Fragment cover areas were measured by creating polygons on Landsat images from Google (2018), in the scale 1:10000, by using QGIS 2.18.0, GNU-GPL, Boston, MA.

Bees were sampled over three 24h-periods per site, during the flowering pick times in October-January 2015-2017, with the help of pantraps (six of each color, white, yellow and blue) (Leong & Thorp 1999) and bait traps for euglossine bees (three of each bait, eugenol and eucalyptol, Dodson et al. 1969; Campos et al. 1989). Trap sets in corridors and fragments were placed on the ground at 10m inside, 0m, and 10m outside from the border line to control from border effects. Trapped bees were taken to the lab for identification to genus or species level (see the list in Appendix 2.1). Pollen grains on bee bodies were removed by washing with ethanol, then prepared through acetolysis (Erdtman 1943) and mounted on slides for identification to the highest level of taxonomic resolution possible (list in Appendix 2.2).

## **Traits**

We classified bee species using four qualitative functional traits that are known to respond to habitat degradation (Williams et al. 2010; Kremen & M'Gonigle 2015; Öckinger et al. 2017; Coutinho et al. 2018): body size, nesting location, sociality and foraging strategy. Bee species were classified based on intertegular distance measures as small-sized ( $\leq 2.2$  mm), medium-sized (2.5 - 4.0 mm) or big-sized ( $\geq 4.3$  mm). Nesting location was classified as below-ground or above-ground; sociality was classified as solitary, semisocial or social; and foraging strategy as polylectic or oligolectic. We selected four traits for assessing the effects on the functional diversity of plant species: habit (herb, liana, woody), successional class (early successional, old successional), geographic origin (native, exotic) and pollination mode (generalist, bee specialist, other). Information on bee and plant traits was compiled from the literature by reviewing published works on each species or inferring trait data based on phylogeny. Species with uncompleted information were dropped from the analysis. By performing chi-tests we found colinearity between various traits (see the results section) and therefore we could not analyzed trait responses and effects by separately. Instead, we pooled all bee and plant species in functional groups according to the interactions found between traits (see Fig. 2.2 and 2.4), and evaluated changes in the bee abundance / plant frequency from each functional group between sites. Additionally, we calculated the richness and the Shannon's diversity of functional groups on each site

(hereafter functional richness and diversity), and the differences in functional group composition between sites with Morisita-Horn distances (hereafter functional similarity).

### **Interaction networks**

We constructed quantitative interaction networks by site with functional groups of bees and plants, and calculated the following topological metrics: weighted nestedness (i.e. specialization asymmetry), interaction diversity (i.e. complexity of associations in networks), interaction evenness (i.e. variation in interaction frequencies indicating different ecological impacts) and network specialization (i.e. deviation from a completely neutral network with the highest redundancy of interactions). The number of observations on networks was not standardized, as the variations in abundance and interaction frequencies are expected to reflect the effects of environmental changes (Blüthgen 2010). Basing on the algorithm from Dormann & Strauss (2014), we calculated modularity  $Q$  and identified modules of functional groups only in the general network, given that the networks from each site were small sized and therefore lacked sufficient statistical power to detect significance in modularity.

### **Data analysis**

Before starting data analysis, we evaluated sampling completeness of bees and plant interactions by using the richness estimators Chao and Jackknife 1, and tested spatial autocorrelation on bee and plant species compositions, using Mantel tests with Bray-Curtis dissimilarity and geographic distances between sites (significance level = 0.05). Additionally, we assessed the sample size effect of bee abundance on plant variables (i.e. overall plant frequency and functional richness, diversity and similarity), as well as the effect of local abundance on the mean frequencies of plant species, by using the abundance data registered in the floristic survey conducted by Naves (2013).

We analyzed bee community responses and effects using generalized and linear models. Overall bee abundance and plant frequency, functional richness, diversity and

similarity of bees and plants, and interaction network indices were included as response variables, whereas habitat type (conserved fragments, disturbed fragments, restored corridors, secondary corridors and sugarcane fields), fragment cover area and their interaction were taken as fixed effects within the models. Bee / plant functional group was included as a new interacting fixed effect in models, taking bee abundance / plant frequency as the response variable, respectively. Other effects such as trap type (pan or bait trap), sampling date and trap-set location (inside, border-line, outside) were excluded from the analysis by pooling all samples from the same site. Best models were selected based on significant differences in AIC values (ANOVA tests, significance level = 0.05), and residuals were visually inspected to assess model fit. All analyses were performed in R v.3.5.0 software (R Development Core Team, 2018).

## RESULTS

A total of 85 bee species (727 individuals) were found to interact with 221 plant species (78320 interactions), corresponding to 70-74% and 72-73% of the expected richness of bees and plants respectively. The distribution of bees and their use of plant resources was found to be not spatially auto-correlated (Mantel test, bees:  $r = 0.06$ ,  $p = 0.08$ ; plants:  $r = 0.1$ ,  $p = 0.09$ ). However, the overall frequency and diversity of plant species varied proportionally to bee abundance in sampling sites (Pearson correlations,  $p$ -values  $< 0.05$ ), while the mean frequencies of plant species were related to their abundance in the study area (Pearson  $r = 0.33$ ,  $n = 55$ ,  $p = 0.02$ ).

Bee communities in general tended to demonstrate negative responses to habitat changes, with derived negative effects on pollen transportation. However, the responses and effects in restored corridors showed an intermediate trend, with mean proportional differences from conserved fragments ( $0.49 \pm 0.37$ ) greater than disturbed fragments ( $0.30 \pm 0.30$ ) but smaller than secondary corridors ( $0.51 \pm 0.63$ ) and sugarcane fields ( $0.54 \pm 0.31$ ) (Table 2.1, Figs. 2.3 and 2.5). From a total of 57 variables tested, 13 significantly changed in restored corridors, while 2 were found in disturbed fragments, 16 in secondary corridors and 23 in sugarcane fields. The effect of habitat isolation was negative in general

and appeared to be stronger in restored corridors (four significant correlations in restored corridors to zero in secondary corridors and one in sugarcane fields).

### **Bee community responses to restoration and habitat degradation**

Overall bee abundance negatively responded to habitat type, decreasing significantly in secondary corridors and sugarcane fields but not in restored corridors and degraded fragments (Table 2.1) (explained deviance  $D^2 = 0.22$ ,  $p = 0.003$ ). Habitat isolation had a negative effect on bee abundance in restored corridors ( $D^2 = 0.21$ ,  $p = 0.03$ ), but had no effect in other habitat type. Functional richness decreased significantly only in sugarcane fields ( $D^2 = 0.13$ ,  $p = 0.19$ ) and was not affected by habitat isolation. Functional diversity was neither related to habitat type nor habitat isolation. Functional group composition was significantly different from conserved habitats in sugarcane fields but not in other habitat type ( $R^2 = 0.13$ ,  $p < 0.001$ ), and did not vary in response to habitat isolation.

Functional traits were not randomly distributed within the overall bee community (Fig 2.2). Small bees were found to be predominant (47%), as well as below-ground nesters (60%), semi-socials (46%) and polylectics (89%). Below-ground nesters were greatly associated to small bees (91%,  $X^2 = 240.8$ ,  $p < 0.001$ ), while above-ground nesters were better represented among medium-sized (54%) and big-sized bees (69%) ( $X^2 = 109.7$ ,  $p < 0.001$ ). Solitary bees were principally found among medium sized bees (56%,  $X^2 = 29.3$ ,  $p < 0.001$ ) social bees were only registered among small (79%) and medium sized bees (21%,  $X^2 = 100.5$ ,  $p < 0.001$ ), semisocials tended to be more common among big sized bees (66%,  $X^2 = 9.4$ ,  $p = 0.008$ ) and above ground nesters (26%,  $X^2 = 19.5$ ,  $p < 0.001$ ), and cleptoparasites were more abundant among big sized bees (80%,  $X^2 = 100.9$ ,  $p < 0.001$ ). Oligolecty was almost exclusively found within a group of solitary, below ground nesting and medium sized bees (97%,  $X^2 = 186.2$ ,  $p < 0.001$ ).

Table 2.1. Effects of habitat types and habitat isolation (fragment cover area) on bee communities, pollen loads and network structure.

<b>Bee community variables</b>																
	Overall Abundance				Functional Richness				Functional Diversity				Functional Similarity			
	Coef*.	SE	Z	P	Coef.	SE	Z	P	Coef.	SE	t	P	Coef.	SE	t	P
Conserved fragment	28.25	8.45	11.17	<0.01	7.00	1.32	10.30	<0.01	1.57	0.23	6.90	<0.01	0.30	0.04	16.96	<0.01
Disturbed fragment	-0.50	0.20	-1.71	0.09	-0.23	0.21	-0.96	0.34	-0.10	0.31	-0.57	0.57	0.09	0.05	1.19	0.23
Restored corridor	-0.42	0.20	-1.59	0.11	-0.19	0.18	-0.97	0.33	-0.12	0.26	-0.79	0.43	-0.01	0.05	-0.11	0.91
:Fragment cover area	<b>1.04</b>	<b>0.02</b>	<b>2.10</b>	<b>0.03</b>	1.00	0.02	0.31	0.76	0.01	0.02	0.15	0.89	<0.01	<0.01	1.61	0.11
Secondary corridor	<b>-0.59</b>	<b>0.15</b>	<b>-2.52</b>	<b>0.01</b>	-0.20	0.18	-1.01	0.32	-0.05	0.26	-0.32	0.75	-0.04	0.05	-0.57	0.57
:Fragment cover area	1.00	0.01	0.63	0.52	1.01	0.01	1.45	0.15	0.02	0.01	2.05	0.07	<0.01	<0.01	1.48	0.15
Sugarcane field	<b>-0.69</b>	<b>0.11</b>	<b>-3.39</b>	<b>&lt;0.01</b>	<b>-0.39</b>	<b>0.14</b>	<b>-2.22</b>	<b>0.03</b>	-0.22	0.25	-1.41	0.16	<b>-0.12</b>	<b>0.05</b>	<b>-2.72</b>	<b>0.01</b>
:Fragment cover area	1.02	0.02	1.09	0.27	-1.00	0.01	-0.24	0.81	-0.01	0.01	-0.38	0.71	<0.01	<0.01	-0.48	0.64
<b>Pollen load variables</b>																
	Overall Frequency				Functional Richness				Functional Diversity				Functional Similarity			
	Coef.	SE	Z	P	Coef.	SE	Z	P	Coef.	SE	t	P	Coef.	SE	t	P
Conserved fragment	212.50	89.81	12.68	<0.01	17.00	2.22	21.72	<0.01	2.40	0.23	10.40	<0.01	0.65	0.05	7.27	<0.01
Disturbed fragment	-0.55	0.26	-1.40	0.16	-0.13	0.16	-0.77	0.44	-0.07	0.31	-0.51	0.61	-0.09	0.06	-0.52	0.60
Restored corridor	<b>-0.60</b>	<b>0.19</b>	<b>-1.93</b>	<b>0.05</b>	<b>-0.32</b>	<b>0.10</b>	<b>-2.54</b>	<b>0.01</b>	-0.16	0.26	-1.50	0.14	<b>-0.42</b>	<b>0.05</b>	<b>-2.78</b>	<b>0.01</b>
:Fragment cover area	<b>1.05</b>	<b>0.02</b>	<b>2.21</b>	<b>0.03</b>	1.02	0.01	1.91	0.06	<b>0.02</b>	<b>0.01</b>	<b>3.07</b>	<b>0.01</b>	<b>0.01</b>	<b>0.00</b>	<b>2.89</b>	<b>0.01</b>
Secondary corridor	<b>-0.67</b>	<b>0.16</b>	<b>-2.25</b>	<b>0.02</b>	<b>-0.27</b>	<b>0.11</b>	<b>-2.01</b>	<b>0.04</b>	-0.09	0.27	-0.85	0.40	<b>-0.46</b>	<b>0.05</b>	<b>-2.96</b>	<b>&lt;0.01</b>
:Fragment cover area	-0.99	0.01	-0.36	0.72	1.00	0.01	0.58	0.57	0.01	0.01	0.87	0.41	<0.01	<0.01	1.89	0.06
Sugarcane field	<b>-0.68</b>	<b>0.15</b>	<b>-2.41</b>	<b>0.02</b>	<b>-0.48</b>	<b>0.08</b>	<b>-4.18</b>	<b>&lt;0.01</b>	<b>-0.21</b>	<b>0.26</b>	<b>-2.69</b>	<b>0.01</b>	<b>-0.88</b>	<b>0.05</b>	<b>5.77</b>	<b>&lt;0.01</b>
:Fragment cover area	<b>1.06</b>	<b>0.03</b>	<b>2.16</b>	<b>0.03</b>	1.01	0.01	0.62	0.53	0.01	0.02	0.76	0.46	<0.01	<0.01	0.76	0.45
<b>Network variables</b>																
	Weighted nestedness				Interaction Diversity				Interaction Evenness				Specialization H <sub>2</sub> '			
	Coef.	SE	t	P	Coef.	SE	t	P	Coef.	SE	t	P	Coef.	SE	t	P
Reference fragment	0.62	0.13	4.82	<0.01	3.44	0.34	10.09	<0.01	0.74	0.06	13.24	<0.01	0.16	0.07	2.28	0.03
Disturbed fragment	-0.27	0.17	-1.01	0.32	-0.10	0.46	-0.72	0.47	-0.01	0.08	-0.06	0.95	0.19	0.09	0.31	0.76
Restored corridor	-0.23	0.15	-0.96	0.34	-0.20	0.38	-1.78	0.08	-0.09	0.06	-1.17	0.25	0.57	0.08	1.18	0.25
:Fragment cover area	<0.01	0.01	0.34	0.74	0.04	0.02	1.53	0.14	0.01	0.01	1.43	0.17	<0.01	0.01	0.37	0.72
Secondary corridor	-0.43	0.15	-1.84	0.07	-0.12	0.39	-1.06	0.29	0.01	0.06	0.08	0.94	0.19	0.08	0.36	0.72
:Fragment cover area	<0.01	0.01	0.17	0.87	0.01	0.01	1.31	0.21	<0.01	<0.01	-0.55	0.59	<0.01	<0.01	0.55	0.59
Sugarcane field	-0.27	0.15	-1.18	0.24	<b>-0.26</b>	<b>0.38</b>	<b>-2.38</b>	<b>0.02</b>	0.02	0.06	0.24	0.81	0.44	0.08	0.84	0.40
:Fragment cover area	<0.01	0.01	-0.27	0.79	0.01	0.01	0.84	0.42	<0.01	<0.01	0.30	0.77	<0.01	<0.01	0.56	0.59

\*Coefficients in restored corridors, secondary corridors and sugarcane fields are presented as mean proportional differences from conserved fragments. Negative values indicate decreases in relation to reference values. Positive values in fragment cover area coefficients indicate detrimental effects of habitat isolation. Significant effects are indicated in bold numbers (significance level = 0.05).

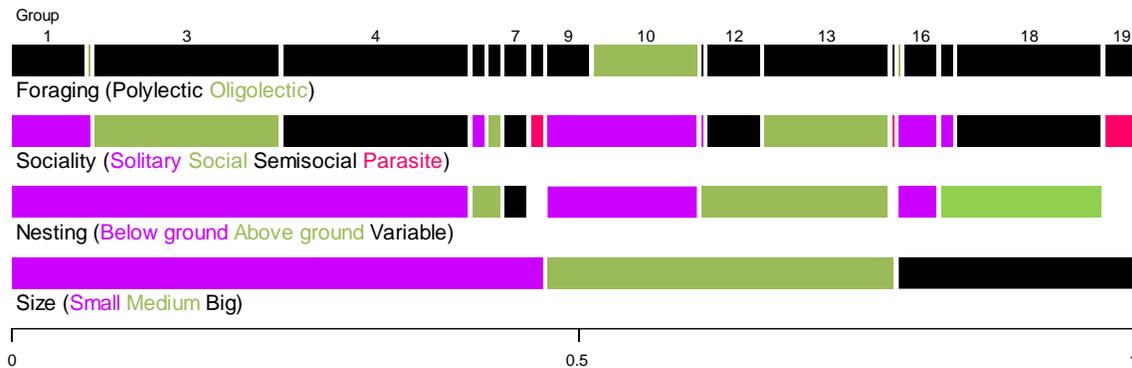


Figure 2.2. Double decker plot for bee traits, showing the distribution of abundance proportions (horizontally) and combinations between traits (vertically). The group numbers on the upper side of the graph represent different combinations between traits.

The bee trait associations mentioned above served to explain the responses of bee functional groups to the predictor variables. The general tendency of functional group abundance was to decrease all habitat types, although with some exceptions ( $D^2 = 0.73$ ) (Fig. 2.3, full model results in Appendix 2.3). Groups 1, 3, 4 and 9, representing species with small or medium size, below-ground nests, variable levels of social behavior and polylectic diet (i.e. mainly Exomalopsine, Eucerine and Halictid bees) were found to be between the most abundant groups in the study area, without being affected by habitat types or with a tendency to increase in some disturbed habitats. Conversely, groups 12, 18 and 19, including species with big or medium size, above ground nests, semisocial or parasitic behavior and polylectic diet (i.e. principally euglossine bees), were found to be predominant in conserved fragments and the most diminished in restored corridors, secondary corridors and sugarcane fields. Group 10 representing oligolectic bees (i.e. mainly Euphorine and Eucerine bees), was also found to respond negatively to habitat types. Habitat isolation had an overall negative effect on bee group abundance (coef. 1.02, SE=0.005,  $D^2= 0.006$ ,  $p<0.001$ ), which did not change significantly between individual functional groups in habitat types (Appendix 2.3).

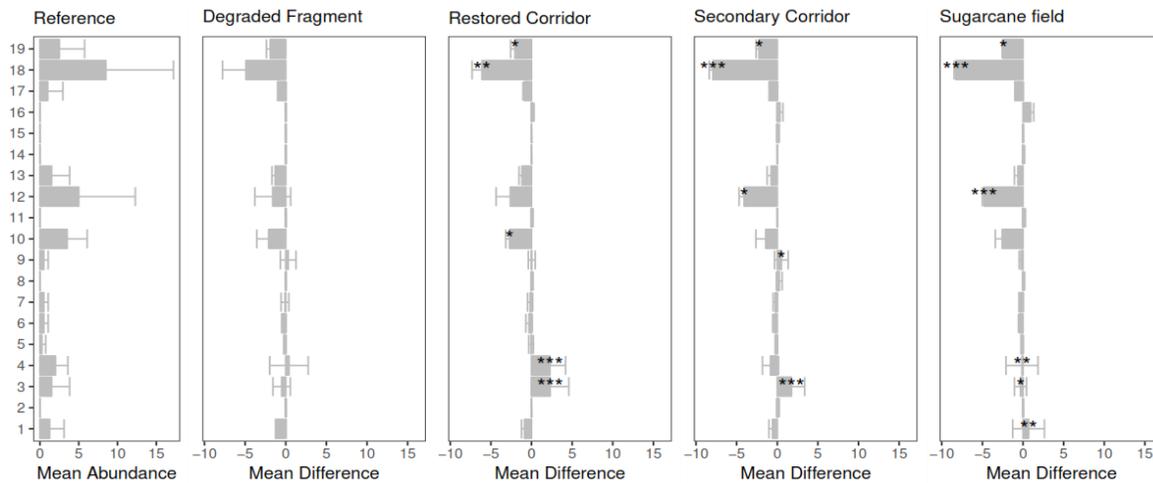


Figure 2.3. Mean values and CIs (95%) for the abundances of bee functional groups at reference (conserved fragments) and the mean differences found among degraded fragments, restored corridors (tree plantings), secondary corridors (naturally regenerated) and sugarcane fields. Group numbers represent different combinations between functional traits (see Fig. 2.2) Asterisks (\*) denote significant differences in GLM: \*0.05, \*\*0.01, \*\*\*0.001.

### Effects on pollen transport and interaction networks

Overall plant frequency tended to decreased in all habitat types, being significantly affected in restored corridors, secondary corridors and sugarcane fields ( $D^2 = 0.12$ ,  $p = 0.08$ ) (Table 2.1), as well as by the effect of habitat isolation in restored corridors ( $D^2 = 0.23$ ,  $p = 0.02$ ) and sugarcane fields ( $D^2 = 0.14$ ,  $p = 0.03$ ). Functional richness was reduced in restored corridors, secondary corridors and sugarcane fields ( $D^2 = 0.26$ ,  $p < 0.001$ ) but not affected by habitat isolation. Functional diversity was only significantly reduced in sugarcane fields ( $R^2 = 0.14$ ,  $p = 0.02$ ), and affected by habitat isolation in restored corridors ( $R^2 = 0.37$ ,  $p = 0.01$ ). Functional composition changed in restored corridors, secondary corridors and sugarcane fields ( $R^2 = 0.24$ ,  $p < 0.001$ ), as well as in response of habitat isolation in restored corridors ( $R^2 = 0.11$ ,  $p = 0.01$ ).

Regarding functional traits, woody plants were found to be predominant (59%), as well as early successional plants (92%), natives (67%) and generalist-pollinated plants (48%) (Fig. 2.4). Old successional and cultivated plants were scarce in general, exotic

species tend to be better represented among herbs (47%,  $X^2 = 13.4$ ,  $p < 0.001$ ), generalist-pollinated species tend to be more common among herbs (71%) and lianas (69%,  $X^2 = 16.8$ ,  $p < 0.001$ ) and bee specialists were better represented among woody plants (56%,  $X^2 = 55.6$ ,  $p < 0.001$ ).

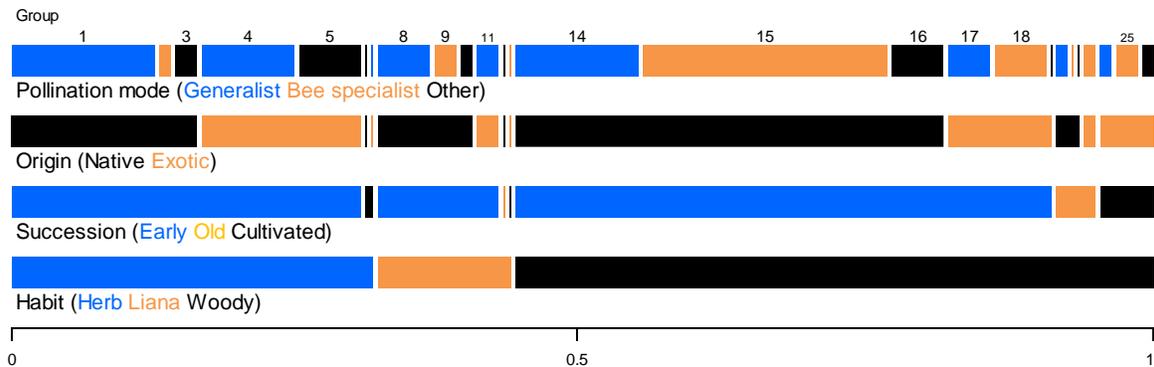


Figure 2.4. Double decker plot for plant traits, showing the distribution of abundance proportions (horizontally) and combinations (vertically) between traits. The group numbers on the upper side of the graph represent different combinations between traits.

The frequency of the majority of functional plant groups tended to decrease in all habitat types ( $D^2 = 0.66$ , Fig. 2.5). Sugarcane fields registered the highest reductions (nine groups with significant effects), followed by secondary corridors (six groups), restored corridors (five groups) and degraded fragments (two groups). Groups 15 and 16 were found within the most affected ones, representing early successional-native-woody plants with specialist pollination modes, as well as groups 1 and 5, including native or exotic early successional herbs with generalist or specialist (“other”) pollination modes. Other groups with minor changes were the woody plant groups 14, 17, 20, 23 and 26, with variable trait arrangements, the initial liana groups 9 and 11, and the early successional herb groups 2 and 4. Habitat isolation had an overall negative effect on plant group frequency in restored corridors (coef. 1.02) secondary corridors (coef. 0.98) and sugarcane fields (coef. 0.98) ( $D^2=0.006$ ,  $p < 0.001$ ), but did not significantly change between plant groups (Appendix 2.4).

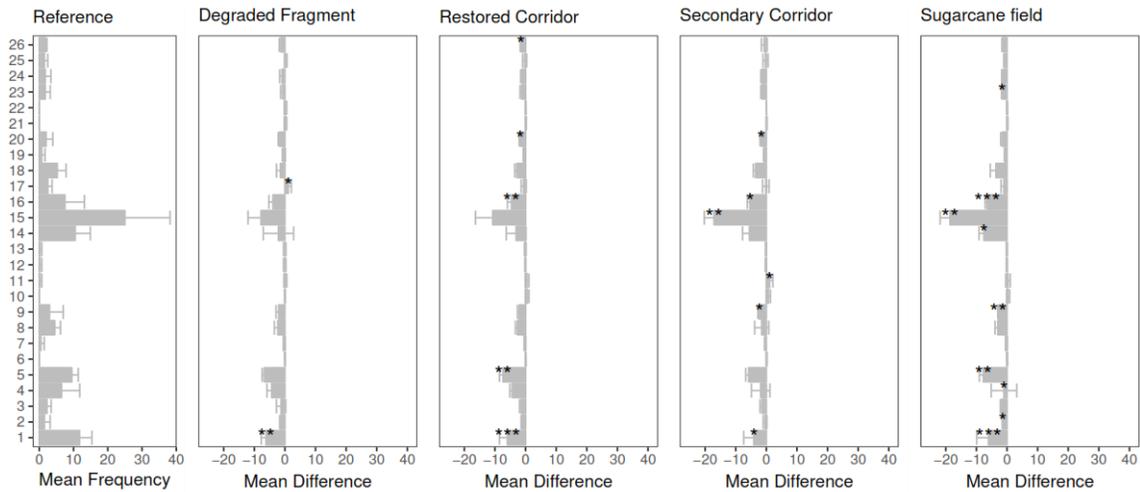


Figure 2.5 Mean values and CIs (95%) for the abundances of plant functional groups at conserved fragments and the mean differences found among degraded fragments, restored corridors (tree plantings), secondary corridors (naturally regenerated) and sugarcane fields. Group numbers represent different combinations between functional traits (see Fig. 2.4) Asterisks (\*) denote significant differences in GLM: \*0.05, \*\*0.01, \*\*\*0.001.

The topology of interaction networks little differed between habitats and was practically unaffected by habitat isolation (Table 2.1). Network nestedness was high in conserved fragments and tended to decrease in all habitat types, interaction diversity showed a similar pattern with a significant reduction in sugarcane fields ( $R^2 = 0.08$ ,  $p = 0.1$ ), interaction evenness was high and conserved among habitat types (differences  $< 0.02$ ), and network specialization was small in conserved fragments and tended to increase in other habitats.

Interactions between bee and plant functional groups were distributed in three modules (modularity = 0.14,  $z = 15.49$ ,  $p < 0.001$ ) (Fig 2.6). The biggest module principally included medium and big sized bees (58%), above-ground nesters (77%), variable social level and polylectics (99%), which were mainly associated to plant groups including woody species (92%), early successional species (90%), natives (87%) and variable pollination modes. A second module corresponded to small and medium sized

bees that were mainly below-ground nesters (95%), had different social level and polylectic strategy (71%), in association with mainly early successional herbs (92%) from variable geographic origin and generalist pollination (74%). The third and smallest module comprised groups with more homogeneously distributed interactions within the network.

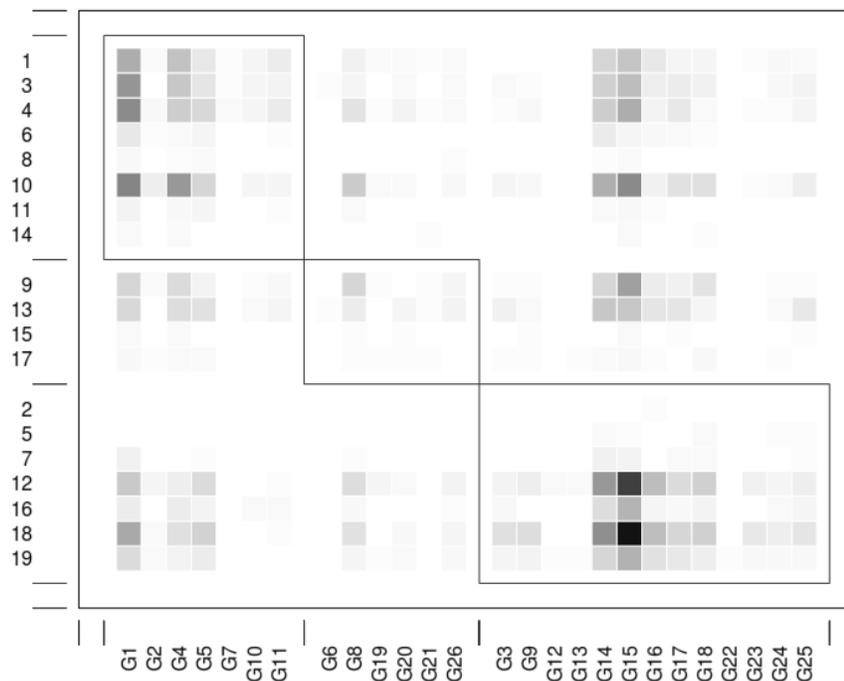


Figure 2.6. Modules identified for the interactions between bee groups (left axis) and plant groups (bottom axis). Darker squares indicate more observed interactions and the boxes delineate the tree modules. Group numbers represent different combinations between functional traits (see Figs. 2.2 and 2.4).

## DISCUSSION

### Bee community responses to restoration and habitat degradation

Bee communities in general showed negative responses to habitat changes, characterized by reductions in abundance, functional richness, changes in functional composition, and variations in the abundance of several functional groups. However, our results suggested that restored corridors better enhanced the recovery of bee communities,

given their smaller differences to conserved fragments. Secondary corridors, even with larger differences still demonstrated to be able to attract bees and therefore should represent important elements in providing habitat and landscape connectivity on bee communities (Dicks et al. 2010; Van Rossum & Triest 2012; Kormann et al. 2016). Similarly, the small differences found between degraded and conserved fragments, and the overall negative effect of habitat isolation, highlight the need for forest remnant conservation to supply bee populations on restored sites (Öckinger et al. 2017).

Overall bee trait responses seemed to be primarily driven by an interaction between nesting location and body size. Larger bees nesting above ground were found to predominate in the more conserved habitats, but replaced by smaller bees that nest below ground in the more degraded habitats. Such relation between nesting location and habitat degradation is well documented (Kremen et al. 2007; Williams et al. 2010; Kremen and M'Gonigle 2015; da Encarnação Coutinho et al. 2018; but see Öckinger et al. 2017), and explained by the major dependency of above ground nesting bees on forest resources like preexisting cavities on trees and other different plant substrates. In this work, the nesting resource availability might be restricted to fragments, as the younger trees in restored corridors and other degraded areas still do not have cavities and substrates enough for them (Morato & Martins 2006).

On the contrary, the negative relation between body size and habitat degradation was expected to be the opposite (Forup et al. 2008; Williams et al. 2010; Menz et al. 2011; de Palma et al. 2015; Öckinger et al. 2017), given the correlation of bee body size with flight range and dispersal capability (Greenleaf et al. 2007), which should make smaller species more vulnerable to landscape barriers (Forup et al. 2008; Menz et al. 2011). Other correlated factors, such as the larger amounts of resources required by larger bees and their higher specialization, in addition to the interaction with nesting location, seemed to be better predictors of body size responses to habitat changes (Larsen et al. 2005; Kremen and M'Gonigle 2015).

Sociality appeared to be benefited by disturbance as a result of the association found between social behavior, below-ground nesting and small body size. However, various studies registered a high vulnerability on social bees to habitat fragmentation and

degradation (Winfree et al. 2009; Williams et al. 2010; Coutinho et al. 2018), specially attributed to their need for big preexisting cavities and available floral resources during their longer yearly activity periods. In this work, the social bees that nest above ground and/or are medium or big sized, such as many stingless bees and bumblebees, were absent and presumably locally extinct even on conserved fragments -with the exception of the exotic species *Apis mellifera* in group 13 whose abundance may be greatly influenced by the presence of apiaries in the zone-, hence corroborating the hypothesis of being the primary affected species by isolation and habitat loss. Conversely, solitary and semisocial bees did not show an overall clear pattern and responded according to combinations with other functional traits, whereas the occurrence of cleptoparasite bees seemed to be controlled by their hosts' abundances (Williams et al. 2010), as it was indicated in this study by a similar variation pattern between the cleptoparasite species *Exaerete smaragdina* (group 19) and its host *Eulaema nigrita* (group 18) (see Fig.2.3).

Foraging strategy seemed to be not an important trait predictor for bee abundance, given the typical great prevalence of polylectic species in the Brazilian tropics (Schlindwein 2004) (Fig. 2.2). Nevertheless, the few oligolectic bees aggregated in group 10 were found to show a decreasing trend in all habitat types, probably due to their high sensibility to habitat disturbances because of their more specific requirements (Williams et al. 2010; de Palma et al. 2015; Öckinger et al. 2017; Coutinho et al. 2018).

### **Effects on pollen transportation and interaction networks**

The effects on pollen transportation were primary driven by bee abundance in sampling sites, and as a consequence, presented patterns similar to bee responses: negative effects in all habitat types that were smaller in degraded fragments, intermediate in restored and secondary corridors and larger in sugarcane fields, with an also general negative effect of habitat isolation. Effects on pollen transportation however, showed to be stronger (14 significant correlations) than bee community responses (five significant correlations) (Table 2.1), suggesting that small changes on bee communities could cause more relevant consequences on their function of pollination (Larsen et al. 2005; Suding et al. 2008).

Conversely, the topology of functional networks little changed in response to habitat or fragment cover area, probably because the reductions on bee abundance were not enough to cause significant effects on the strength and complexity of the interactions at this functional level. Nevertheless, the small reductions in nestedness and interaction diversity, and the increases in specialization, denote a trend to higher mutual dependencies and loss of redundancy among the interacting species, which could lead to negative implications on the robustness and resilience of these restored and degraded ecosystems (Forup et al. 2008; Bluthgen 2010; Williams 2011; Kaiser-Bumbury et al. 2017).

The functional networks also revealed to be modular, showing non-random patterns of interaction among both, bees and plants (Olesen et al. 2007; Dormann & Strauss 2014). This result helps us to explain the variations between habitats in plant group frequencies, as well as to identify target interactions for the improvement of restoration processes. We found two general main modules: a first module included bee groups that were unaffected by habitat degradation (i.e. bees with small to medium size, below ground nesting location, different social levels and polylectic strategy), in association with mainly ruderal plants that are also not affected or even benefited by antropogenic disturbance (i.e. mainly initial herbs with native or exotic origin and generalist pollination), hence representing a fraction of the community that little contributes to the restoration process and may not require conservation priority. However, the frequencies from the principal plant groups in this module (groups 1, 2, 4, and 5, Fig. 2.5) were reduced in degraded habitats in response to decreases in oligolectic bees (group 10, Fig. 2.3). It is not clear why oligolectic bees decreased in abundance, given their association with such unobstructed floral resources. Probably their limiting factors are more related to other aspects that were not considered in this work (p.e. parasitism, soil requirements, reproductive rates, population sizes) and may deserve further analysis. For the rest of bee species in this module, such association with ruderal plants represents an additional adaptive trait that enables them to colonize and disperse through disturbed habitats without relying on remnant vegetation fragments.

The second module was mainly compound by the most vulnerable bee species (i.e. medium to large bees that nest above ground, with variable social behavior and polylectic strategy), in interaction with plants that constitute the principal component of restoration

plantings and forest remnants (i.e. woody plants from initial succession stages, native origin and different pollination modes), both responding in the same way to habitat changes and isolation as a result of their association (bee groups 12, 18, 19 in Fig. 2.3, plant groups 14, 15, 16 in Fig. 2.5). The great abundance of plants from this module in restored corridors supports our initial hypothesis, which states that the more vulnerable bee species rely on primary forest fragments not because of limitation on floral resources, but more probably on nesting resources. Additionally, this module revealed that pollination of the most important tree species in restored and conserved areas strongly depends on larger bees, whose longer flight ranges facilitate the outcrossing with individuals at further distances, contributing in this way to maximize their genetic diversity (Dick et al. 2008). Hence, the conservation of the bee species from this module should be prioritized in restoration programs, for example, throughout the reintroduction of nesting materials and/or populated nests in cases of local extinct species (Cortopassi-Laurino et al. 2006; Dicks et al. 2010; Menz et al. 2011).

It is worthy to remark that bee species in general were strongly related with plants abundant in the study area. The preference for abundant plants is common among bees (Waser 1986; Ghazoul 2006) and could lead to negative effects on the reproductive success of rare plants if their pollinators are monopolized by the more attractive abundant species (e.g. Ghazoul 2006; Bartomeus et al. 2007). In some cases though, abundant plants have demonstrated to have no effect or even facilitate the pollination of rare plants by attracting more visitors (e.g. Ghazoul 2006; Bartomeus et al. 2007). Given the difficulty to predict the consequences of bee preference for abundant plants, we recommend restoration practitioners to make an effort to resemble the original plant densities in plantings, with special consideration on isolated species (e.g. old successional species in this work), which could require increases in population size to achieve adequate rates of pollen dispersal (Menz et al. 2011).

## Conclusions

Here we demonstrated that the functional diversity of bee communities was not fully recovered in restored habitats especially because of probable deficiencies in nesting resource provisioning, although these areas showed to be important in floral resources. The restoration of bee communities might be achieved in restored corridors as the time goes by and the trees get bigger and older, bringing this way new nesting sites and other plant substrates for bee species. Secondary corridors were also found to play a role of complementary habitat support in spite of their high degradation stage, in the same way as other studies indicate that antropogenic landscape elements are important for directing the dispersal of pollinators to better quality patches throughout a hostile matrix (e.g. Dicks et al. 2010; Van Rossum & Triest 2012; Kormann et al. 2016). Among sugarcane fields, however, different bee species with variable sizes and flight capabilities were also present even at far distances from fragments (>1000 m), hence supporting the idea that in order to enhance the dispersal and colonization of bees in restored areas, the implementation of corridors directly connected to source fragments might not be required since bees can disperse throughout the matrix, but other cheaper possibilities as for example the creation or preservation of stepping-stone vegetation areas between habitat patches could result more adequate (Menz et al. 2011; Forup et al. 2008).

Regarding pollen transportation, we found that although the functional structure of the interactions between bees and plants was not very affected, the diversity and composition of floral resources significantly changed, with more negative consequences on the woody species that represent the basis of restored and remnant ecosystems, given their stronger association with the more vulnerable bee species. Environmental degradation is driving the communities of interacting bees and plants to a new state where both are well adapted to each other and therefore, do not depend on conserved habitats for their maintenance. Consequently, new plant communities as restoration plantings should not rely on the pollinators present on degraded areas, but on those in the surrounding primary forests for ensuring their reproductive success. In cases of highly degraded remnants, additional actions such as reintroducing extinct pollinators or increasing plant/bee population sizes might be required.

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## General Conclusions

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On the first chapter, we demonstrate how different restoration practices can lead to variable functional assemblages in plant communities that could alter the equilibrium of ecological functions like pollination. Changes on the proportions of several pollination modes could affect pollinators by decreasing or increasing floral resource availability, but also, may have negative or positive consequences on plant pollination throughout competition or facilitation processes, respectively. Such changes on pollination modes were found to be stronger under higher levels of historical disturbance in the region, and human manipulation in active restoration practices.

The information obtained from the first chapter allows us to estimate the pollinator diversity requirements of tree communities, and the resource availability for pollinators in these tropical forests. Specifically in the case of bees, we found that the demand for their function as pollinators in restored forests is even higher than that in primary forests, since many bee pollinated tree species are widely and preferably used in restoration plantings due to their great colonizing ability, or because of the many other ecosystem functions and services that they provide.

On the second chapter we observed that bee communities were getting benefited by such over-representation of bee floral resources in restoration plantings. Many bee species were found to visit more frequently the tree species in these areas than other plants in primary forests (i.e. old successional species) and other more disturbed sites (i.e. ruderals). In spite of this preference, the pollination function in restored communities was probably still not assured, since the bee abundance and functional diversity of bee communities was not fully recovered, maybe because of other habitat requirements that remain undersupplied (e.g. nesting resources).

Nevertheless, we found that there was a high functional diversity on bee communities in restored areas and their associated habitats in the landscape, that were able to survive under conditions of very high habitat degradation and fragmentation. However, only a small part of these communities, which was also found to be the most vulnerable one, was the principal in charge of the pollination of the most important plant species in primary and restored forests. We hope these groups of bee species, as well as other susceptible plant groups that were indicated throughout this work, get prioritized and considered in future decisions on conservation and restoration planning of tropical forests.

## General Abstract

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The conservation and restoration of pollinators is essential for sustaining viable plant populations in fragmented landscapes because they promote genetic diversity among isolated individuals. As it is expected that populations in remnant and restored forests perpetuate with the passing of the years, restoration programs on highly fragmented agricultural landscapes should be planned with consideration for achieving this purpose. In this work, we evaluated plant-pollinator interactions in restored tropical forests, aiming to establish first, the pollination requirements of plant species in these communities, and secondly, if the pollinator requirements are being fulfilled and the interactions between plants and pollinators are being recovered throughout restoration practices.

This work comprises two chapters: On the first one (*“Are the assemblages of tree pollination modes being recovered by tropical forest restoration?”*) we did an extensive literature review about the pollination biology of tree species in primary forests, restoration plantings and naturally regenerated forests, to compare and identify patterns on the functional diversity and the assemblages of plant pollination modes. On the second chapter (*“Functional responses and effects from bee communities in restored tropical forests”*) we sampled bees (i.e. the most important pollinators) and identified the pollen grains attached to their bodies in primary forests, restoration plantings, disturbed herbaceous areas and sugar cane fields; afterwards we analyzed and compared the functional diversity of bee communities and their floral resources, and the structure of plant-bee interactions, as well as in response to habitat isolation.

We found that different restoration practices led to changes on patterns of abundance and species proportions of several plant pollination modes, which were stronger in locations under active restoration activities than in naturally regenerated forests. Specifically in the case of bees, we found that the demand for their function as pollinators in restoration plantings was even higher than that in primary forests, since many bee

pollinated tree species were being widely and preferably used due to their great colonizing ability, or because of the many other ecosystem functions and services that they provide. We observed that bee communities were getting benefited by such over-representation of bee floral resources, since many species visited more frequently the tree species in restoration plantings than any other habitat. In spite of such preference, the bee abundance and functional diversity of bee communities was not fully recovered in restoration areas, maybe because of other habitat requirements that still remained undersupplied (e.g. nesting resources). Although the functional diversity on bee communities was high in general, only a small part, which was also the most vulnerable (i.e. larger bees that nest above-ground, have different levels of sociality and are polylectics), was the principal in charge of the pollination of the most important plant species in primary and restored forests (i.e. native woody plants, from early successional stages and with different pollination modes).

Throughout this work we analyzed and discussed the implications of these results for the recovery of plant-pollinator interactions and on future decisions in restoration and conservation planning.

**Keywords:** biodiversity conservation; community assemblage; ecosystem management; forest fragmentation; functional diversity; pollination syndromes; semi-deciduous forest.

## Resumo Geral

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A conservação e restauração dos polinizadores são essenciais para a manutenção das populações vegetais nas paisagens fragmentadas, pois eles proporcionam diversidade genética entre os indivíduos espacialmente isolados. Dado que se espera que as populações nas florestas remanescentes e restauradas se perpetuem com o passar dos anos, os programas de restauração devem ser planejados também considerando alcançar este objetivo. Neste trabalho avaliamos as interações planta-polinizador em florestas tropicais em restauração, objetivando estabelecer primeiro, os requerimentos de polinização nestas comunidades e segundo, se os requerimentos de habitat dos polinizadores estão sendo satisfeitos e as interações entre plantas e polinizadores estão se recuperando através das práticas de restauração.

O trabalho compreende dois capítulos: No primeiro (*“Os sistemas de polinização de espécies arbóreas estão se recuperando por meio da restauração de florestas tropicais?”*) realizamos uma revisão exaustiva na literatura sobre a biologia da polinização das espécies de árvores em florestas primárias, plantios de restauração e florestas naturalmente regeneradas, para depois comparar e identificar os padrões na diversidade funcional e nas assembleias de modos de polinização. No segundo capítulo (*“Respostas e efeitos funcionais das comunidades de abelhas em florestas tropicais restauradas”*) coletamos abelhas (i.e. os principais polinizadores) e identificamos os grãos de pólen aderidos no seu corpo, em florestas primárias, plantios de restauração, áreas herbáceas degradadas e cultivos de cana-de-açúcar; depois analisamos e comparamos a diversidade funcional das comunidades de abelhas e seus recursos florais, a estrutura das redes de interação e também em resposta ao isolamento do habitat.

Encontramos que diferentes práticas de restauração geraram maiores mudanças nas proporções de vários modos de polinização, em lugares submetidos a atividades de restauração ativa do que nas florestas regeneradas naturalmente. Especificamente no caso

das abelhas, encontramos que a demanda pela sua função como polinizadores nos plantios de restauração era ainda maior do que nas florestas primárias, pois muitas espécies de árvores polinizadas por abelhas estavam sendo preferivelmente plantadas graças a sua maior habilidade como colonizadoras, ou devido à outras funções e serviços ecossistêmicos que elas provem. Observamos que as abelhas estavam se beneficiando dessa super-representação de recursos florais, dado que várias espécies visitaram mais frequentemente as árvores presentes nos plantios de restauração do que em outras áreas. Apesar dessa preferência, a abundância de indivíduos e a diversidade funcional nas comunidades de abelhas ainda não estavam totalmente recuperadas nas áreas em restauração, provavelmente porque alguns dos seus requerimentos de habitat estão ainda pouco fornecidos (e.g. recursos de nidificação). Mesmo que a diversidade funcional nas comunidades de abelhas tenha sido alta de maneira geral, somente uma pequena parte dela, que também foi a mais vulnerável (i.e. abelhas de maior porte que nidificam por cima do solo, tem diferentes níveis de sociabilidade e são poliléticas), foi a principal encarregada do transporte de pólen das plantas mais importantes das florestas primárias e restauradas (i.e. plantas lenhosas, nativas, de sucessão inicial e com diferentes modos de polinização).

Ao longo deste trabalho analisamos e discutimos as implicações destes resultados para a recuperação das interações planta-polinizador e nas futuras decisões no planejamento da restauração e conservação ecológica.

**Palavras chave:** floresta semidecidual; manutenção de ecossistemas; fragmentação florestal; diversidade funcional; síndromes de polinização, conservação da biodiversidade; estrutura de comunidades

# Appendices

## APPENDIX 1.1. LOCATION AND DESCRIPTION OF THE STUDIED SITES.

Location	coordinates	Description	Ref*
<b>Remnants</b>			
1	São João Sugar Factory, Araras (SP)	22°22'44.80"S, 47°18'28.43"W	100 ha protected fragment within a sugar cane matrix. Sample size 0.3 ha, 69 spp. (12)
2	Cafundó Natural Reserve, Itapemirim (ES)	20°43'S, 41°13'W	517 ha forest reserve, occasional selective logging. Sample size 2.4 ha, 232 spp. (1)
3	Fazenda Atibaia, Sao Jose do Barreiro (SP)	22°38'34"S, 44°39'22"W	14 ha fragment close to a natural reserve, occasional selective logging. Sample size 540 ind, 113 spp. (5)
4	Fazenda São Domingos, Areias (SP)	22°38'34"S, 44°43'24"W	300 ha fragment close to a natural reserve, occasional selective logging. Sample size 540 ind, 125 spp. (5)
5	Fazenda Atibaia, Sao Jose do Barreiro (SP)	22°38'19"S, 44°39'39"W	14 ha fragment close to a natural reserve, occasional selective logging. Sample size 540 ind, 132 spp. (5)
6	dos Caetetus Ecological Station, Gália (SP)	22°22'S, 49°40'W	2178.84 ha protected area. Sample size 0.6 ha, 62 spp. (3)
7	Santa Genebra Natural Reserve, Campinas (SP)	22°49'45"S, 47°06'33"W	251.77 ha forest reserve, sampled area 100 m far from border, selective logging, not recently perturbed. Sample size 0.35 ha, 37 spp. (6)
8	Santa Genebra Natural Reserve, Campinas (SP)	22°49'45"S, 47°06'33"W	251.77 ha forest reserve, sampled area 50 m far from border, selective logging, recently perturbed. Sample size 0.35 ha, 68 spp. (6)
9	Santa Genebra Natural Reserve, Campinas (SP)	22°49'45"S, 47°06'33"W	251.77 ha forest reserve, sampled area 10 m far from border, selective logging, not recently perturbed. Sample size 0.35 ha, 90 spp. (6)
10	Fazenda Santa Irene, Itatinga (SP)	23°17'S, 48°33'W	15 ha fragment influenced by Cerrado vegetation. Sample size 0.42 ha, 95 spp. (7)
11	Cachoeira River, Itarapina (SP)	22°23'S, 47°53'W	Riparian forest with high inclination. Sample size 12.8 ha, 59 spp. (8)
12	Mata do Paraíso Natural Reserve, Vicoso (MG)	20°48'07"S, 42°51'31"W	195 ha forest reserve, occasional selective logging. Sample size 0.3 ha, 78 spp. (14)
13	Passa Cinco River, Ipeúna (SP)	22°24'02"S, 47°43'32"W	60 ha riparian forest. Sample size 0.8 ha, 66 spp. (19)
14	Sao Roque Municipal Park, Sao Roque (SP)	23°31'26"S, 47°06'45"W	130 ha forest reserve sampled area close to border. Sample size 0.31 ha, 77 spp. (9)
15	Sao Roque Municipal Park, Sao Roque (SP)	23°31'26"S, 47°06'45"W	130 ha forest reserve sampled area at interior forest. Sample size 0.31 ha, 65 spp. (9)
16	Sao Roque Municipal	23°31'26"S,	130 ha forest reserve sampled area at interior (9)

	Park, Sao Roque (SP)	47°06'45"W	forest. Sample size 0.31 ha, 68 spp.	
17	Sebastião Aleixo da Silva Ecological Station, Bauru (SP)	22°19'S, 49°04'W	200 ha forest reserve, selective logging and occasional livestock grazing. Sample size 0.8 ha, 55 spp.	(22)
18	Sebastião Aleixo da Silva Ecological Station, Bauru (SP)	22°19'S, 49°04'W	200 ha forest reserve, selective logging and intense livestock grazing. Sample size 0.8 ha, 69 spp.	(22)
<b>Restored forests</b>				
19	São João Sugar Factory, Araras (SP)	22°26'22.13"S, 47°21'43.33"W	8 ha, 50 m-width riparian forest stripe, restored 8 years ago after sugar cane cultivation. 3m x 2m spacing plantations using pioneers, secondary initials and climax species without any pre-established spatial arrangement. Sample size 0.3 ha, 69 spp.	(12)
20	São João Sugar Factory, Araras (SP)	22°25'46.95"S, 47°20'36.80"W	12 ha, 150 m riparian forest stripe, planted 12 years ago after sugar cane cultivation. 3m x 2m spacing plantations using pioneers, secondary initials and climax species without any pre-established spatial arrangement. Sample size 0.3 ha, 51 spp.	(12)
21	Bandeirantes highway, Santa Bárbara D'Oeste (SP)	22°46'S, 47°26'W	146.3 ha forest stripe at a highway margin, restored 8 years ago after sugar cane cultivation and pasture. 3m x 2m spacing plantations in quadrangular modules, interspersing species from initial and late successional states. Sample size 0.54 ha, 65 spp.	(15)
22	Ester Sugar Factory, Cosmopolis (SP)	22°40'S, 47°12'W	25 ha riparian forest, planted 55 years ago after sugar cane cultivation and pasture. Plantations included 71 native and exotic species without any pre-established spatial arrangement. Sample size 0.75 ha, 93 spp.	(15)
23	Ribeirao Cachoerinha, Iracemapolis (SP)	22°34'S, 47°30'W	30-50 m width riparian forest stripe, restored 23 years ago after sugar cane cultivation. 3m x 3m and 4m x 4m spacing plantations, interspersing species from initial and late successional states. Sample size 0.72 ha, 92 spp.	(15)
24	Edmundo Navarro de Andrade Forest reserve, Rio Claro (SP)	22°25'S, 47°31'W	1.3 ha <i>Eucalyptus</i> stand planted 93 years ago. Plantations included native species with spacing of 3m x 2m. Sample size 0.12 ha, 26 spp.	(15)
25	Fazenda Cananeia, Candido Motta (SP)	22°46'S, 50°27'W	640 ha riparian forest restored 18 years ago after agriculture. Plantations include native and introduced species continuously planted until the study date and interspersed with cultivars when light conditions were proper. Sample size 1ha, 23 spp.	(16)
26	Fazenda Cananeia, Candido Motta (SP)	22°46'S, 50°27'W	640 ha riparian forest planted 28 years ago after agriculture. Plantations include native and introduced species continuously planted until the study date and interspersed with cultivars when light conditions were proper. Sample size 1ha, 37 spp.	(16)
27	Viçosa Federal	20°46'28.37"S,	40 year-old forest restored after <i>Eucalyptus</i>	(10)

	University, Viçosa (MG)	42°52'37.26"W	cultivation, surrounded by exotic timberlands. Plantations included 56 native and exotic species, with spacing of 4m x 4m. Sample size 1ha, 110 spp.	
28	Pacotuba National Forest, Cachoeiro de Itapemirim ES	20°44'22"S, 41°17'38"W	10 year-old small forest planted after pasture, surrounded by secondary and conserved forest. Plantations included native and exotic species, with spacing of 3m x 4m. Sample size 0.4 ha, 38 spp.	(18)
29	Sao Luiz Dam, Santa Bárbara D'Oeste (SP)	22°45'S, 47°24'W	12 km-length riparian forest stripe, restored 13 years ago after agriculture. Plantations included mainly native local species, with spacing of 3m x 2m. Sample size 1 ha, 55 spp.	(11)
<b>Secondary forests</b>				
30	Viçosa Federal University, Viçosa (MG)	20°46'S, 42°52'W	50 ha forest regenerated 28 years ago after coffee cultivation and pasture, surrounded by conserved forest. Sample size 0.25 ha, 75 spp.	(2)
31	Viçosa Federal University, Viçosa (MG)	20°46'S, 42°52'W	50 ha forest recovered for 50 years after coffee cultivation and pasture, surrounded by conserved forest. Sample size 0.25 ha. 58 spp.	(2)
32	Fazenda Santa Cecília do Ingá, Volta Redonda (RJ)		90 ha forest recovered for 50 years after coffee cultivation. Sample size 0.1 ha, 30 spp.	(4)
33	Dona Rita Hydroelectric Reservoir, Itambé do Mato Dentro (MG)	19°26'S, 43°14'W	9.8 ha fragment recovered for 15 years after logging for charcoal production. Sample size 0.45 ha, 152 spp.	(13)
34	Dona Rita Hydroelectric Reservoir, Itambé do Mato Dentro (MG)	19°26'S, 43°14'W	9.8 ha fragment recovered for 40 years after logging for charcoal production. Sample size 0.38 ha, 145 spp.	(13)
35	Mata do Paraíso Forest Reserve, Viçosa (MG)	20°48'07"S, 42°51'31"W	small forest recovered for 40 years after pasture, surrounded by conserved forest, Sample size 0.3 ha, 55 spp.	(14)
36	Piranga (MG)	20°41'34.3"S, 43°19'38.2"W	139.14 ha forest fragment recovered for 40 years after burning and logging. Sample size 22 ha, 169 spp.	(17)
37	Sao Paulo University, Sao Paulo (SP)	23°33'S, 46°43'W	10.2 ha forest fragment in urban area, recovered for about 100 years after agriculture and pasture, occasional selective logging. Sample size 0.25 ha, 72 spp.	(20)
38	Santa Genebra Natural Reserve, Campinas (SP)	22°49'45"S, 47°06'33"W	10 ha forest recovered for 17 years after burning, surrounded by conserved forest. Sample size 0.45ha, 48 spp.	(21)
39	Sebastião Aleixo da Silva Ecological Station, Bauru (SP)	22°19'S, 49°04'W	forest recovered for 40 years after agriculture and pasture, surrounded by conserved forest, recently perturbed by occasional livestock grazing. Sample size 0.8 ha, 75 spp.	(22)
40	Sebastião Aleixo da Silva Ecological Station, Bauru (SP)	22°19'S, 49°04'W	forest recovered for 40 years after agriculture and pasture, surrounded by conserved forest, recently perturbed by intense livestock grazing. Sample size 0.8 ha, 59 spp.	(22)

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APPENDIX 1.2. TREE SPECIES WITH POLLINATION MODES AND NUMBER OF SITES PRESENT ON EACH FOREST TYPE.

Specialized pollination modes were classified as ‘bird’, ‘bat’, ‘wasp’, ‘fly’, ‘moth’, ‘beetle’, ‘small insect’ (trips, rove beetles, etc.), ‘bee’ and ‘wind’. Mixed pollination modes corresponding to combinations of two or more functional groups included ‘insect’ (various types), ‘pollen consumer’ (various types of insects excluding nectar consumers such as lepidopterans), ‘big animal’ (large bees, birds, lepidopterans and bats), ‘long tongue’ (bees, lepidopterans, birds) and ‘vertebrate’ (hummingbirds and bats).

Family	Species	Pollination mode	Remnant (n=18)	Restored (n=11)	Secondary (n=11)
Achariaceae	<i>Carpotroche brasiliensis</i>	pollen consumer	2	1	4
	<i>Astronium concinnum</i>	pollen consumer	1		
Anacardiaceae	<i>Astronium fraxinifolium</i>	pollen consumer		1	2
	<i>Astronium graveolens</i>	pollen consumer	11	5	7
	<i>Lithraea molleoides</i>	insect	1	1	
	<i>Mangifera indica</i>	insect		5	
	<i>Myracrodruon urundeuva</i>	insect		3	
	<i>Rhus succedanea</i>	insect		1	
	<i>Schinus molle</i>	insect		1	
	<i>Schinus therebinthifolius</i>	insect	1	9	
	<i>Spondias macrocarpa</i>	insect		1	
	<i>Spondias mombin</i>	insect		1	
	<i>Spondias venulosa</i>	insect	1		
	<i>Tapirira guianensis</i>	insect	4	1	3
Annonaceae	<i>Thyrsodium spruceanum</i>	insect			2
	<i>Anaxagorea dolichocarpa</i>	beetle	1		
	<i>Anaxagorea phaeocarpa</i>	beetle			2
	<i>Annona acutiflora</i>	beetle	1		
	<i>Annona cacans</i>	beetle	7	1	3
	<i>annonia glabra</i>	beetle	3		
	<i>Annona muricata</i>	beetle		3	
	<i>Cymbopetalum brasiliense</i>	beetle			1
	<i>Duguetia flagellaris</i>	beetle	1		
	<i>Duguetia lanceolata</i>	beetle	2		2
	<i>Guatteria australis</i>	beetle	5		1
	<i>Guatteria nigrescens</i>	beetle	4	1	3
	<i>Guatteria pogonopus</i>	beetle			2
	<i>Guatteria seaustralis</i>	beetle			1
	<i>Guatteria sellowiana</i>	beetle	3		1
	<i>Guatteria villosissima</i>	beetle			2
	<i>Oxandra nitida</i>	beetle	1		
	<i>Rollinia emarginata</i>	beetle		1	
	<i>Rollinia laurifolia</i>	beetle			2
	<i>Rollinia mucosa</i>	beetle	1	1	
	<i>Rollinia sericea</i>	beetle	2		1
	<i>Rollinia sylvatica</i>	beetle	5	1	3
	<i>Trigynaea oblongifolia</i>	beetle	1		
	<i>Unonopsis guatterioides</i>	beetle	2		1
	<i>Xylopia aromatica</i>	beetle			1
	<i>Xylopia brasiliensis</i>	beetle	4		2
	<i>Xylopia sericea</i>	beetle	3	1	5
Apocynaceae	<i>Aspidosperma camporum</i>	moth	3		
	<i>Aspidosperma cylindrocarpon</i>	moth	4	1	
	<i>Aspidosperma discolor</i>	moth	1		
	<i>Aspidosperma dispernum</i>	moth	1		
	<i>Aspidosperma illustre</i>	moth	1		
	<i>Aspidosperma olivaceum</i>	moth	1	1	

	<i>Aspidosperma parvifolium</i>	moth	3		2
	<i>Aspidosperma polyneuron</i>	moth	11	2	2
	<i>Aspidosperma ramiflorum</i>	moth	4	3	1
	<i>Aspidosperma spruceanum</i>	moth			2
	<i>Himatanthus bracteatus</i>	moth	1		
	<i>Himatanthus lancifolius</i>	moth			3
	<i>Himatanthus phagedaenicus</i>	moth	1		
	<i>Malouetia arborea</i>	moth	3		2
	<i>Rauvolfia mattfeldiana</i>	long tongue	1		
	<i>Rauvolfia sellowii</i>	insect			1
	<i>Tabernaemontana catharinensis</i>	moth	3		2
	<i>Tabernaemontana fuchsiaeifolia</i>	moth		1	
	<i>Tabernaemontana hystrix</i>	moth	3		1
	<i>Tabernaemontana laeta</i>	moth	3		1
Aquifoliaceae	<i>Ilex cerasifolia</i>	insect			3
	<i>Ilex paraguariensis</i>	insect	1		
	<i>Ilex pseudobuxus</i>	insect	1		
	<i>Ilex theezans</i>	insect	1		
Araliaceae	<i>Aralia warmingiana</i>	insect	1		1
	<i>Dendropanax cuneatus</i>	insect	3	2	1
	<i>Schefflera morototoni</i>	insect		1	4
	<i>Schefflera calva</i>	insect	3		
Araucariaceae	<i>Araucaria angustifolia</i>	wind		1	
Arecaceae	<i>Acrocomia aculeata</i>	beetle		1	1
	<i>Aiphanes horrida</i>	insect-wind		1	
	<i>Allagoptera caudescens</i>	undetermined			1
	<i>Archontophoenix cunninghamiana</i>	bee		1	1
	<i>Astrocaryum aculeatissimum</i>	beetle	2		1
	<i>Attalea dubia</i>	undetermined		1	
	<i>Bactris acanthocarpa</i>	beetle			1
	<i>Caryota urens</i>	undetermined		1	
	<i>Dypsis lutescens</i>	undetermined		1	
	<i>Euterpe edulis</i>	bee	2	1	
	<i>Geonoma schottiana</i>	insect	2		
	<i>Mauritia flexuosa</i>	beetle		1	
	<i>Phoenix reclinata</i>	insect-wind		1	
	<i>Roystonea oleracea</i>	bee		1	
	<i>Syagrus oleracea</i>	beetle-bee	6		
	<i>Syagrus romanzoffiana</i>	beetle-bee	9	3	8
Asparagaceae	<i>Cordyline fruticosa</i>	insect	2		
Asteraceae	<i>Eremanthus erythropappus</i>	insect			1
	<i>Eremanthus incanus</i>	insect			2
	<i>Eupatorium macrophyllum</i>	insect	1		
	<i>Gochnatia polymorpha</i>	insect	2		2
	<i>Morithamnus ganophyllus</i>	insect			1
	<i>Piptocarpha angustifolia</i>	insect	1		
	<i>Piptocarpha axillaris</i>	insect	1		
	<i>Piptocarpha macropoda</i>	insect	2		3
	<i>Piptocarpha ramiflora</i>	insect	1		
	<i>Piptocarpha sellowii</i>	insect	2		
	<i>Vernonanthura diffusa</i>	insect	2		2
	<i>Vernonanthura divaricata</i>	insect			1
	<i>Vernonia diffusa</i>	insect	4	1	
	<i>Vernonia polyanthes</i>	insect			1
Bignoniaceae	<i>Cybistax antisyphilitica</i>	bee	2		1
	<i>Handroanthus achraceus</i>	bee	1		
	<i>Handroanthus chrysotrichus</i>	bee		4	
	<i>Handroanthus heptaphyllus</i>	bee	2	2	
	<i>Handroanthus impetiginosus</i>	bee		4	
	<i>Handroanthus ochraceus</i>	bee	1	4	
	<i>Handroanthus vellosi</i>	bee		1	
	<i>Jacaranda cuspidifolia</i>	bee		2	
	<i>Jacaranda macrantha</i>	bee	6		4
	<i>Jacaranda mimosifolia</i>	bee		4	
	<i>Jacaranda puberula</i>	bee	1		5
	<i>Paratecoma peroba</i>	long tongue	1	1	
	<i>Sparattosperma leucanthum</i>	bee	3	2	7
	<i>Spathodea campanulata</i>	vertebrate		5	
	<i>Tabebuia alba</i>	bee			1
	<i>Tabebuia arianaeae</i>	bee	1		

	<i>Tabebuia avellanedae</i>	bee			
	<i>Tabebuia chrysotricha</i>	bee	1		1
	<i>Tabebuia heptaphylla</i>	bee	2	2	1
	<i>Tabebuia heterophylla</i>	bee			
	<i>Tabebuia impetiginosa</i>	bee		1	1
	<i>Tabebuia pentaphylla</i>	bee			
	<i>Tabebuia rosea</i>	bee		1	
	<i>Tabebuia roseoalba</i>	bee	1	4	
	<i>Tabebuia vellosi</i>	bee			2
	<i>Tecoma stans</i>	bee	1	3	2
Bixaceae	<i>Zeyheria tuberculosa</i>	bee	3	2	3
Boraginaceae	<i>Bixa orellana</i>	bee		2	
	<i>Cordia abyssinica</i>	insect		5	
	<i>Cordia americana</i>	insect	4	4	2
	<i>Cordia ecalyculata</i>	insect	6	1	3
	<i>Cordia magnoliifolia</i>	insect			2
	<i>Cordia nodosa</i>	insect			1
	<i>Cordia sellowiana</i>	insect	3		2
	<i>Cordia superba</i>	insect	3	2	1
	<i>Cordia trichotoma</i>	insect	2	2	2
Burseraceae	<i>Crepidospermum atlanticum</i>	insect	1		
	<i>Protium brasiliense</i>	insect			1
	<i>Protium heptaphyllum</i>	insect	6	2	4
	<i>Protium warmingianum</i>	insect	1	1	4
	<i>Protium widgrenii</i>	insect			1
	<i>Protium spruceanum</i>	insect	1		2
Cactaceae	<i>Opuntia brasiliensis</i>	bee	1		
Calophyllaceae	<i>Kielmeyera lathrophyton</i>	pollen consumer			1
Canellaceae	<i>Cinnamodendron dinisii</i>	beetle			1
Cannabaceae	<i>Celtis iguanaea (syn. ehrenbergiana)</i>	wind	3		2
	<i>Trema micrantha</i>	wind	6	3	3
Capparaceae	<i>Capparidastrum brasilianum</i>	big animal	1		
	<i>Crateva benthamii</i>	big animal		1	
Cardiopteridaceae	<i>Citronela megaphylla</i>	insect	1		
	<i>Citronella paniculata</i>	insect	4		
	<i>Villaresia congonha</i>	insect	1		
Caricaceae	<i>Carica papaya</i>	long tongue		1	
	<i>Carica quercifolia</i>	long tongue	1		
	<i>Jacaratia heptaphylla</i>	moth	1		
	<i>Jacaratia spinosa</i>	moth	7	1	1
Casuarinaceae	<i>Casuarina equisetifolia</i>	wind		1	
Celastraceae	<i>Maytenus alaternoides</i>	insect			1
	<i>Maytenus cestrifolia</i>	insect	1		
	<i>Maytenus evonymoides</i>	insect	4		1
	<i>Maytenus glazioviana</i>	insect			1
	<i>Maytenus ilicifolia</i>	insect	4		1
	<i>Maytenus multiflora</i>	insect	1		
	<i>Maytenus robusta</i>	insect	5		1
	<i>Maytenus salicifolia</i>	insect	4		2
Chrysobalanaceae	<i>Couepia meridionalis</i>	insect			2
	<i>Hirtella hebeclada</i>	moth	1		
	<i>Licania hoehnei</i>	insect	3		
	<i>Licania hypoleuca</i>	insect			2
	<i>Licania kunthiana</i>	insect	2		1
	<i>Licania octandra</i>	insect			1
	<i>Licania tomentosa</i>	insect		2	
Clethraceae	<i>Clethra scabra</i>	insect	4		2
Clusiaceae	<i>Calophyllum brasiliensis</i>	insect	1		2
	<i>Garcinia garneriana</i>	bee	1		
	<i>Garcinia brasiliensis</i>	bee	1	1	
	<i>Tovomitopsis saldanhae</i>	bee	1		2
Combretaceae	<i>Terminalia argentea</i>	insect	1	1	1
	<i>Terminalia glabrescens</i>	insect	1		3
	<i>Terminalia kuhlmannii</i>	insect	1		
	<i>Terminalia phaeocarpa</i>	insect	1		
	<i>Terminalia triflora</i>	insect	3	1	2
Connaraceae	<i>Connarus detersus</i>	insect	1		
Cycadaceae	<i>Cycas circinalis</i>	insect-wind		1	
Dichapetalaceae	<i>Stephanopodium engleri</i>	insect			1
Dilleniaceae	<i>Dillenia indica</i>	bee		3	

Ebenaceae	<i>Diospyros capreifolia</i>	moth	1			
	<i>Diospyros hispida</i>	moth			1	
	<i>Diospyros inconstans</i>	moth	4		1	
Elaeocarpaceae	<i>Sloanea guianensis</i>	bee	3		1	
	<i>Sloanea monosperma</i>	bee	4		2	
Erythroxylaceae	<i>Erythroxylum buxus</i>	insect	1			
	<i>Erythroxylum citrifolium</i>	insect	2		2	
	<i>erythroxylum pelleterianum</i>	insect	2		6	
	<i>Erythroxylum pulchrum</i>	insect	3	1	1	
	<i>Erythroxylum campestre</i>	insect	1			
Euphorbiaceae	<i>Acalypha sp.</i>	wind	1			
	<i>Actinostemon communis</i>	wind	1			
	<i>Actinostemon conceptionis</i>	wind	1			
	<i>Actinostemon concolor</i>	wind	7		2	
	<i>Actinostemon klotzschii</i>	wind	6		1	
	<i>Alchornea glandulosa</i>	wind	12	8	5	
	<i>Alchornea iricurana</i>	wind	1		1	
	<i>Alchornea sidifolia</i>	wind			1	
	<i>Alchornea triplinervia</i>	wind	4		3	
	<i>Aleurites moluccana</i>	insect		1		
	<i>Aparisthium cordatum</i>	wind	2		3	
	<i>Cnidocolus oligandrus</i>	insect	1			
	<i>Croton floribundus</i>	insect	13	3	8	
	<i>Croton piptocalyx</i>	insect	4			
	<i>Croton salutaris</i>	insect	2		1	
	<i>Croton urucurana</i>	insect	1	5	2	
	<i>Croton verrucosus</i>	insect			1	
	<i>Glycydendron amazonicum</i>	insect	1			
	<i>Hevea brasiliensis</i>	insect		1		
	<i>Hura crepitans</i>	bat		1		
	<i>Joannesia princeps</i>	insect		7		
	<i>Mabea fistulifera</i>	big animal	1		5	
	<i>Mabea piriri</i>	big animal	2			
	<i>Manihot pilosa</i>	insect	1	1	2	
	<i>Maprounea guiwindsis</i>	wind	3	1	2	
	<i>Pachystroma longifolium</i>	wind	1	1		
	<i>Philyra brasiliensis</i>	undetermined	1			
	<i>Ricinus communis</i>	insect-wind		1		
	<i>Sapium glandulosum</i>	insect	3	1	5	
	<i>Sebastiania serrata</i>	wind	2		1	
	<i>Sebastiania commersoniana</i>	wind	6			
	<i>Senefeldera verticillata</i>	wind	3			
	<i>Tetrorchidium rubrivenium</i>	wind	5			
	Leguminosae	<i>Abarema limae</i>	big animal	1		
		<i>Acacia glomerosa</i>	insect	2		
		<i>Acacia polyphylla</i>	insect	5	1	6
		<i>Acosmium lentiscifolium</i>	insect	1		
		<i>Acosmium subelegans</i>	insect	1		
		<i>Albizia hasslerii</i>	big animal	1		
		<i>Albizia lebbeck</i>	big animal		3	
		<i>Albizia niopoides</i>	big animal		1	1
		<i>Albizia polycephala</i>	big animal	7		7
<i>Anadenanthera colubrina</i>		insect	1	3	3	
<i>Anadenanthera falcata</i>		insect				
<i>Anadenanthera macrocarpa</i>		insect	1	1	1	
<i>Anadenanthera peregrina</i>		insect	1	3	3	
<i>Anadenanthera peregrina var. falcata</i>		insect		1		
<i>Andira anthelmia</i>		bee			1	
<i>Andira fraxinifolia</i>		bee			2	
<i>Andira legalis</i>		bee			1	
<i>Andira ormosioides</i>		bee	2		1	
<i>Apuleia leiocarpa</i>		insect	1	1	7	
<i>Bauhinia forficata</i>		moth	4	3	1	
<i>Bauhinia longifolia</i>		vertebrate	3	1	3	
<i>Bauhinia rufa</i>		bat	1			
<i>Bauhinia variegata</i>		vertebrate		1		
<i>Bowdichia virgilioides</i>		bee			1	
<i>Caesalpinia echinata</i>		bee		3		
<i>Caesalpinia ferrea</i>		bee		3	1	
<i>Caesalpinia leiostachya</i>		bee		1		

<i>Caesalpinia pluviosa</i>	bee		3	
<i>Calliandra foliolosa</i>	big animal	2		1
<i>Calliandra tweedii</i>	bird	1		
<i>Cassia ferruginea</i>	bee	5	2	3
<i>Cassia fistula</i>	bee		1	
<i>Centrolobium robustum</i>	bee		1	
<i>Centrolobium tomentosum</i>	bee	8	5	3
<i>Chloroleucon tortum</i>	big animal		1	
<i>Clitoria fairchildiana</i>	bee		2	
<i>Copaifera langsdorffii</i>	insect	5	2	6
<i>Copaifera lucens</i>	insect	1		
<i>Copaifera trapezifolia</i>	insect	1		
<i>Dahlstedtia pinnata</i>	bird	1		
<i>Dalbergia brasiliensis</i>	insect	1		
<i>Dalbergia elegans</i>	insect	1		
<i>Dalbergia frutescens</i>	insect			4
<i>Dalbergia nigra</i>	insect	4	2	6
<i>Dalbergia villosa</i>	insect			3
<i>Deguelia</i> sp.	bee	1		
<i>Delonix regia</i>	bird		1	
<i>Dimorphandra mollis</i>	insect		1	
<i>Diplotropis incexis</i>	bee	1		
<i>Dipteryx alata</i>	bee		1	
<i>Enterolobium contortisiliquum</i>	insect	2	5	1
<i>Enterolobium monjollo</i>	insect			1
<i>Erythrina falcata</i>	bird	2	1	
<i>Erythrina speciosa</i>	bird		5	
<i>Erythrina verna</i>	bird		1	1
<i>Exostyles venusta</i>	insect	1		
<i>Gliricidia sepium</i>	bee		1	
<i>Goniorrhachis marginata</i>	bee	1		
<i>Holocalyx balansae</i>	insect	8	5	1
<i>Hymenaea courbaril</i>	bat	2	7	
<i>Hymenaea courbaril</i> var. <i>Stilbocarpa</i>	bat			
<i>Hymenaea martiana</i>	bee		1	
<i>Hymenolobium janeirensis</i>	bee	1		2
<i>Inga affinis</i>	big animal	1		
<i>Inga capitata</i>	big animal			2
<i>Inga cylindrical</i>	insect	1		1
<i>Inga edulis</i>	big animal	1		
<i>Inga hispida</i>	big animal	1		
<i>Inga ingoides</i>	big animal			1
<i>Inga laurina</i>	moth		1	
<i>Inga leptantha</i>	big animal			1
<i>Inga luschnathiana</i>	big animal	3		
<i>Inga marginata</i>	big animal	6	2	3
<i>Inga sessilis</i>	big animal	2		1
<i>Inga striata</i>	big animal	6		4
<i>Inga uruguayensis</i>	big animal	1		
<i>Inga vera</i>	big animal		4	2
<i>Inga vera subespaffinis</i>	big animal			1
<i>Inga vulpine</i>	big animal			1
<i>Leucochloron incuriale</i>	insect		1	
<i>Leucaena leucocephala</i>	insect		4	
<i>Libidibia ferrea</i>	bee		1	
<i>Lonchocarpus campestris</i>	bee		2	
<i>Lonchocarpus cultratus</i>	bee	5	3	3
<i>Lonchocarpus guilleminianus</i>	bee	2		
<i>Lonchocarpus muehlbergianus</i>	bee	4	7	1
<i>Luetzelburgia guaissara</i>	bee	1		
<i>Machaerium acutifolium</i>	bee	3		2
<i>Machaerium brasiliense</i>	bee	2	1	4
<i>Machaerium dimorphandrum</i>	bee			1
<i>Machaerium fulvovenosum</i>	bee	1		
<i>Machaerium hirtum</i>	bee	3		3
<i>Machaerium lanceolatum</i>	bee			1
<i>Machaerium nictitans</i>	bee	11	3	5
<i>Machaerium scleroxylon</i>	bee	1	1	
<i>Machaerium stipitatum</i>	bee	9	2	7
<i>Machaerium vestitum</i>	bee	2		

	<i>Machaerium villosum</i>	bee	3	1	2
	<i>beeanoxylon brauna</i>	bee	2		3
	<i>Mimosa artemisiana</i>	insect			1
	<i>Mimosa bimucronata</i>	insect		3	
	<i>Mimosa caesalpiniiifolia</i>	insect		3	
	<i>Myrocarpus frondosus</i>	insect	2	1	
	<i>Myroxylon peruiferum</i>	insect-bird	3	7	1
	<i>Ormosia arborea</i>	insect	3		
	<i>Parapiptadenia pterosperma</i>	insect	1		
	<i>Parapiptadenia rigida</i>	insect	3	3	2
	<i>Parkia</i> sp.	bat-bee		1	
	<i>Peltogyne angustiflora</i>	bee	1		
	<i>Peltophorum dubium</i>	bee	6	7	3
	<i>Phyllocarpus riedelii</i>	butterfly-moth-bird	1		
	<i>Piptadenia gonoacantha</i>	insect	12	6	10
	<i>Piptadenia paniculata</i>	insect	1		
	<i>Plathymenia foliolosa</i>	insect	1		
	<i>Plathymenia reticulata</i>	insect			3
	<i>Plathymiscium floribundus</i>	bee	4		
	<i>Platycyamus regnellii</i>	bee	1		
	<i>Platymiscium pubescens</i>	bee		1	2
	<i>Platypodium elegans</i>	bee	4	2	6
	<i>Poecilanthe falcata</i>	bee	1		
	<i>Poecilanthe parviflora</i>	bee		3	
	<i>Poeppigia procera</i>	insect	1		
	<i>Poincianella pluviosa</i>	bee		2	
	<i>Pseudopiptadenia contorta</i>	insect	5	1	3
	<i>Pseudopiptadenia leptostachya</i>	insect	2		
	<i>Pseudopiptadenia warmingii</i>	insect	1		1
	<i>Pterocarpus rohrii</i>	bee	1	1	
	<i>Pterocarpus violaceus</i>	bee		2	
	<i>Pterodon emarginatus</i>	bee	1		
	<i>Pterogyne nitens</i>	insect	1	5	2
	<i>Samanea tubulosa</i>	big animal		1	
	<i>Schizolobium parahyba</i>	bee	2	7	1
	<i>Sclerolobium rugosum</i>	insect			2
	<i>Senegalia polyphylla</i>	insect	1	2	
	<i>Senna macranthera</i>	bee	2	2	3
	<i>Senna multijuga</i>	bee	3	4	4
	<i>Stryphnodendron guianense</i>	insect			2
	<i>Stryphnodendron obovatum</i>	insect			1
	<i>Stryphnodendron polyphyllum</i>	insect			2
	<i>Swartzia acutifolia</i>	bee	1		1
	<i>Swartzia apetala</i>	bee	1		1
	<i>Swartzia flaemingii</i>	bee			1
	<i>Swartzia macrostachya</i>	bee			1
	<i>Swartzia multijuga</i>	bee			2
	<i>Swartzia myrtifolia</i>	bee	3		2
	<i>Swartzia oblata</i>	bee	1	1	
	<i>Swartzia polyphylla</i>	bee			2
	<i>Sweetia fruticosa</i>	insect	4		2
	<i>Tachigali denudata</i>	insect	2		1
	<i>Tachigali paratyensis</i>	insect	1		2
	<i>Tachigali rugosa</i>	insect	2		
	<i>Tipuana tipu</i>	bee		8	
	<i>Vatairea heteroptera</i>	bee	1		
	<i>Zollernia glabra</i>	bee	1		
	<i>Zollernia ilicifolia</i>	bee		1	
	<i>Zollernia modesta</i>	insect	1		
	<i>Zygia latifolia</i>	big animal			2
Fagaceae	<i>Castwindia sativa</i>	wind		1	
Humiriaceae	<i>Humiriastrum dentatum</i>	insect	1		
Hypericaceae	<i>Vismia brasiliensis</i>	bee			1
	<i>Vismia guianensis</i>	bee		1	2
Juglandaceae	<i>Juglans regia</i>	wind		1	
Lacistemataceae	<i>Lacistema pubescens</i>	wind	1	1	2
	<i>Lacistema robustum</i>	wind			1
Lamiaceae	<i>Callicarpa reevesii</i>	insect		1	
	<i>Gbeeina arborea</i>	bee		1	
Lauraceae	<i>Aniba formula</i>	insect	3		2

	<i>Cinnamomum verum</i>	insect		1	
	<i>Cinnamomum triplinerve</i>	insect			1
	<i>Cryptocarya aschersoniana</i>	insect	4		
	<i>Cryptocarya moschata</i>	insect	2		
	<i>Cryptocarya saligna</i>	insect	2		
	<i>Endlicheria glomerata</i>	insect			2
	<i>Endlicheria paniculata</i>	insect	7	1	3
	<i>Nectandra grandiflora</i>	insect	1		1
	<i>Nectandra hihua</i>	insect	1		
	<i>Nectandra lanceolata</i>	insect	1	1	2
	<i>Nectandra megapotamica</i>	insect	8	7	4
	<i>Nectandra membranacea</i>	insect	1		
	<i>Nectandra oppositifolia</i>	insect	10	2	7
	<i>Nectandra puberula</i>	insect			1
	<i>Nectandra reticulata</i>	insect			1
	<i>Nectandra rigida</i>	insect	1		
	<i>Nectandra saligna</i>	insect			1
	<i>Nectandra warmingii</i>	insect			1
	<i>Ocotea beulahiae</i>	insect	2		
	<i>Ocotea bicolor</i>	insect	1		
	<i>Ocotea brachybotra</i>	insect	3		
	<i>Ocotea campininha</i>	insect	2		
	<i>Ocotea conferta</i>	insect	1		
	<i>Ocotea confertiflora</i>	insect	1		
	<i>Ocotea corymbosa</i>	insect	9		4
	<i>Ocotea diospyrifolia</i>	insect	3		1
	<i>Ocotea dispersa</i>	insect			1
	<i>Ocotea divaricata</i>	insect			3
	<i>Ocotea elegans</i>	insect	3		
	<i>Ocotea glaziovii</i>	insect			1
	<i>Ocotea indecora</i>	insect	4		
	<i>Ocotea lancifolia</i>	insect	1		
	<i>Ocotea laxa</i>	insect			2
	<i>Ocotea minarum</i>	insect	1		
	<i>Ocotea nitida</i>	insect	1		
	<i>Ocotea odorifera</i>	insect	3		2
	<i>Ocotea pretiosa</i>	insect	1		1
	<i>Ocotea puberula</i>	insect	4	2	
	<i>Ocotea pulchella</i>	insect	1		
	<i>Ocotea silvestris</i>	insect	2		
	<i>Ocotea teleiandra</i>	insect			1
	<i>Ocotea velloziana</i>	insect	2		
	<i>Ocotea velutina</i>	insect	1		4
	<i>Persea americana</i>	insect	1	2	
	<i>Persea pyrifolia</i>	insect	1		
	<i>Persea venosa</i>	insect			1
	<i>persea willdenowii</i>	insect	1		
	<i>Urbanodendron bahiense</i>	insect	1		
	<i>Urbanodendron verrucosum</i>	insect			3
Lecythidaceae	<i>Cariniana estrellensis</i>	bee	14	5	6
	<i>Cariniana legalis</i>	bee	4	6	1
	<i>Cariniana rubra</i>	bee		1	
	<i>Couratari asterotricha</i>	bee	1		
	<i>Lecythis lanceolata</i>	bee		1	1
	<i>Lecythis lurida</i>	bee	1		
	<i>Lecythis pisonis</i>	bee	1	2	
Loganiaceae	<i>Strychnos brasiliensis</i>	insect			1
Lythraceae	<i>Lafoensia glyptocarpa</i>	bat		3	
	<i>Lafoensia pacari</i>	bat	2	1	
	<i>Lagerstroemia speciosa</i>	bee		2	
Magnoliaceae	<i>Magnolia champaca</i>	beetle		7	
	<i>Magnolia ovata</i>	beetle	1		
Malpighiaceae	<i>Bunchosia palleescens</i>	bee	1		
	<i>Byrsonima ligustrifolia</i>	bee	2		
	<i>Byrsonima sericea</i>	bee			2
	<i>Heteropterys byrsonimifolia</i>	bee			1
Malvaceae	<i>Adansonia digitata</i>	bat		1	
	<i>Basiloxylon brasiliensis</i>	bee		2	
	<i>Bastardiopsis densiflora</i>	insect		1	
	<i>Ceiba glaziovii</i>	bat	1		

	<i>Ceiba speciosa</i>	bat	6	7	5
	<i>Christiana macrodon</i>	insect	1		
	<i>Eriotheca candolleana</i>	bat			3
	<i>Guazuma crinita</i>	fly	1		
	<i>Guazuma ulmifolia</i>	fly	3	4	2
	<i>Helicteres lhotzkyana</i>	vertebrate		1	
	<i>Helicteres ovata</i>	vertebrate			1
	<i>Heliocarpus americanus</i>	insect	1		
	<i>Heliocarpus popayanensis</i>	insect		2	
	<i>Luehea candicans</i>	moth	2		1
	<i>Luehea divaricata</i>	big animal	5	3	5
	<i>Luehea grandiflora</i>	bat	4	5	6
	<i>Luehea mediterranea</i>	undetermined	1		
	<i>Luehea speciosa</i>	big animal		1	
	<i>Pachira aquatica</i>	bat		1	
	<i>Pachira glabra</i>	bat		5	
	<i>Pseudobombax grandiflorum</i>	bat	9	4	2
	<i>Pseudobombax longiflorum</i>	bat			1
	<i>Pterygota brasiliensis</i>	insect	1		
	<i>Quararibea penduliflora</i>	moth-bat	1		
	<i>Sterculia curiosa</i>	undetermined	1		
	<i>Sterculia apetala</i>	big animal		2	
Melastomataceae	<i>Miconia budlejoides</i>	bee	1		
	<i>Miconia calvescens</i>	bee			1
	<i>Miconia candolleana</i>	bee			1
	<i>Miconia cinnamomifolia</i>	bee	3	1	1
	<i>Miconia discolor</i>	bee			1
	<i>Miconia fasciculata</i>	bee			1
	<i>Miconia hymenonervia</i>	bee	2		
	<i>Miconia inconspicua</i>	bee	1		
	<i>Miconia latecrenata</i>	bee	1		
	<i>Miconia lepidota</i>	bee	2		
	<i>Miconia pusilliflora</i>	bee	1		
	<i>Miconia theaezans</i>	bee			1
	<i>Miconia trianae</i>	bee			1
	<i>Miconia tristis</i>	bee			1
	<i>Tibouchina estrellensis</i>	bee			1
Meliaceae	<i>Tibouchina granulosa</i>	bee		1	1
	<i>Cabralea canjerana</i>	moth	11	2	5
	<i>Cedrela fissilis</i>	insect	10	6	4
	<i>Guarea guidonia</i>	moth	2	4	4
	<i>Guarea kunthiana</i>	moth	6	2	4
	<i>Guarea macrophylla</i>	moth	5		3
	<i>Melia azedarach</i>	insect		3	1
	<i>Toona ciliata</i>	insect		1	
	<i>Trichilia casaretti</i>	insect	1		
	<i>Trichilia catigua</i>	insect	11	3	1
	<i>Trichilia clausenii</i>	insect	8	3	2
	<i>Trichilia elegans</i>	insect	5		2
	<i>Trichilia emarginata</i>	insect	1		
	<i>Trichilia hirta</i>	insect	1		1
	<i>Trichilia lepidota</i>	insect	2	1	2
	<i>Trichilia pallens</i>	insect	2		1
	<i>Trichilia pallida</i>	insect	9	1	8
	<i>Trichilia quadrijuga</i>	insect	1		
	<i>Trichilia ramalhoi</i>	insect	1		
	<i>Trichilia silvatica</i>	insect	2		
	<i>Trichilia tetrapetala</i>	insect	1		
Monimiaceae	<i>Mollinedia argyrogyna</i>	small insect	3		
	<i>Mollinedia glabra</i>	small insect	2		
	<i>Mollinedia lanceolata</i>	small insect	1		
	<i>Mollinedia longifolia</i>	small insect	2		
	<i>Mollinedia schottiana</i>	small insect	1	1	1
	<i>Mollinedia triflora</i>	small insect			1
	<i>Mollinedia widgrenii</i>	small insect	4		2
	<i>Siparuna arianae</i>	small insect	1		
	<i>Siparuna guianensis</i>	small insect	4	1	7
	<i>Siparuna reginae</i>	small insect			1
Moraceae	<i>Artocarpus heterophyllus</i>	insect-wind		1	
	<i>Artocarpus integer</i>	insect		1	

	<i>Brosimum gaudichaudii</i>	insect-wind	1		
	<i>Brosimum glaziovii</i>	insect-wind	3		
	<i>Brosimum guianense</i>	insect-wind	4		3
	<i>Brosimum lactescens</i>	insect-wind	1		3
	<i>Clarisia ilicifolia</i>	wind	2		
	<i>Ficus citrifolia</i>	wasp	2	1	
	<i>Ficus clusiifolia</i>	wasp	1		
	<i>Ficus enormis</i>	wasp			1
	<i>Ficus eximia</i>	wasp		2	
	<i>Ficus glabra</i>	wasp	4		2
	<i>Ficus gomelleira</i>	wasp	3		1
	<i>Ficus guaranitica</i>	wasp		3	
	<i>Ficus insipida</i>	wasp	3	2	2
	<i>Ficus longifolia</i>	wasp	1		
	<i>Ficus microcarpa</i>	wasp		1	
	<i>Ficus organensis</i>	wasp			1
	<i>Ficus trigona</i>	wasp		1	
	<i>Maclura tinctoria</i>	wind	5	3	5
	<i>Morus nigra</i>	wind		2	
	<i>Naucleopsis oblongifolia</i>	small insect	1		1
	<i>Pseudolmedia hirtula</i>	undetermined	1		
	<i>Sorocea bonplandii</i>	wind	7		5
	<i>Sorocea guillerminiana</i>	wind	1		3
Myristicaceae	<i>Bicuiba oleifera</i>	small insect	2		
	<i>Virola bicuhyba</i>	small insect			1
Myrtaceae	<i>Blepharocalyx salicifolius</i>	bee			1
	<i>Calycorectes acutatus</i>	insect	1		
	<i>Calyptranthes clusiifolia</i>	insect			3
	<i>Calyptranthes concinna</i>	insect	2		1
	<i>Campomanesia dichotoma</i>	bee			2
	<i>Campomanesia espiritosantensis</i>	bee	1		
	<i>Campomanesia guaviroba</i>	bee	6		1
	<i>Campomanesia guazumaefolia</i>	bee	7		2
	<i>Campomanesia laurifolia</i>	bee	1		
	<i>Campomanesia rhombea</i>	bee	1	1	
	<i>Campomanesia xanthocarpha</i>	bee	7		2
	<i>Corymbia citriodora</i>	big animal		1	
	<i>Eucalyptus sp.</i>	big animal		1	1
	<i>Eugenia blastantha</i>	pollen consumer	5		
	<i>Eugenia brasiliensis</i>	pollen consumer			1
	<i>Eugenia cerasiflora</i>	pollen consumer	3		1
	<i>Eugenia cuprea</i>	pollen consumer			1
	<i>Eugenia dodoneaefolia</i>	pollen consumer	1		
	<i>Eugenia egensis</i>	pollen consumer	2		
	<i>Eugenia excelsa</i>	pollen consumer	2		
	<i>Eugenia florida</i>	pollen consumer	1	1	3
	<i>Eugenia francavilleana</i>	pollen consumer	1		
	<i>Eugenia gardneriana</i>	pollen consumer			1
	<i>Eugenia glazioviana</i>	pollen consumer	2		
	<i>Eugenia involucrata</i>	pollen consumer			1
	<i>Eugenia ligustrina</i>	pollen consumer	1		
	<i>Eugenia melanogyna</i>	pollen consumer	3		
	<i>Eugenia moraviana</i>	pollen consumer	1		
	<i>Eugenia myrcianthes</i>	pollen consumer			
	<i>Eugenia neoglomerata</i>	pollen consumer			1
	<i>Eugenia neolanceolata</i>	pollen consumer			2
	<i>Eugenia piryformis</i>	pollen consumer	1		
	<i>Eugenia platyphylla</i>	pollen consumer	1		
	<i>Eugenia platysema</i>	pollen consumer	1		
	<i>Eugenia pluriflora</i>	pollen consumer	1		
	<i>Eugenia prasina</i>	pollen consumer	1		
	<i>Eugenia racemulosa</i>	pollen consumer	1		
	<i>Eugenia repanda</i>	pollen consumer	1		
	<i>Eugenia speciosa</i>	pollen consumer	1		
	<i>Eugenia stictosepala</i>	pollen consumer	4		1
	<i>Eugenia subterminalis</i>	pollen consumer	1		
	<i>Eugenia tinguyensis</i>	pollen consumer	2		
	<i>Eugenia uniflora</i>	pollen consumer	2	3	1
	<i>Eugenia vattimoana</i>	pollen consumer	1		
	<i>Eugenia verrucosa</i>	pollen consumer	1		

	<i>Marlierea excoriata</i>	pollen consumer	2		
	<i>Marlierea racemosa</i>	pollen consumer			1
	<i>Marlierea warmingiana</i>	pollen consumer			2
	<i>Marlieria tomentosa</i>	pollen consumer	1		
	<i>Myrceugenia myrcioides</i>	pollen consumer	1		
	<i>Myrceugenia ovata</i>	pollen consumer			1
	<i>Myrcia albotomentosa</i>	pollen consumer	1		
	<i>Myrcia anacardiifolia</i>	pollen consumer			2
	<i>Myrcia detergens</i>	pollen consumer			2
	<i>Myrcia eriopus</i>	pollen consumer			1
	<i>Myrcia fallax</i>	pollen consumer	2	1	3
	<i>Myrcia glabra</i>	pollen consumer			1
	<i>Myrcia hebeptala</i>	pollen consumer	1		1
	<i>Myrcia laruotteana</i>	pollen consumer			1
	<i>Myrcia lineata</i>	pollen consumer	1		
	<i>Myrcia multiflora</i>	pollen consumer	1		
	<i>Myrcia riatenella</i>	pollen consumer			1
	<i>Myrcia richardiana</i>	pollen consumer			1
	<i>Myrcia rostrata</i>	pollen consumer	1		3
	<i>Myrcia rufula</i>	pollen consumer			1
	<i>Myrcia selloi</i>	pollen consumer	1		
	<i>Myrcia sphaerocarpa</i>	pollen consumer	1		
	<i>Myrcia splendens</i>	pollen consumer	8	1	1
	<i>Myrcia tijuensis</i>	pollen consumer	1		
	<i>Myrcia tomentosa</i>	pollen consumer	3		
	<i>Myrcianthes pungens</i>	insect	1		
	<i>Myrciaria ciliolata</i>	bee			1
	<i>Myrciaria floribunda</i>	pollen consumer	12		1
	<i>Myrciaria glomerata</i>	pollen consumer		2	2
	<i>Neomitranthes glomerata</i>	pollen consumer	2		
	<i>Neomitranthes langsdorffii</i>	pollen consumer	1		
	<i>Neomitranthes stictophylla</i>	pollen consumer	1		
	<i>Pimenta pseudocaryophyllus</i>	pollen consumer			2
	<i>Plinia cauliflora</i>	insect	2		2
	<i>Plinia grandifolia</i>	insect	1		
	<i>Plinia involucrata</i>	insect	1		
	<i>Psidium cattheianum</i>	bee		2	1
	<i>Psidium guajava</i>	bee		5	2
	<i>Psidium guineense</i>	bee	1	1	
	<i>Psidium myrtilloides</i>	bee	1		
	<i>Psidium robustum</i>	bee			1
	<i>Psidium rufum</i>	bee			3
	<i>Syzygium cumini</i>	bee		7	1
	<i>Syzygium jambos</i>	big animal	2		
Nyctaginaceae	<i>Andradea floribunda</i>	undetermined	1		
	<i>Guapira hirsuta</i>	insect	3		2
	<i>Guapira noxia</i>	insect	1		
	<i>Guapira opposita</i>	insect	14	2	7
	<i>Guapira tomentosa</i>	insect	1		
	<i>Pisonia ambigua</i>	insect	7		1
	<i>pisonia zapallo</i>	insect			1
	<i>Ramisia brasiliensis</i>	undetermined	1		
Ochnaceae	<i>Ouratea parviflora</i>	bee			1
	<i>Ouratea polygyna</i>	bee			1
	<i>Ouratea semiserrata</i>	bee			1
Olacaceae	<i>Cathedra rubricaulis</i>	insect	1		
	<i>Dulacia sp.</i>	insect	1		
	<i>Heisteria ovata</i>	insect	1		
	<i>Heisteria silvianii</i>	insect	1		
Oleaceae	<i>Ligustrum lucidum</i>	insect		4	
Opiliaceae	<i>Agonandra excelsa</i>	wind	4		1
Peraceae	<i>Chaetocarpus echinocarpus</i>	insect			2
Peraceae	<i>Pera glabrata</i>	insect	3	1	4
	<i>Pera heteranthera</i>	insect	2		
	<i>Pogonophora schomburgkiana</i>	insect			2
Phyllanthaceae	<i>Hieronyma alchorneoides</i>	insect	3		2
	<i>Hieronyma oblonga</i>	insect	1		
	<i>margaritaria nobilis</i>	small insect	1		1
	<i>Phyllanthus acuminatus</i>	small insect	4		
	<i>Savia dictyocarpa</i>	insect	3		3

Phytolaccaceae	<i>Gallsia integrifolia</i>	insect	7	4	
	<i>Seguiera langsdorffii</i>	insect	4		1
Picramniaceae	<i>Picramnia ciliata</i>	insect	1		
	<i>Picramnia parvifolia</i>	insect			1
	<i>Picramnia regnelli</i>	insect	1		
	<i>Picramnia warmingiana</i>	insect	1		
Pinaceae	<i>Pinus strobus</i>	wind		1	
Piperaceae	<i>Piper aduncum</i>	pollen consumer		2	
	<i>Piper amalago</i>	pollen consumer	3	2	1
	<i>Piper arboreum</i>	insect-wind	2		1
	<i>Piper cernuum</i>	insect-wind	1		
	<i>Piper gaudichaudianum</i>	insect-wind	1		
Pittosporaceae	<i>Pittosporum undulatum</i>	insect		2	
Poaceae	<i>Guadua angustifolia</i>	wind			1
Podocarpaceae	<i>Podocarpus sellowii</i>	wind	1		
Polygalaceae	<i>Acanthocladus pulcherrimus</i>	insect	1		
Polygonaceae	<i>Triplaris americana</i>	insect		5	
	<i>Coccoloba glaziovii</i>	insect	1		
	<i>Coccoloba laevis</i>	insect	1		
	<i>Coccoloba warmingii</i>	insect	1		
	<i>Ruprechtia laurifolia</i>	insect	1		
	<i>Ruprechtia laxiflora</i>	insect	2		
Primulaceae	<i>Ardisia sp</i>	insect	1		
	<i>Myrsine coriacea</i>	wind	2	1	2
	<i>Myrsine gardneriana</i>	wind			1
	<i>Myrsine guiwindsis</i>	wind			1
	<i>Myrsine umbellata</i>	wind	7	2	3
Proteaceae	<i>Euplassa incana</i>	moth			1
	<i>Euplassa legalis</i>	moth			1
	<i>Euplassa organensis</i>	moth			1
	<i>Grevillea robusta</i>	mammal-bird		2	
	<i>Roupala brasiliensis</i>	moth			1
	<i>Roupala montana</i>	moth	1		2
Proteaceae	<i>Roupala montana var. paraensis</i>	moth	3		
Putranjivaceae	<i>Drypetes sp.</i>	insect	1		
Rhamnaceae	<i>Colubrina glandulosa</i>	insect	5	2	2
	<i>Hovenia dulcis</i>	insect		2	
	<i>Rhamnidium elaeocarpum</i>	insect	5	3	2
	<i>Ziziphus glaziovii</i>	insect	1		
Rhizophoraceae	<i>Paradrypetes ilicifolia</i>	insect	1		
Rosaceae	<i>Eriobotrya japonica</i>	insect		2	
	<i>Prunus myrtifolia</i>	insect	3	1	2
	<i>Prunus sellowii</i>	insect	5	1	3
Rubiaceae	<i>Alseis floribunda</i>	insect		1	1
	<i>Amaioua guianensis</i>	insect	3		5
	<i>amaioua intermedia</i>	insect	5		1
	<i>Bathysa australis</i>	insect	4		1
	<i>Bathysa gymnocarpa</i>	insect			1
	<i>Bathysa mendoncae</i>	insect			1
	<i>Bathysa nicholsonii</i>	insect			4
	<i>Bathysa stipulata</i>	insect	2		
	<i>Calycophyllum spruceanum</i>	long tongue		1	
	<i>Chomelia obtusa</i>	long tongue	1		
	<i>Chomelia parvifolia</i>	long tongue			1
	<i>Chomelia pubescens</i>	long tongue	1		
	<i>Chomelia sericea</i>	long tongue	1		
	<i>Coffea arabica</i>	insect	4		1
	<i>Cordia elliptica</i>	insect	1		
	<i>Coutarea hexandra</i>	big animal	3		5
	<i>Faramea cyanea</i>	long tongue	1		
	<i>Faramea montevidensis</i>	long tongue			1
	<i>Genipa americana</i>	bee		4	
	<i>Genipa infundibuliformis</i>	bee	1		2
	<i>Guettarda angelica</i>	long tongue	1		
	<i>Guettarda uruguensis</i>	long tongue			2
	<i>Guettarda viburnoides</i>	long tongue	4		2
	<i>Ixora brevifolia</i>	long tongue	1		
	<i>Ixora gardneriana</i>	long tongue	1	1	
	<i>Ixora venulosa</i>	long tongue	2		1
	<i>Ixora warmingii</i>	long tongue	1		1

	<i>Melanopsidium nigrum</i>	long tongue	1		
	<i>Posoqueria acutifolia</i>	moth			1
	<i>Posoqueria latifolia</i>	moth	5		1
	<i>Psychotria carthagenensis</i>	insect	2		1
	<i>Psychotria mapourioides</i>	insect	3		
	<i>Psychotria myriantha</i>	insect	1		
	<i>Psychotria nuda</i>	long tongue	2		
	<i>Psychotria sessilis</i>	insect	1		
	<i>Psychotria suterella</i>	insect	2		
	<i>Psychotria vauthieri</i>	insect	1		
	<i>Psychotria vellosiana</i>	insect			2
	<i>Randia armata</i>	moth	2		
	<i>Rudgea jasminoides</i>	long tongue	6		4
	<i>Schizocalyx cuspidatus</i>	insect	2		
	<i>Simira corumbensis</i>	insect	1		
	<i>Simira viridiflora</i>	insect	2		
	<i>Sphinctanthus insignis</i>	long tongue	2		
	<i>Tocoyena sellowiana</i>	moth			2
	<i>Warszewiczia longistaminea</i>	butterfly-moth-bird			1
Rutaceae	<i>Almeidea lilacina</i>	long tongue		1	
	<i>Balfourodendron riedelianum</i>	insect	6	4	1
	<i>Citrus x aurantium</i>	insect			2
	<i>Clausena excavata</i>	insect		1	
	<i>Conchocarpus pentandrus</i>	long tongue	2		
	<i>Dictyoloma vandellianum</i>	insect			2
	<i>Esenbeckia febrifuga</i>	insect	4	2	2
	<i>Esenbeckia grandiflora</i>	insect	6		
	<i>Esenbeckia leiocarpa</i>	insect	3	4	
	<i>Galipea jasminiflora</i>	long tongue	5		
	<i>Galipea laxiflora</i>	long tongue	1		
	<i>Galipea multiflora</i>	long tongue			1
	<i>Helieta apiculata</i>	insect	1	1	
	<i>Metrodorea nigra</i>	fly	8	1	
	<i>Metrodorea stipularis</i>	insect	2		1
	<i>Murraya paniculata</i>	insect		1	
	<i>Neoraputia alba</i>	insect	1		
	<i>Pilocarpus giganteus</i>	insect			3
	<i>Pilocarpus pauciflorus</i>	insect	2		
	<i>Pilocarpus pennatifolius</i>	insect	1		
	<i>Zanthoxylum hiemale</i>	insect	1		
	<i>Zanthoxylum petiolare</i>	insect			1
	<i>Zanthoxylum acuminatum</i>	insect	4		
	<i>Zanthoxylum caribaeum</i>	insect	2	1	3
	<i>Zanthoxylum chiloperone</i>	insect	1		
	<i>Zanthoxylum fagara</i>	insect	2	1	2
	<i>Zanthoxylum monogynum</i>	insect	1		
	<i>Zanthoxylum rhoifolium</i>	insect	3	3	6
	<i>Zanthoxylum riedelianum</i>	insect	3	2	
	<i>Zanthoxylum tingoassuiba</i>	insect			1
Sabiaceae	<i>Meliosma itatiaiae</i>	insect	1		
	<i>Meliosma sellowii</i>	insect	2		
Salicaceae	<i>Banara serrata</i>	insect	2		
	<i>Casearia arborea</i>	insect	2	1	2
	<i>Casearia commersoniana</i>	insect	1		
	<i>Casearia decandra</i>	insect	4		2
	<i>Casearia gossypiosperma</i>	insect	4	2	5
	<i>casearia lasiophylla</i>	insect			1
	<i>Casearia obliqua</i>	insect	5		1
	<i>Casearia oblongifolia</i>	insect	1		
	<i>Casearia seloana</i>	insect	1		
	<i>Casearia sylvestris</i>	insect	11	4	8
	<i>Casearia ulmifolia</i>	insect	1		3
	<i>Macrothumia kuhlmannii</i>	insect	1		
	<i>Prockia crucis</i>	insect	4		
	<i>Xylosma ciliatifolia</i>	wind			2
	<i>Xylosma prockia</i>	wind		1	3
	<i>Xylosma salzmännii</i>	wind	1		
	<i>Xylosma pseudosalzmanii</i>	wind	4		
Sapindaceae	<i>Allophylus edulis</i>	insect	10	3	6
	<i>Allophylus laevigatus</i>	insect	1		

	<i>Allophylus racemosus</i>	insect	2		1
	<i>Cupania concolor</i>	insect	1		
	<i>Cupania emarginata</i>	insect			3
	<i>Cupania ludwigii</i>	insect	3		
	<i>Cupania oblongifolia</i>	insect	3		3
	<i>Cupania rugosa</i>	insect	1		
	<i>Cupania tenuivalvis</i>	insect	1		
	<i>Cupania vernalis</i>	insect	8		8
	<i>Diatenopteryx sorbifolia</i>	insect	6		
	<i>Dilodendron bipinnatum</i>	insect		1	
	<i>Dilodendron elegans</i>	insect			1
	<i>Koelreuteria bipinnata</i>	insect		1	
	<i>Koelreuteria paniculata</i>	insect		1	
	<i>Matayba elaeagnoides</i>	insect	7	1	5
	<i>Matayba guianensis</i>	insect			2
	<i>Matayba juglandifolia</i>	insect			2
	<i>Matayba leocodictya</i>	insect	1		
	<i>Matayba talisioides</i>	insect	1		
	<i>Melicoccus oliviformis subsp. intermedius</i>	insect	1		
	<i>Pseudima frutescens</i>	insect	1		
	<i>Sapindus saponaria</i>	insect		3	
	<i>Toulicia laevigata</i>	insect			2
Sapotaceae	<i>Chrysophyllum flexuosum</i>	insect	1		
	<i>Chrysophyllum gonocarpum</i>	insect	8	1	2
	<i>Chrysophyllum lucentifolium</i>	insect	1		
	<i>Chrysophyllum marginatum</i>	insect	1		
	<i>Ecclinusa ramiflora</i>	insect	2		
	<i>Manilkara salzmannii</i>	insect	1		
	<i>Micropholis crassipedicellata</i>	insect	1		
	<i>Micropholis cuneata</i>	insect	1		
	<i>Micropholis gardneriana</i>	insect			2
	<i>Pouteria caimito</i>	insect	1	1	1
	<i>Pouteria filipes</i>	insect	1		
	<i>Pouteria gardneri</i>	insect	1		
	<i>Pouteria gardneriana</i>	insect	1		
	<i>Pouteria reticulata</i>	insect	1		
	<i>Pradosia lactescens</i>	insect	1		
Schoepfiaceae	<i>Schoepfia brasiliensis</i>	insect	1		2
Simaroubaceae	<i>Simaba cedron</i>	undetermined	1		
Solanaceae	<i>Brunfelsia uniflora</i>	long tongue			1
	<i>Cestrum intermedium</i>	long tongue	1		
	<i>Cestrum mariquitense</i>	long tongue		1	
	<i>Cestrum schlechtendahlii</i>	long tongue	3		1
	<i>Cyphomandra fragrans</i>	bee	1		
	<i>Sessea brasiliensis</i>	moth	2		
	<i>Solanum argenteum</i>	bee	2	1	
	<i>Solanum bullatum</i>	bee	4		1
	<i>Solanum cernuum</i>	bee			3
	<i>Solanum cinnamomeum</i>	bee	1		
	<i>Solanum erianthum</i>	bee			1
	<i>Solanum granuloso-leprosum</i>	bee		2	
	<i>Solanum leucodendron</i>	bee		1	4
	<i>Solanum mauritanium</i>	bee		1	
	<i>Solanum pseudoquina</i>	bee	1	2	
	<i>Solanum rufescens</i>	bee	2		1
	<i>Solanum swartzianum</i>	bee	3		1
Styracaceae	<i>Styrax camporum</i>	insect	1		
	<i>Styrax glaber</i>	insect	2		
	<i>Styrax pohlii</i>	insect	1		
Symplocaceae	<i>Symplocos pubescens</i>	insect	2		
	<i>Symplocos tenuifolia</i>	insect	1		
	<i>Symplocos uniflora</i>	insect	1		
Theaceae	<i>Laplacea tomentosa</i>	bee			1
Thymelaeaceae	<i>Daphnopsis fasciculata</i>	insect	1		
Trigonaceae	<i>Trigoniodendron spiritusanctense</i>	bee	1		
Ulmaceae	<i>Ampelocera glabra</i>	wind	1		
	<i>Cecropia glaziovii</i>	insect-wind	4	1	4
	<i>Cecropia hololeuca</i>	insect-wind	4		4
	<i>Cecropia pachystachya</i>	insect-wind	4	4	2
	<i>Coussapoa curranii</i>	wind	1		

	<i>Pourouma cecropifolia</i> Mart.	insect-wind		1	
	<i>Pourouma guianensis</i>	insect-wind			1
	<i>Urera baccifera</i>	wind	7	1	1
Verbenaceae	<i>Aegiphila sellowiana</i>	long tongue	3	2	4
	<i>Aloysia virgata</i>	long tongue	4	2	6
	<i>Citharexylum myrianthum</i>	long tongue		6	
	<i>Vitex megapotamica</i>	long tongue	1		1
	<i>Vitex orinocensis</i>	long tongue	1		
	<i>Vitex polygama</i>	long tongue	2	1	1
Violaceae	<i>Rinorea bahiensis</i>	insect	1		
Vochysiaceae	<i>Callisthene minor</i>	insect	1		
	<i>Qualea jundiahy</i>	big animal	1		2
	<i>Qualea megalocarpa</i>	big animal	1		
	<i>Qualea multiflora</i> subsp. <i>Pubescens</i>	big animal	2		
	<i>Vochysia magnifica</i>	big animal	1		1
	<i>Vochysia schwackeana</i>	big animal	1		
	<i>Vochysia tucanorum</i>	big animal	4		

APPENDIX 2.1. LIST OF SAMPLED BEE SPECIES AND THE FUNCTIONAL GROUPS WHERE THESE WERE CLASSIFIED.

Bee species	Functional Group
<b>Andrenidae</b>	
<i>Oxaea flavescens</i>	16
<i>Psaenythia sp. 1</i>	1
<i>Psaenythia sp. 2</i>	1
<b>Apidae</b>	
<i>Apis mellifera</i>	13
<i>Centris</i>	15
<i>Ceratina sp. 1</i>	5
<i>Ceratina sp. 2</i>	5
<i>Ceratina sp. 3</i>	5
<i>Diadasina</i>	10
<i>Doeringiella</i>	14
Eucerini	
<i>Eufriesea violacea</i>	17
<i>Euglossa annectans</i>	12
<i>Euglossa cordata</i>	12
<i>Euglossa fimbriata</i>	12
<i>Euglossa pleiosticta</i>	12
<i>Euglossa truncate</i>	12
<i>Eulaema cingulate</i>	18
<i>Eulaema nigrita</i>	18
<i>Exaeretes maragdina</i>	19
<i>Exomalopsis aff. analis</i>	1
<i>Exomalopsis aff. auropilosa</i>	1
<i>Exomalopsis aff. vernoniae</i>	1
<i>Exomalopsis sp. 1</i>	1
<i>Exomalopsis sp. 2</i>	1
<i>Exomalopsis sp. 3</i>	1
<i>Exomalopsis sp. 4</i>	1
<i>Exomalopsis sp. 5</i>	1
<i>Exomalopsis sp. 6</i>	1
<i>Exomalopsis sp. 7</i>	1
<i>Exomalopsis sp. 8</i>	1
<i>Florilegus</i>	10
<i>Lophothygater</i>	
<i>Melissodes sp. 1</i>	9
<i>Melissodes sp. 2</i>	9
<i>Melissoptila</i>	10
<i>Melitoma segmentaria</i>	10
<i>Nomada sp. 1</i>	8
<i>Nomada sp. 2</i>	8
<i>Nomada sp. 3</i>	8
<i>Protosiris</i>	8
<i>Pseudepeolus</i>	
<i>Ptilothrix aff. Tricolor</i>	10
<i>Ptilothrix relata</i>	10
<i>Ptilothrix sp. 1</i>	10
<i>Thalestria aff. spinosa</i>	19
<i>Thygater analis</i>	9
<i>Thygater sp. 1</i>	9
<i>Thygater sp. 2</i>	9
<i>Trigona hyalinata</i>	6
<i>Trigona sp. 1</i>	6
<i>Trigona sp. 2</i>	6
<i>Trigona spinipes</i>	6
<i>Xylocopa</i>	17

<b>Colletidae</b>	
<i>Ptiloglossa</i>	
<b>Halictidae</b>	
<i>Augochlora sp. 1</i>	7
<i>Augochlora sp. 2</i>	7
<i>Augochlora sp. 3</i>	7
<i>Augochlora sp. 4</i>	7
<i>Augochlora sp. 5</i>	7
<i>Augochlora sp. 6</i>	7
<i>Augochlora sp. 7</i>	7
<i>Augochlorella sp. 1</i>	4
<i>Augochlorella sp. 2</i>	4
<i>Augochlorella sp. 3</i>	4
<i>Augochlorella sp. 4</i>	4
<i>Augochlorella sp. 5</i>	4
<i>Augochlorella sp. 6</i>	4
<i>Augochlorella sp. 7</i>	4
<i>Augochlorella sp. 8</i>	4
<i>Augochlorella sp. 9</i>	4
<i>Augochlorini sp.1</i>	
<i>Augochlorini sp. 2</i>	
<i>Augochlorini sp. 3</i>	
<i>Augochloropsis sp. 1</i>	4
<i>Augochloropsis sp. 2</i>	4
<i>Dialictus sp. 1</i>	3
<i>Dialictus sp. 2</i>	3
<i>Dialictus sp. 3</i>	3
<i>Dialictus sp. 4</i>	3
<i>Pseudoagapostemon</i>	2
<i>Pseudoaugochlora</i>	
<b>Megachilidae</b>	
<i>Megachile laeta</i>	11
<i>Megachile</i>	11

APPENDIX 2.2. LIST OF POLLEN TYPES FOUND ON THE BODIES OF SAMPLED BEES, AND THE FUNCTIONAL GROUPS WHERE THESE WERE CLASSIFIED.

Pollen species	Functional Group
<b>Acanthaceae</b>	
<i>Acanthaceae</i>	
<i>Herpetacanthus Type</i>	3
<i>Mendoncia Type</i>	12
<i>Thunbergia</i>	13
<b>Alismataceae</b>	
<i>Echinodorus Type</i>	1
<i>Sagittaria Type</i>	1
<b>Amaranthaceae</b>	
<i>Alternanthera</i>	1
<i>Amaranthaceae</i>	3
<i>Chamissoa Type</i>	10
<i>Chenopodium Type</i>	3
<b>Anacardiaceae</b>	
<i>Manguifera indica Type</i>	17
<i>Schinus therebinthifolius</i>	14
<i>Spondias</i>	14
<b>Apiaceae</b>	
<i>Apiaceae</i>	1
<b>Apocynaceae</b>	
<i>Allamanda Type</i>	3
<i>Apocynaceae sp. 1</i>	
<i>Apocynaceae sp. 2</i>	
<i>Aspidosperma Type</i>	22
<i>Mandevilla Type</i>	3
<i>Nerium Type</i>	
<b>Araceae</b>	
<i>Spatiphyllum</i>	3
<b>Araliaceae</b>	
<i>Araliaceae</i>	
<b>Areaceae</b>	
<i>Astrocaryum Type</i>	
<i>Cocos Type</i>	
<i>Euterpe Type</i>	
<i>Mauritia Type</i>	16
<i>Syagrus romanzoffiana</i>	16
<b>Asparagaceae</b>	
<i>Asparagaceae</i>	5
<b>Asteraceae</b>	
<i>Ambrosia Type</i>	
<i>Asteraceae sp. 1</i>	
<i>Asteraceae sp. 2</i>	
<i>Asteraceae sp. 3</i>	

<i>Bidens Type</i>	
<i>Conyza bonariensis</i>	1
<i>Cyrtocymura scorpioides</i>	1
<i>Eirmocephala Type</i>	
<i>Elephantopus Type</i>	1
<i>Emilia Type</i>	1
<i>Jungia Type</i>	1
<i>Parthenium hysterophorus</i>	4
<i>Sonchus Type</i>	4
<i>Sphagneticola trilobata</i>	1
<i>Tridax procumbens</i>	1
<b>Begoniaceae</b>	
<i>Begonia Type</i>	2
<b>Bignoniaceae</b>	
<i>Amphilophium Type</i>	9
<i>Anemopaegma Type</i>	9
<i>Anemopaegma Type</i>	9
<i>Bignonia binata Type</i>	9
<i>Bignoniaceae sp. 1</i>	
<i>Bignoniaceae sp. 2</i>	
<i>Bignoniaceae sp. 3</i>	
<i>Bignoniaceae sp. 4</i>	
<i>Jacaranda Type</i>	15
<i>Mansoa difficilis Type</i>	9
<i>Spatodea Type</i>	19
<i>Tecoma Type</i>	18
<b>Bixaceae</b>	
<i>Bixa orellana</i>	15
<b>Boraginaceae</b>	
<i>Cordia</i>	17
<b>Brassicaceae</b>	
<i>Brassicaceae</i>	
<b>Cannabaceae</b>	
<i>Cannabaceae Type</i>	
<i>Trema micrantha</i>	16
<b>Caricaceae</b>	
<i>Carica</i>	19
<b>Caryocaraceae</b>	
<i>Caryocar brasiliense</i>	16
<b>Caryophyllaceae</b>	
<i>Caryophyllaceae</i>	4
<i>Spergula</i>	4
<b>Celastraceae</b>	
<i>Hippocratea volubilis</i>	8
<b>Cleomaceae</b>	
<i>Tarenaya spinosa Type</i>	6
<b>Commelinaceae</b>	
<i>Tradescantia</i>	7
<b>Convolvulaceae</b>	
<i>Convolvulaceae</i>	8
<i>Ipomoea sp. 1</i>	8
<i>Ipomoea sp. 2</i>	8
<i>Ipomoea sp. 3</i>	8
<i>Ipomoea sp. 4</i>	8
<i>Ipomoea sp. 5</i>	8
<i>Ipomoea cairica</i>	8
<i>Merremia Type</i>	8

<b>Cucurbitaceae</b>			
<i>Cayaponia</i> Type	8		
<i>Melothria</i> Type	8		
<i>Momordica charantia</i>	11		
<b>Cyperaceae</b>			
<i>Cyperaceae</i>	3		
<i>Rynchospora</i> Type	1		
<i>Scleria</i> Type	3		
<b>Ericaceae</b>			
<i>Gaultheria</i> Type	16		
<b>Euphorbiaceae</b>			
<i>Alchornea</i> Type	16		
<i>Croton floribundus</i>	14		
<i>Croton urucurana</i>	14		
<i>Dalechampia</i> sp. 1	9		
<i>Dalechampia</i> sp. 2	9		
<i>Euphorbiaceae</i>			
<i>Euphorbia hirta</i>	1		
<i>Ricinus communis</i>	17		
<i>Sapium</i>	14		
<b>Gentianaceae</b>			
<i>Gentianaceae</i>	1		
<b>Heliconiaceae</b>			
<i>Heliconiaceae</i>			
<b>Lamiaceae</b>			
<i>Hyptis</i> Type	1		
<i>Lamiaceae</i> sp. 1			
<i>Lamiaceae</i> sp. 2	1		
<i>Lamiaceae</i> sp. 3			
<i>Leonorus sibiricus</i>	4		
<i>Tectona grandis</i> Type			
<b>Lauraceae</b>			
<i>Lauraceae</i> Type			
<b>Leguminosae</b>			
<i>Anadenanthera</i>	14		
<i>Bauhinia forficata</i>	16		
<i>Centrolobium</i> Type	15		
<i>Clitoria fairchildiana</i>	15		
<i>Crotalaria</i> Type			
<i>Gliricidia</i> Type			
<i>Inga semialata</i> Type	16		
<i>Inga</i> Type	16		
<i>Leguminosae</i> sp. 1			
<i>Leguminosae</i> sp. 2			
<i>Leucaena leucacephala</i>	17		
<i>Lonchocarpus</i> Type			
<i>macroptilium lathyroides</i>	2		
<i>Mimosapudica</i> Type	1		
<i>Mimosa</i> Type	14		
<i>Mimosa</i> Type	14		
<i>Ormosiatype</i>			
<i>Peltophorum dubium</i>	15		
<i>Piptadenia gonoacantha</i>	14		
<i>Poincianella libidibia</i> Type	21		
<i>Schizolobium parahyba</i>	15		
<i>Senegalia</i>	14		
<i>Senna</i>	15		
		<i>Tipuana tipu</i>	15
		<b>Loganiaceae</b>	
		<i>Spigelia</i> Type	1
		<b>Loranthaceae</b>	
		<i>Struthanthus</i>	
		<b>Lythraceae</b>	
		<i>Cuphea melvilla</i> Type	3
		<i>Cuphearacemos</i> aType	3
		<i>Lagestroemia</i>	
		<b>Malpighiaceae</b>	
		<i>Heteropterys pteropetala</i> Type	
		<i>Malpighiaceae</i> sp. 1	
		<i>Malpighiaceae</i> sp. 2	
		<i>Malpighiaceae</i> sp. 3	
		<i>Malpighiaceae</i> sp. 4	
		<i>Malpighiaceae</i> sp. 5	
		<b>Malvaceae</b>	
		<i>Apeiba tibourbou</i>	15
		<i>Hibiscus</i> sp. 1	19
		<i>Hibiscus</i> sp. 2	19
		<i>Luehea</i> Type	16
		<i>Pachira</i> Type	
		<i>Sida</i>	1
		<i>Waltheria</i> Type	
		<b>Melastomataceae</b>	
		<i>Melastomataceae</i> sp. 1	
		<i>Melastomataceae</i> sp. 2	15
		<i>Tibouchina granulosa</i>	15
		<b>Meliaceae</b>	
		<i>Meliaceae</i>	
		<i>Trichilia elegans</i>	20
		<b>Menispermaceae</b>	
		<i>Menispermaceae</i>	1
		<b>Muntingiaceae</b>	
		<i>Muntingia calabura</i>	14
		<b>Myrtaceae</b>	
		<i>Eucalyptus</i> sp. 1	26
		<i>Eucalyptus</i> sp. 2	26
		<i>Eugenia</i> Type	
		<i>Myrtaceae</i>	
		<i>Psidium</i> Type	18
		<i>Syzygium cumini</i>	25
		<b>Onagraceae</b>	
		<i>Ludwigia</i> sp. 1	2
		<i>Ludwigia</i> sp. 2	2
		<b>Oxalidaceae</b>	
		<i>Oxalis</i> Type	1
		<b>Passifloraceae</b>	
		<i>Passiflora</i>	
		<b>Phytolaccaceae</b>	
		<i>Phytolacca</i> Type	1
		<b>Piperaceae</b>	
		<i>Piper</i>	14
		<b>Poaceae</b>	
		<i>Brachiaria</i>	5
		<i>Poaceae</i> sp. 1	5
		<i>Poaceae</i> sp. 2	5

<i>Zeamays Type</i>	5
<b>Polygonaceae</b>	
<i>Polygonaceae</i>	
<i>Polygonum</i>	1
<i>Triplaris Type</i>	14
<b>Portulacaceae</b>	
<i>Portulaca oleacea</i>	1
<b>Primulaceae</b>	
<i>Myrsine Type</i>	16
<b>Rhamnaceae</b>	
<i>Colubrina glandulosa</i>	20
<b>Rosaceae</b>	
<i>Prunus Type</i>	14
<b>Rubiaceae</b>	
<i>Coffea Arabica</i>	24
<i>Declieuxia fruticosa Type</i>	3
<i>Genipa Americana</i>	23
<i>HilliaType</i>	
<i>Psychotria sp. 1</i>	20
<i>Psychotria sp. 2</i>	20
<i>Psychotria sp. 3</i>	
<i>Richardia Type</i>	1
<i>Rubiaceae sp. 1</i>	
<i>Rubiaceae sp. 2</i>	
<i>Rubiaceae sp. 3</i>	
<i>Rubiaceae sp. 4</i>	
<b>Rutaceae</b>	
<i>Citrus</i>	24
<i>Citrus aff. lemon</i>	24
<i>Zanthoxylum Type</i>	14
<b>Sapindaceae</b>	
<i>Paullinia Type</i>	8
<b>Sapotaceae</b>	
<i>Chrysophyllum</i>	20
<b>Scrophulariaceae</b>	
<i>Scrophulariaceae sp. 1</i>	
<i>Scrophulariaceae sp. 2</i>	
<b>Solanaceae</b>	
<i>Solanaceae sp. 1</i>	
<i>Solanaceae sp. 2</i>	
<i>Solanaceae sp. 3</i>	
<i>Solanaceae sp. 4</i>	
<i>Solanum sp. 1</i>	15
<i>Solanum sp. 2</i>	
<i>Solanum mauritianum</i>	15
<b>Styracaceae</b>	
<i>Styrax Type</i>	14
<b>Urticaceae</b>	
<i>Cecropia</i>	14
<i>Urera Type</i>	16
<b>Verbenaceae</b>	
<i>Lantana Type</i>	1
<i>Stachytarpheta</i>	1
<b>Vitaceae</b>	
<i>Cissus Type</i>	8
<b>Vochysiaceae</b>	
<i>Vochysia</i>	16

## APPENDIX 2.3 EFFECTS OF HABITAT CHANGES AND ISOLATION ON BEE FUNCTIONAL GROUPS.

Table 2.3.1. Specific responses of bee functional groups to the different habitat types. Significant effects are indicated in bold.

	Coef.	S.E.	z value	Pr(> z )
<i>Reference Fragment</i>				
group 1	0.044	0.020	-6.843	<0.01
group 2	0.000	0.000	-0.008	0.994
group 3	0.053	0.022	-7.03	<0.01
group 4	0.070	0.026	-7.264	<0.01
group 5	0.009	0.009	-4.716	<0.01
group 6	0.018	0.013	-5.668	<0.01
group 7	0.018	0.013	-5.668	<0.01
group 8	0.000	0.000	-0.008	0.994
group 9	0.018	0.013	-5.668	<0.01
group 10	0.123	0.035	-7.405	<0.01
group 11	0.000	0.000	-0.008	0.994
group 12	0.175	0.043	-7.179	<0.01
group 13	0.053	0.022	-7.03	<0.01
group 14	0.000	0.000	-0.008	0.994
group 15	0.000	0.000	-0.008	0.994
group 16	0.000	0.000	-0.008	0.994
group 17	0.035	0.018	-6.585	<0.01
group 18	0.298	0.058	-6.191	<0.01
group 19	0.088	0.029	-7.379	<0.01
<i>Degraded Fragment</i>				
group 1	0.000	0.000	-0.007	0.994
group 2	2.065	7921.012	0	1.000
group 3	1.377	0.860	0.512	0.609
group 4	2.478	1.193	1.886	0.059
group 5	0.000	0.000	-0.006	0.995
group 6	0.000	0.000	-0.007	0.995
group 7	1.652	1.671	0.496	0.620
group 8	2.065	7921.012	0	1.000
group 9	3.304	2.906	1.359	0.174
group 10	0.826	0.403	-0.392	0.695
group 11	2.065	7921.013	0	1.000
group 12	1.404	0.510	0.934	0.350
group 13	0.275	0.300	-1.182	0.237
group 14	2.065	7921.012	0	1.000

group 15	2.065	7921.012	0	1.000
group 16	2.065	7921.011	0	1.000
group 17	0.000	0.000	-0.007	0.995
group 18	0.875	0.288	-0.407	0.684
group 19	0.496	0.335	-1.039	0.299
<i>Restored Corridor</i>				
group 1	0.552	0.340	-0.966	0.334
group 2	1.724	5546.183	0.000	1.000
<b>group 3</b>	<b>4.367</b>	<b>1.938</b>	<b>3.321</b>	<b>0.001</b>
<b>group 4</b>	<b>3.677</b>	<b>1.440</b>	<b>3.325</b>	<b>0.001</b>
group 5	1.379	1.600	0.277	0.782
group 6	0.690	0.634	-0.404	0.686
group 7	1.149	0.970	0.165	0.869
group 8	1.02E+7	2.919E+10	0.006	0.995
group 9	1.839	1.468	0.763	0.446
<b>group 10</b>	<b>0.394</b>	<b>0.161</b>	<b>-2.275</b>	<b>0.023</b>
group 11	1.02E+7	2.919E+10	0.006	0.995
group 12	0.827	0.249	-0.629	0.529
group 13	0.383	0.236	-1.558	0.119
group 14	1.724	5546.184	0.000	1.000
group 15	1.724	5546.183	0.000	1.000
group 16	2.042E+7	5.839E+10	0.006	0.995
group 17	0.230	0.201	-1.684	0.092
<b>group 18</b>	<b>0.487</b>	<b>0.129</b>	<b>-2.722</b>	<b>0.006</b>
<b>group 19</b>	<b>0.322</b>	<b>0.163</b>	<b>-2.243</b>	<b>0.025</b>
<i>Secondary Corridor</i>				
group 1	1.285	0.750	0.429	0.668
group 2	1.783E+7	5.098E+10	0.006	0.995
<b>group 3</b>	<b>5.218</b>	<b>2.381</b>	<b>3.622</b>	<b>&lt;0.01</b>
group 4	1.405	0.647	0.738	0.461
group 5	0.000	0.000	-0.010	0.992
group 6	0.803	0.809	-0.218	0.827
group 7	1.204	1.110	0.202	0.840
group 8	5.350E+7	1.529E+11	0.006	0.995
<b>group 9</b>	<b>4.817</b>	<b>3.729</b>	<b>2.031</b>	<b>0.042</b>
group 10	1.434	0.511	1.010	0.313
group 11	2.408	7950.343	0.000	1.000
<b>group 12</b>	<b>0.442</b>	<b>0.175</b>	<b>-2.065</b>	<b>0.039</b>
group 13	1.204	0.652	0.343	0.732
group 14	2.408	7950.342	0.000	1.000
group 15	1.783E+7	5.098E+10	0.006	0.995
group 16	7.134E+7	2.039E+11	0.006	0.995
group 17	0.000	0.000	-0.011	0.992
<b>group 18</b>	<b>0.165</b>	<b>0.072</b>	<b>-4.151</b>	<b>&lt;0.01</b>
<b>group 19</b>	<b>0.241</b>	<b>0.161</b>	<b>-2.124</b>	<b>0.034</b>
<i>Sugarcane Field</i>				
<b>group 1</b>	<b>5.013</b>	<b>2.497</b>	<b>3.236</b>	<b>0.001</b>
group 2	3.234	10336.64	0.000	1.000
<b>group 3</b>	<b>2.560</b>	<b>1.242</b>	<b>1.939</b>	<b>0.053</b>

<b>group 4</b>	<b>3.032</b>	<b>1.265</b>	<b>2.658</b>	<b>0.008</b>
group 5	0.000	0.000	-0.011	0.991
group 6	0.404	0.498	-0.736	0.462
group 7	0.000	0.000	-0.011	0.991
group 8	1.796E+7	5.135E+10	0.006	0.995
group 9	1.617	1.415	0.549	0.583
group 10	0.866	0.340	-0.366	0.714
group 11	3.592E+7	1.027E+11	0.006	0.995
group 12	<b>0.121</b>	<b>0.077</b>	<b>-3.339</b>	<b>0.001</b>
group 13	1.887	0.951	1.260	0.208
group 14	1.796+7	5.135E+10	0.006	0.995
group 15	3.234	10336.64	0.000	1.000
group 16	2.694E+8	7.702E+11	0.007	0.995
group 17	0.000	0.000	-0.012	0.990
group 18	<b>0.095</b>	<b>0.052</b>	<b>-4.330</b>	<b>&lt;0.01</b>
group 19	<b>0.081</b>	<b>0.085</b>	<b>-2.381</b>	<b>0.017</b>

Table 2.3.2. ANOVA table of the best model selected for the effect of functional group (“group”), habitat change (“habitat”) and habitat isolation (“fragment”) on bee abundance.

	<b>Df</b>	<b>Deviance</b>	<b>Resid. Df</b>	<b>Resid. Dev</b>	<b>Pr(&gt;Chi)</b>
NULL			859	1819.56	
habitat	2	40.46	857	1779.1	1.64E-09
group	19	1109.74	838	669.36	< 2.2e-16
fragment	1	12.11	837	657.25	0.000502
habitat: group	38	111.82	799	545.43	3.39E-09

APPENDIX 2.4. EFFECTS OF HABITAT CHANGES AND ISOLATION ON PLANT FUNCTIONAL GROUPS.

Table 2.4.1. Specific responses of plant functional groups to the different habitat types. Significant effects are indicated in bold.

	Estimate	Std. Error	z value	Pr(> z )
<i>Reference Fragment</i>				
group 1	11.750	1.714	16.891	<0.001
group 2	0.128	0.055	-4.748	<0.001
group 3	0.191	0.070	-4.543	<0.001
group 4	0.553	0.135	-2.422	0.015
group 5	0.809	0.176	-0.974	0.330
group 6	0.000	0.000	-0.011	0.991
group 7	0.043	0.031	-4.373	<0.001
group 8	0.383	0.106	-3.463	0.001
group 9	0.255	0.083	-4.221	<0.001
group 10	0.000	0.000	-0.011	0.991
group 11	0.021	0.022	-3.810	<0.001
group 12	0.021	0.022	-3.810	<0.001
group 13	0.021	0.022	-3.810	<0.001
group 14	0.894	0.190	-0.530	0.596
group 15	2.128	0.376	4.269	<0.001
group 16	0.638	0.149	-1.921	0.055
group 17	0.213	0.074	-4.444	<0.001
group 18	0.447	0.117	-3.069	0.002
group 19	0.064	0.038	-4.621	<0.001
group 20	0.170	0.065	-4.630	<0.001
group 21	0.000	0.000	-0.011	0.991
group 22	0.000	0.000	-0.011	0.991
group 23	0.149	0.060	-4.700	<0.001
group 24	0.149	0.060	-4.700	<0.001
group 25	0.128	0.055	-4.748	<0.001
group 26	0.149	0.060	-4.700	<0.001
<i>Degraded Fragment</i>				
<b>group 1</b>	<b>0.477</b>	<b>0.114</b>	<b>-3.104</b>	<b>0.002</b>
group 2	0.280	0.309	-1.152	0.250
group 3	0.933	0.566	-0.115	0.908
group 4	0.710	0.307	-0.793	0.428
group 5	0.618	0.243	-1.222	0.222
group 6	2.098	4881.097	0.000	1.000
group 7	0.000	0.000	-0.010	0.992
group 8	1.026	0.463	0.056	0.955

group 9	0.699	0.408	-0.613	0.540
group 10	2.098	4881.098	0.000	1.000
group 11	3.357	4.189	0.971	0.332
group 12	1.679	2.407	0.361	0.718
group 13	1.679	2.407	0.361	0.718
group 14	1.679	0.543	1.601	0.109
group 15	1.444	0.405	1.309	0.190
group 16	1.007	0.385	0.019	0.985
<b>group 17</b>	<b>3.021</b>	<b>1.393</b>	<b>2.398</b>	<b>0.016</b>
group 18	1.519	0.602	1.054	0.292
group 19	1.119	1.056	0.119	0.905
group 20	0.210	0.228	-1.436	0.151
group 21	1.372E+07	2.379E+10	0.009	0.992
group 22	1.372E+07	2.379E+10	0.009	0.992
group 23	1.199	0.758	0.287	0.774
group 24	0.959	0.643	-0.062	0.950
group 25	2.518	1.457	1.596	0.110
group 26	0.480	0.401	-0.878	0.380
<i>Restored corridor</i>				
<b>group 1</b>	<b>0.494</b>	<b>0.089</b>	<b>-3.900</b>	<b>&lt;0.001</b>
group 2	0.360	0.241	-1.523	0.128
group 3	0.780	0.367	-0.528	0.598
group 4	0.665	0.213	-1.275	0.202
<b>group 5</b>	<b>0.455</b>	<b>0.137</b>	<b>-2.620</b>	<b>0.009</b>
group 6	2.026	3953.415	0.000	1.000
group 7	0.000	0.000	-0.018	0.986
group 8	0.840	0.296	-0.494	0.621
group 9	0.585	0.257	-1.219	0.223
group 10	3.532E+07	6.124E+10	0.010	0.992
group 11	5.943	6.299	1.681	0.093
group 12	0.000	0.000	-0.017	0.986
group 13	1.080	1.338	0.063	0.950
group 14	1.428	0.366	1.390	0.164
group 15	1.156	0.252	0.666	0.505
group 16	0.774	0.231	-0.856	0.392
group 17	1.513	0.621	1.008	0.313
group 18	0.926	0.305	-0.233	0.815
group 19	0.360	0.335	-1.097	0.272
<b>group 20</b>	<b>0.203</b>	<b>0.142</b>	<b>-2.278</b>	<b>0.023</b>
group 21	4.415E+06	7.655E+09	0.009	0.993
group 22	2.026	3953.415	0.000	1.000
group 23	0.540	0.305	-1.091	0.275
group 24	0.617	0.339	-0.880	0.379
group 25	1.621	0.818	0.956	0.339
<b>group 26</b>	<b>0.232</b>	<b>0.165</b>	<b>-2.051</b>	<b>0.040</b>
<i>Secondary corridor</i>				
<b>group 1</b>	<b>0.652</b>	<b>0.117</b>	<b>-2.381</b>	<b>0.017</b>
group 2	1.107	0.581	0.193	0.847
group 3	0.568	0.280	-1.148	0.251
group 4	1.100	0.327	0.321	0.748

group 5	0.605	0.172	-1.769	0.077
group 6	4.175E+06	7.239E+09	0.009	0.993
group 7	0.255	0.316	-1.103	0.270
group 8	1.022	0.347	0.063	0.950
<b>group 9</b>	<b>0.383</b>	<b>0.182</b>	<b>-2.015</b>	<b>0.044</b>
group 10	3.340E+07	5.791E+10	0.010	0.992
<b>group 11</b>	<b>8.174</b>	<b>8.552</b>	<b>2.008</b>	<b>0.045</b>
group 12	0.511	0.728	-0.471	0.638
group 13	0.000	0.000	-0.015	0.988
group 14	0.730	0.197	-1.169	0.242
<b>group 15</b>	<b>0.485</b>	<b>0.111</b>	<b>-3.150</b>	<b>0.002</b>
<b>group 16</b>	<b>0.443</b>	<b>0.143</b>	<b>-2.527</b>	<b>0.012</b>
group 17	1.430	0.586	0.874	0.382
group 18	0.511	0.182	-1.882	0.060
group 19	0.341	0.317	-1.158	0.247
<b>group 20</b>	<b>0.255</b>	<b>0.163</b>	<b>-2.139</b>	<b>0.032</b>
group 21	4.175E+06	7.239E+09	0.009	0.993
group 22	1.533	3068.542	0.000	1.000
group 23	0.292	0.190	-1.889	0.059
group 24	0.292	0.190	-1.889	0.059
group 25	1.277	0.658	0.475	0.635
group 26	0.949	0.476	-0.105	0.917
<i>Sugarcane field</i>				
<b>group 1</b>	<b>0.484</b>	<b>0.087</b>	<b>-4.039</b>	<b>&lt;0.001</b>
<b>group 2</b>	<b>0.086</b>	<b>0.094</b>	<b>-2.240</b>	<b>0.025</b>
group 3	0.402	0.215	-1.705	0.088
<b>group 4</b>	<b>1.748</b>	<b>0.501</b>	<b>1.949</b>	<b>0.051</b>
<b>group 5</b>	<b>0.381</b>	<b>0.117</b>	<b>-3.146</b>	<b>0.002</b>
group 6	2.066	4005.003	0.000	1.000
group 7	0.000	0.000	-0.018	0.985
group 8	0.689	0.248	-1.037	0.300
<b>group 9</b>	<b>0.129</b>	<b>0.087</b>	<b>-3.055</b>	<b>0.002</b>
group 10	2.533E+07	4.391E+10	0.010	0.992
group 11	4.648	4.970	1.437	0.151
group 12	0.000	0.000	-0.018	0.986
group 13	0.000	0.000	-0.018	0.986
<b>group 14</b>	<b>0.578</b>	<b>0.161</b>	<b>-1.971</b>	<b>0.049</b>
<b>group 15</b>	<b>0.527</b>	<b>0.120</b>	<b>-2.809</b>	<b>0.005</b>
<b>group 16</b>	<b>0.275</b>	<b>0.099</b>	<b>-3.602</b>	<b>&lt;0.001</b>
group 17	1.240	0.517	0.515	0.607
group 18	0.639	0.220	-1.300	0.194
group 19	0.344	0.320	-1.146	0.252
group 20	0.452	0.248	-1.450	0.147
group 21	8.442E+06	1.464E+10	0.009	0.993
group 22	2.066	4005.003	0.000	1.000
<b>group 23</b>	<b>0.148</b>	<b>0.121</b>	<b>-2.329</b>	<b>0.020</b>
group 24	0.516	0.291	-1.172	0.241
group 25	1.205	0.627	0.359	0.720
group 26	0.443	0.259	-1.394	0.163

Table 2.4.2. ANOVA table of the best model selected for the effect of functional group (“group”), habitat change (“habitat”) and habitat isolation (“fragment”) on pollen frequency.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			1117	4861.8	
habitat	2	55.66	1115	4806.1	8.20E-13
group	25	2727.99	1090	2078.2	< 2.2e-16
fragment	1	12.81	1089	2065.3	0.000345
habitat: group	50	160.15	1039	1905.2	1.85E-13
habitat: Fragment	2	16	1037	1889.2	0.000336