SILVER JONAS ALVES FARFAN

Agrônomo, Mestre em agronomia

A MELIPONICULTURA COMO INDUTORA DE PROCESSOS DE RESILIÊNCIA SOCIOECOLÓGICA EM AGROECOSSISTEMAS CAMPONESES NA BAIXADA MARANHENSE

Tese apresentada ao Curso de Doutorado do Programa de Pós-Graduação em Agroecologia da Universidade Estadual do Maranhão, para a obtenção do título de Doutor em Agroecologia.

Orientadora: Prof. Dra. Danielle Camargo Celentano Augusto

Coorientador: Prof. Dr. Guillaume Rousseau

São Luís

2021

Capítulo III

The effect of landscape composition on stingless bee (*Melipona fasciculata*) honey productivity in a wetland ecosystem of Eastern Amazon, Brazil

Artigo submetido para '*Journal of Apicultural Research*' (ID. 216083144), revisado pelos pares e submetido (ID: 216083144.R1) em 10 de fevereiro de 2022.

Artigo Disponível em: https://www.tandfonline.com/doi/abs/10.1080/00218839.2022.2137307

Tese completa disponível em: https://repositorio.uema.br/handle/123456789/480/simple-search?filterquery=Farfan%2C+Silver+Jonas+Alves&filtername=author&filtertype=equals

A colmeia: nossa história com as abelhas

Bee Wilson, 2005

The effect of landscape composition on stingless bee (*Melipona fasciculata*) honey productivity in a wetland ecosystem of Eastern Amazon, Brazil

Manuscript prepared for the *Journal of Apicultural Research* as an Original Research Article

Word count: 8,487 words (without SM).

Silver Jonas Alves Farfan[1,2*], Danielle Celentano[1], Celso Henrique Leite Silva Junior[1,3], Marcus Vinicius de Freitas Silveira[3], Raymony Tayllon Alves Serra[1], Jhonatan Andres Munoz Gutierrez[1], Harryson Corrêa Barros[4], Monique Hellen Martins Ribeiro[5], Ortrud Monika Barth Schatzmayr[6], Rogério Marcos de Oliveira[7], Luis Manuel Hernández García[1], Guillaume Xavier Rousseau[1,8]

[1] Post-Graduate Program in Agroecology, Laboratory of Ecological Restoration (LARECO), State University of Maranhão (UEMA). Cidade Universitária Paulo VI, Av. Lourenço Vieira da Silva, nº 1000, Jd. São Cristovão. 65055-310, São Luís/MA, Brazil.

[2] Technological Vocational Center (CVT Agroecology), Federal Institute of Sertão Pernambucano (IFSertãoPE), PE-647, Km 22, PISNC N - 4, Zona Rural, Cx. Postal 277 CEP 56302-970, Petrolina/PE, Brazil.

[3] Post-Graduate Program in Remote Sensoring, Tropical Ecosystem and Environmental Science Laboratory (TREES), National Institute for Space Research / Instituto Nacional de Pesquisas Espaciais (INPE). Av. dos Astronautas, 1758 - Jardim da Granja, 12227-010, São José dos Campos/SP, Brazil.

[4] Laboratory for the Study of Bees (LEA),Federal University of Maranhão (UFMA). Av. dos Portugueses, nº 1966 - Vila Bacanga, 65080-805, São Luís /MA, Brazil.

[5] State University of Maranhão (UEMA), Campus of Lago da Pedra, Lago da Pedra/MA, Brazil.

[6] Laboratory for Viral Morphogenesis and Morphology of the Oswaldo Cruz Institute, Fiocruz. Oswaldo Cruz Foundation, Instituto Oswaldo Cruz. Avenida Brasil, nº 4365, Manguinhos, 21040-900 - Rio de Janeiro/ RJ, Brazil.

[7] Federal Institute for Education, Science and Technology of Bahia (IFBAIANO). Rua da Gratidão, nº 232, Piatã. 41650-195-Salvador/BA, Brazil.

[8] Network for Biodiversity and Biotechnology of Legal Amazon (Bionorte). State University of Maranhão. Cidade Universitária Paulo VI, Av. Lourenço Vieira da Silva, nº 1000, Jd. São Cristovão. 65055-310, São Luís/MA. Brazil.

* Correspondent author (silverjonasf@gmail.com)

Abstract

Humanity depends on the processes and resources of natural ecosystems, such as natural grassland fields and forests. These ecosystems depend on pollinators, especially bees, to ensure crossbreeding and plant productivity. Faced with deforestation and the fragmentation of forest remnants, meliponiculture plays an important role in biodiversity conservation, ecological restoration and generating income for family farmers. Little is known about the effect of landscape on the productivity of native tiúba bees (*Melipona fasciculata*) in the Baixada Maranhense Environmental Protection Area (APA) in the Brazilian Amazon. This study aimed to evaluate the landscape effect on *M. fasciculata* honey productivity in APA. We selected 34 stingless beekeepers, mapped and classified landscapes within a 2,000 m radius around the meliponaries, measured honey productivity, and identified the pollen types in each meliponary. We analyzed productivity as a function of mapping the landscape and associated beekeeping. Our results have found that honeys from forest landscapes have greater richness and abundance of species, indicating more pollination services in these landscapes, but have lower productivity. The highest honey productivity occurs in landscapes with a greater percentage of natural grassland field and a composition dominated by shrubs. Melissopalynology and geographical information from landscape mapping provide a precise ecological dimensioning of *M. fasciculata* honey productivity in the APA, which can guide conservation, management and restoration actions in this region, and enhance the recognition of environmental services provided by stingless beekeepers.

Key words: Meliponiculture, melissopalynology, mapping, forest, natural grassland field

1 INTRODUCTION

In the Brazilian state of Maranhão, 75 % of the Amazon Biome has already been deforested to provide space for the expansion of large-scale agriculture and cattle ranching (Celentano et al., 2017), which compromises the provision of essential ecosystem services such as pollination due to reduced habitats and pollinators (Pioker-Hara et al., 2014). Furthermore, among the Brazilian states, Maranhão is considered one of the poorest and most vulnerable to climate change disasters (Almeida et al., 2016). Thus, the establishment of state policies become crucial for forest conservation and restoration (Celentano et al., 2017), as well as the promotion of low-impact economic activities that value sociobiodiversity, such as the raising of native bees (Ribeiro et al., 2019).

Deforestation reduces the abundance and richness of pollinators, leading to reduced gene flow and putting the entire plant community at risk, especially allogamous plants that depend on pollinators to maintain heterozygosity (Sujii et al., 2021). This compromises the maintenance of ecosystems, especially their ability to adapt to landscape and climate changes (Waddell et al., 2020).

In Brazil, the native bees represent 40 % of pollinators (Kerr et al., 2001) while environmental degradation alters their nesting, foraging and pollination behavior (Roubik, 2006). The bees are disappearing from natural landscapes due to the loss and fragmentation of habitats, to the expansion of large-scale agriculture and to the indiscriminate use of pesticides (Myerscough et al., 2017). This trend has drastic ecological, social and economic impacts, given that the productivity of cultivated plants also depends on pollinators (Brancalion et al., 2016).

In Maranhão the native stingless bee 'tiuba' (*Melipona fasciculata* Smith, 1854) is traditionally the principal bee raised in an Environmental Protection Area (APA from Portuguese *Área de Proteção Ambiental*) of the *Baixada Maranhense*, in the Amazon Biome, and has economic importance in the generation of income by family farmers (Venturieri et al., 2018). This bee prefers diversified sources of nectar and pollen from native species available at the landscape level (Sponsler and Johnson, 2015). The greater variety of flavors, colors and aromas found in the honey from the native bees is a function of the high diversity of the plants they visit (Roubik, 2006), which gives that honey high medicinal and culinary value (de Oliveira Alves, 2013).

These honeys contain higher content of water, sucrose and minerals than those of *Apis mellifera* L., while the ash content and colors vary as a function of the botanical origin

(González-Miret et al., 2005). The floral origin of honey can be estimated using melissopalynology, which reveals the richness of plants visited during the production period, in addition to providing important information about plant diversity in the landscape (Fernandes et al., 2020).

The raising of native bees (meliponiculture), conservation and restoration of landscapes are synergistic processes (win-win); just as bees benefit from the amount and diversity of pollen in the landscape, the landscape benefits from the pollination process (Härtel and Steffan-Dewenter, 2014). However, the mechanism behind this interaction and the effect of the landscape on honey productivity have remained poorly elucidated (Sponsler and Johnson, 2015). Understanding the role of meliponiculture in maintaining this process, and knowing these relationships are fundamental for encouraging policies and incentives for sustainable productive activities.

The diversified context of the APA – with landscapes formed by agroecosystems of small properties, forest remnants, areas in natural regeneration, floodplains and natural grassland fields – configures a natural laboratory for studying the relationship between landscape and honey productivity. We tested the hypothesis that *M. fasciculata* honey productivity responds positively to old growth forest cover. In this context, our objective was to identify how honey production varies as a function of different landscape configurations. For this: 1) we measured the productivity of *M. fasciculata* honey; 2) we mapped land use and land cover (LULC) in landscapes of meliponaries; 3) we identified the pollen types in the honey samples; and 4) we modeled productivity as a function of landscapes and floral origin.

2 METHODOLOGY

2.1 Study area

The study was carried out between the years 2017 and 2021 in 13 municipalities of an Environmental Protection Area (APA) in the state of Maranhão, Brazil: Anajatuba, Arari, Matinha, Cajapió, São João Batista, São Vicente Ferrer, São Bento, Palmerândia, Peri Mirim, Bequimão, Pinheiro, Santa Helena and Turilândia (Figure 1A). This APA is a sustainable use conservation unit created in 1991 and designated as Sítio Ramsar in 2000 (site number: 1,020), which contains 17,750 km² (Figure 1B). The estimated population is 387 thousand inhabitants; the economy is based on the extraction of babassu (*Attalea speciosa*), artisanal fishing and family farming (Ramsar, 2000). The study area is located in the Amazon Biome with palm vegetation, the location of the largest lacustrine complex in the Northeast, floodplains and a part of the mangrove belt. According to the Koppen climate classification, the climate is tropical including Am, Aw and As, with an average temperature of 25 ºC and annual rainfall between 1,600 and 2,000 mm, concentrated mainly between January and June (Alvares et al., 2013). The soils come from alluvial fluvial-marine geological formations with low natural fertility, fragile structure and limited drainage (Martin et al., 1980).

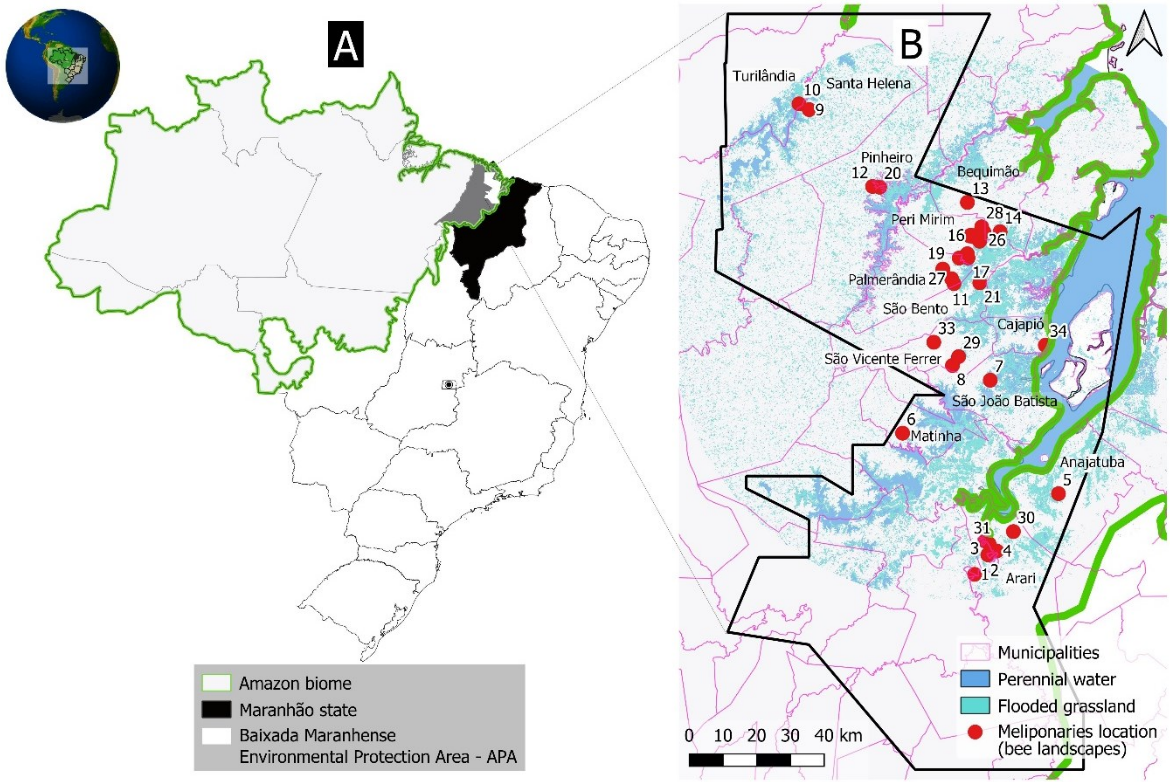


Figure 1. (a) Location of the study area in the Baixada Maranhense Environmental Protected Area (APA), Maranhão state, eastern Amazon, Brazil, and (b) the 34 sampling units (bee landscapes) enumerated (id) in the APA.

2.2 Experimental design

Thirty-four *M. fasciculata* beekeepers were selected to participate in this research through the 'snowball' sampling methodology (Albuquerque et al., 2014) where visits to the beekeepers residences were initiated by a key informant who indicated other beekeepers, a process that was reiterated until the sampling size was achieved. From the group of 47 beekeepers visited, we excluded those with less than 12 boxes of bees or with productivity lower than 260 $mL.year^{-1}$. We included beekeepers who used standardized or rustic-type boxes (without standard measures), beekeepers in urban, peri-urban and rural locations, and excluded those who raised bees in hollow tree trunks.

The research was authorized by the environmental agency of the state of Maranhão (Sema A08/2019) and by the appropriate federal agency (Sisbio 68238/2019). All selected beekeepers agreed to participate in the research and signed an informed consent form, which was registered with the research ethics committee (CAAE: 84113418.3.0000.5554/2018) as required by law. We carried out semi-structured interviews, which lasted about 30 minutes each, to ascertain the social profile of beekeepers and the details of beehive management: gender, age, number of years in beekeeping, name and number of beekeepers in the network of contacts and number of boxes.

2.3 Honey productivity

To measure honey productivity ($ml.bx^{-1}$) three bee boxes from each meliponary were randomly selected and reserved among those in the production phase – as it was previously arranged with each beekeeper. We collected the samples in November 2019, respecting the usual harvest schedule, containing the entire annual accumulation of pollen (December 2018 – November 2019) to account for a broad measure of the set of resource-providing melittophilous plants. The sampling methodology allowed to control the temporal and spatial variation in the species flowering, whose concentration occurs in the dry season between July and December (de Oliveira Alves, 2013). For the harvest, a portable electric vacuum suction pump (Aspiramax MA520-60) was employed, according to a hygiene protocol and utilizing sterilized containers to avoid contamination between samples and the environment. The total honey content of each box harvested was collected and measured, and the meliponary yield was estimated as the mean production of the three boxes. We measured the internal volume of the three harvested boxes and averaged the volume of the boxes. We standardized the productivity value to minimize the effect of the variation in the volume of boxes between meliponaries as follows: the average value of productivity ($\bar{p}$) of each meliponary (ml) was divided by the average internal volume of the boxes from each meliponary ($volbx$) and multiplied by the average volume of the total number of boxes in the study (16.84cm³), as described in the following calculation: $\bar{p} = ml/volbx \times 16.84$.

2.4 Mapping the bee landscape

We considered the landscape of the bee (sampling unit) as the circular area around each of the 34 meliponaries within a radius of 2,000 m (an area equivalent to 1,256 hectares). The radius was determined based on the flight of the bee *M. fasciculata* (Nunes-Silva et al., 2020; Borges et al., 2020), controlling the spatial variation of plant flowering in the different landscapes. We collected data from 2018 on land use and land cover (LULC) data from the mapping carried out by the MapBiomas project (Souza et al., 2020). MapBiomas performs the annual classification of the LULC of Brazilian biomes based on satellite images from the Landsat satellite, with a spatial resolution of 30 m. We defined 12 classes in the studied landscapes: mature forest, secondary vegetation subdivided into three classes (1-15 years, 16-25 years, 26-33 years) (Silva Junior et al., 2020), water, mangrove, urban area, pasture, agriculture, natural grassland field, floodplain and mosaic. The classification 'mosaic' includes shifting cultivation, sandy formations, small pastures and villages (Capanema et al., 2019). From the LULC classification of each bee landscape, we calculated two metrics for each class: area percentage (% = class area/total area × 100) and patch density (pd = number of patches/area). These metrics were calculated using the landscape metrics package in the software R. (Hesselbarth et al., 2019; R Core Team, 2020).

Complementarily, we calculated five landscape entropy measures (joint, marginal, conditional, mutual, relative mutual information) (Nowosad and Stepinski, 2019) and systematized climate variables with CHIRPS data (annual rainfall, annual rainy days, mean rainfall per day) (Katsanos et al., 2016) and geographic metrics (long, $long^2$, $long^3$, lat, lat×long, lat×$long^2$, lat^2, long×lat^2, lat^3) (Borcard et al., 2011).

2.5 Floral origin with Melissopalynology

For the melissopalynological analysis of each of the 34 meliponaries, we took a subsample of 15 mL of honey harvested and homogenized from each box separately (see item 2.3); this subsample was kept cooled until the moment of preparation of the slides by acetolysis (Melhem et al., 2003). One slide was prepared from each box of bees studied, 3 boxes × 34 meliponaries = 102 slides (102 samples).

The slides were subjected to qualitative and quantitative analysis through microscopy to determine the richness of species and the relative frequency of abundance among all meliponaries with a minimal count of 500 pollen grains per sample. Although this count with a predefined minimum value has as its main objective to determine the participation of botanical species in the floral origin, it was adopted herein to estimate the abundance of pollen in the samples.

The taxonomic identification of the species was determined according to the specialized literature (Carreira et al., 1996; Carreira and Barth, 2003; Albuquerque et al., 2013), and the classification system adopted for the botanical family level was APG IV (Chase et al., 2016). The same samples were prepared in parallel without acetolysis to analyze contaminants visible under a microscope (Barth, 2004).

We classified each pollen type identified by life form (tree, palm, shrub, herb, vine, aquatic herb), floral resource (nectar, pollen, unidentified), origin (native to Brazil or exotic), and preferential habitat (wetland, grassland, forest, savannah, anthropogenic) ("RCPol – Rede de Catálogos Polínicos Online," 2020). The origin of honey from each meliponary was classified as: monofloral (when there is a dominant pollen type with presence of more than 45%) or heterofloral (when there is a set of types with more than 9% presence and the absence of a dominant type), taking into account only the nectariferous species (Ribeiro et al., 2019). The set of pollen types with low frequency (less than 9%) was considered in calculations of richness, relative abundance and modeling.

2.6 Data analysis

2.6.1 Preparation of matrices

To evaluate the effect of landscape and floral origin on honey productivity, we set up six data matrices. A: LULC, subdivided into A1: percentage of coverage of classes (%), A2: density of patches by class (pd), B: profile and management of the beekeepers, C: richness and abundance of pollen types by meliponary, D: counts of botanical species, E: life form of species identified by meliponary (richness and abundance), F: entropy, climate and geographic metrics.

The honey productivity values had an asymmetric distribution and were transformed with the natural logarithmic function before the linear regression calculation to obtain normalization of the residuals and homogeneity of the variance of the models used.

All mapping data (LULC) were tested for normality and heteroscedasticity with the Shapiro-Wilk and Breusch-Pagan tests. The mapping variables did not have multinormality (Mardia's test $p < 0.05$) and 35.7% of the variables have more than 50% of zeros; thus, no transformations were performed, only the standardization of each variable in z values (each original value was subtracted from the mean and divided by the standard deviation of the respective variable) (Borcard et al., 2011). We evaluated the variance and the number of zeros, and eliminated the very rare variables and those with a variance close to zero (Marchant, 2002): mangrove(%), agriculture(%), mangrove(pd), mature forest(pd), urban(pd), agriculture(pd), mosaic(pd), floodplain(pd) and; multicollinearity: secondary vegetation 26-33 years(%). Thus, 15 landscape variables remained, nine of which were measures of area percentage (A1: secondary vegetation 1-15 years, secondary vegetation 16-25 years, mature forest, permanent water, urban area, pasture, mosaic, natural grassland field, floodplain) and six measures of patch density (A2: secondary vegetation 1-15 years, secondary vegetation 16-25 years, mature forest, permanent water, pasture, natural grassland field).

2.6.2 Modeling the effects of landscapes on productivity

To model the landscape effect (LULC) on honey productivity, we applied a redundancy analysis (RDA) using matrices A1 and A2 as explanatory variables for honey productivity and profile and management variables (matrix B) as covariates to remove their effects (Borcard et al., 2011; Jaffé et al., 2015). RDA is a multivariate analysis method that consists of performing a multiple linear regression between the explanatory variables of an X matrix with each response variable of a Y matrix and then performing a Principal Component Analysis (PCA) on the adjusted values of the Y matrix (Borcard et al., 2011). The analysis was performed by the package Vegan v.2.5-7 (Oksanen et al., 2020). We made a direct selection of variables using the Ordistep function from the Vegan package with each of the matrices A1 and A2 separately as explanatory variables and grouped to obtain the best final model (Borcard et al., 2011). To control the collinearity between the variables in the final model, we ensured that all selected variables had a variance inflation factor (VIF) below 10 and, at the end, we partitioned the variation of A1 and A2 (Borcard et al., 2011).

Furthermore, we performed a multiple linear regression with the same variables as the final RDA model to evaluate the linear coefficients of each variable and to verify whether the linear regression assumptions (normality of the distribution and constant variance of the residuals) had been achieved, with the packages Stats v.4.0.5 and lmtest v.0.9-38. The transformations and modeling were performed with functions from the package Vegan and Stats (Oksanen et al., 2020). The same script was performed with the F matrix, but the models were not significant ($p > 0.05$) and the results will not be presented.

We organized the set of landscapes according to the honey productivity gradient, indicating the high and low honey productivity meliponaries according to the categories: low (up to the first quartile), medium (between the first and third quartiles) and high (above the third quartile) to obtain a visual description of the effects of landscape variables.

2.6.3 Modeling the effects of floral origin on productivity

We analyzed honey productivity as a function of pollen analysis variables. The relationship between productivity and, richness and abundance (matrix C) was determined through independent linear regressions. For the counts of identified botanical species (matrix D), we applied the Hellinger transformation that is recommended for abundance data (Borcard et al., 2011) and the relationship with productivity followed the same steps described for the mapping analysis to obtain a final independent model, whereas a second model was obtained by repeating the analysis after omitting some species selected in the first because they were very rare (Marchant, 2002). The relationship between productivity and life forms (matrix E) followed the same steps as the multivariate analysis; and with the selected variables, we calculated independent linear regressions, since there was no significant multiple model ($p > 0.05$).

3 RESULTS

3.1 Profile of beekeepers and honey productivity

In the Baixada Maranhense APA, the meliponaries were established mainly in the rural area (76.5%) and to a lesser extent in the urban area (23.5%). The backyard of the houses was the preferred place in 88% of the cases. Those responsible for this activity were mostly men (75%) with an average age of 56 years (± 13.24), working in this activity for 18.3 years (± 14). The size of their contact network varied from 1 to 40 people (18.3 ± 11.1), and allowed us to estimate the existence of 150 Melipona beekeepers in the APA, which means that the 34 sampled represent 23% of the universe. Respondents had between 12 and 320 tiuba bee boxes (79 ± 73), boxes whose internal volume varied from 10 to 25cm^3 (16.8 ± 3.6). Meliponiculture was not the main activity of the interviewees, but rather was part of the family's set of activities. The honey productivity in meliponaries ranged from 260.0 to 4,794.8mL.bx^{-1} (1.302 ± 928.7); the low productivity category ranged from 260.0 to 513.8mL.bx^{-1} and high from 1,788.4 to 4,794.8mL.bx^{-1}.

3.2 Bee landscape

The following classes occurred in all 34 landscapes: secondary vegetation 26 to 33 years old which is the most representative class with a cover gradient ranging from 2.4 to 72% (34.8 ± 19.6); secondary vegetation varying from 16 to 25 years, ranging from 3.6 to 32.2% (15.5 ± 6.2); secondary vegetation between 1 to 15 years ranging from 0.4 to 9% (2.3

± 2.1); floodplain ranging from 1.3 to 52.4% (14.6 ± 14.0) and permanent water from 0.1 to 31.6% (8.1 ± 8.3). Other important classes were: pasture that occurred in 29 landscapes ranging from 0 to 50% (10.8 ± 11.9); natural grassland field occurring in 27 landscapes and ranging from 0 to 41.7% (7.2 ± 11.5); mosaic found in 29 landscapes ranging from 0 to 9% (2.0 ± 2.6) and mature forest occurring in 10 landscapes and varying from 0 to 10% (0.5 ± 1.8).

3.3 Landscape effects on honey productivity

When the LULC variables were modeled separately (matrices A1 and A2), the percentage of classes (R^2 = 0.36, p = 0.036) and the patch density (R^2 = 0.08, p = 0.050) resulted in lower explanatory values than when considering the 15 variables together (R^2 = 0.63, p = 0.001) (Table 1). The profile and management covariates were significant, after discounting their effects; the landscape explained almost half of the variance of honey production in the final additive model (R^2 = 0.44, p = 0.001); six variables were selected: three with a positive effect (% natural grassland field, % permanent water and natural grassland field patch density) and three with a negative effect (% mosaic; % mature forest and pasture patch density). The construction of the multiple linear model with the same variables selected in the RDA revealed a significant model ($p < 0.0001$) that fulfills the assumptions of the regression. When partitioned, the variances of the final additive model, matrix A1 and matrix A2, have respective explanatory powers of 0.561 ($p < 0.0001$) and 0.245 ($p < 0.0001$) with no interaction effect between them. In general, the RDA and multiple linear regression coefficients are coherent (Table 2).

The landscape variables selected in the modeling and their effect on productivity can be visualized when organized according to the productivity gradient, using the categories of meliponaries with low and high honey productivity (Figure 2). In line with the modeling, there is a greater predominance of native field coverage and density of native field patches in the landscapes among meliponaries with high productivity (at the top of the figure), as well as the permanent water class. The higher frequency of landscapes with low productivity meliponaries (at the bottom of the figure) contain higher forest cover and greater presence of mosaic and pasture patches.

Table 1. Redundancy analysis (RDA) sequence to test landscape effects (Land use and Land Cover) on *Melipona fasciculata* honey productivity (Y) in the Baixada Maranhense Environmental Protected Area (APA), Maranhão state, eastern Amazon, Brazil, in 2019.

Step	**LULC**	**Model[¥]**	**p**	**R^2 adj.**
Original independent models	A1 (%)	Y ~ sf15+sf25+old forest+water+urban+pasture+mosaic+natural grassland+floodplain	0.002	0.36
	A2 (pd)	Y ~ sf15pd+sf25pd+sf33pd+waterpd+pasture pd+ natural grassland pd	0.050	0.08
	A1 (%)+ A2 (pd)	Y ~ sf15+sf25+old forest+water+urban+pasture+mosaic+ natural grassland + floodplain + Sf15pd+ sf25pd+sf33pd+waterpd+pasturepd+ natural grassland pd	0.001	**0.63**
Covariable - management		Y ~ age+b-time+network+n-box+vol	0.047	0.17
Additive model	All	Y ~ A1 (%) + A2 (pd) – management (network+n-box)		
Final additive model		**Y ~ native grassland(%) + water(%) + native grassland(pd) + mosaic(%) + old forest(%) + pasture(pd)**	0.001	**0.44**

[¥] sf15 is secondary forest 1-15 year(%); sf25 is secondary forest 16-25 year(%); sf33 is secondary forest 26-33 year(%); old forest is old-growth forest(%); water is perennial water(%); urban is urban area; pasture is pasture; mosaic is shifting agriculture; sandy formations; small pastures and villages; natural grassland is natural grassland fields; floodplain is flooded grassland; pd is density patches; age is age of beekeeper; b-time is time that raises bees; network is size of the network; n-box is number of beehives; vol is average volume of boxes; R^2 adj. is r square adjusted; p is significance level.

Table 2. Analysis of variance of the final additive model to test on *Melipona fasciculata* honey productivity, in the Baixada Maranhense Environmental Protected Area (APA), Maranhão state, eastern Amazon, Brazil, in 2019.

explanatory variable: landscape / covariable: management[¥]	**Df**	**F**	**p**	**score rda**	**coef lm**
natural grassland (%)	1	29.12	0.001	0.690	0.494
perennial water (%)	1	9.033	0.005	0.380	0.230
native grassland (pd)	1	5.460	0.027	0.358	0.233
mosaic (%)	1	4.172	0.050	-0.388	-0.195
old-growth forest (%)	1	7.460	0.010	-0.355	-0.240
pasture (pd)	1	8.532	0.006	-0.244	0.556
residual	27				
network	1	4.499	0.042	0.724	0.245
n-box	1	4.575	0.046	-0.710	-0.239
residual	31				

[¥] network is size of the network, n-box is number of beehives. pd is density of patches, df is degrees of freedom, F is Fischer test, score rda is biplot scores for constraining variables, coef lm is multiple linear regression coefficients; p is significance level.

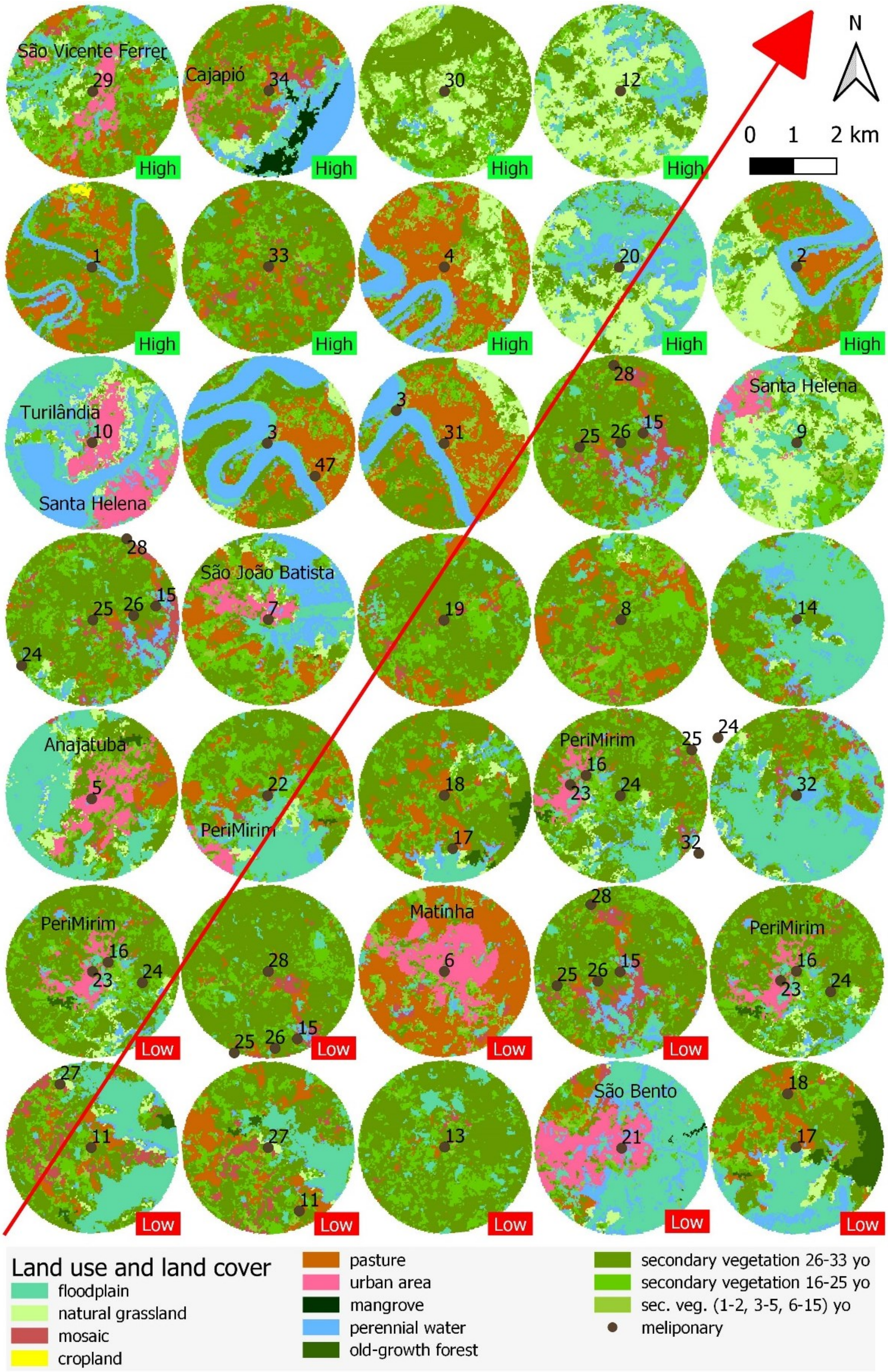


Figure 2. Composition of the bee landscape (*Melipona fasciculata*) in 34 meliponary arranged in a productivity gradient, sampling unit (id) refer to the meliponary in the center of the bee landscape, indication of low and high honey productivity, cities (urban area) are identified, in APA of Baixada Maranhense, state of Maranhão, Brazil, in 2018.

3.4 Floral origin of honey

The pollen present in the analyzed honeys was classified into 77 pollen types belonging to 23 botanical families, of which 50 were identified at the species level, 26 at the genus level and one only to the family level (see Table 4 in SM), with the majority of plants (84.2%) being native, 28.5% arboreal, 28.5% shrubs, 15.6% herbaceous, 14.2% vines, 0.05% palms and 0.03% aquatic plants. As for the floral origin, 19 honey samples were classified as heterofloral and 15 as monofloral. Cultivated plants (*Eucalyptus globulus* Labill, *Psidium guajava* L.) were representative in honey samples from three sites only (6, 19, and 33), in the other honey samples (93.1%) the floral origin is composed of native plants (details in Table 5 in SM).

The floral origin of honeys from 29 meliponaries (83%) is explained by 15 plant species with greater relative abundance (Figure 3), they are: *Eichhornia crassipes* Mart. (Solms), *Myrcia cuprea* (O. Berg) Kiaersk., *Senna occidentalis* (L.) Link, *Distimake aegyptius* (L.) A.R. Simões & Staples, *Mimosa pudica* L., *Pontederia parviflora* Alexander, *Attalea speciosa* Mart. ex Spreng, *Mimosa verrucosa* Benth, *Mimosa caesalpiniifolia* Benth, *Hyptis atrorubens* Poit, *Chamaecrista diphylla* (L.) Greene, *Machaerium* sp., *Camptosema* sp., *Eucalyptus globulus* Labill. and *Mouriri acutiflora* Naudin. The description of these plants and their frequencies in the 34 landscapes studied are displayed in Table 6 (SM).

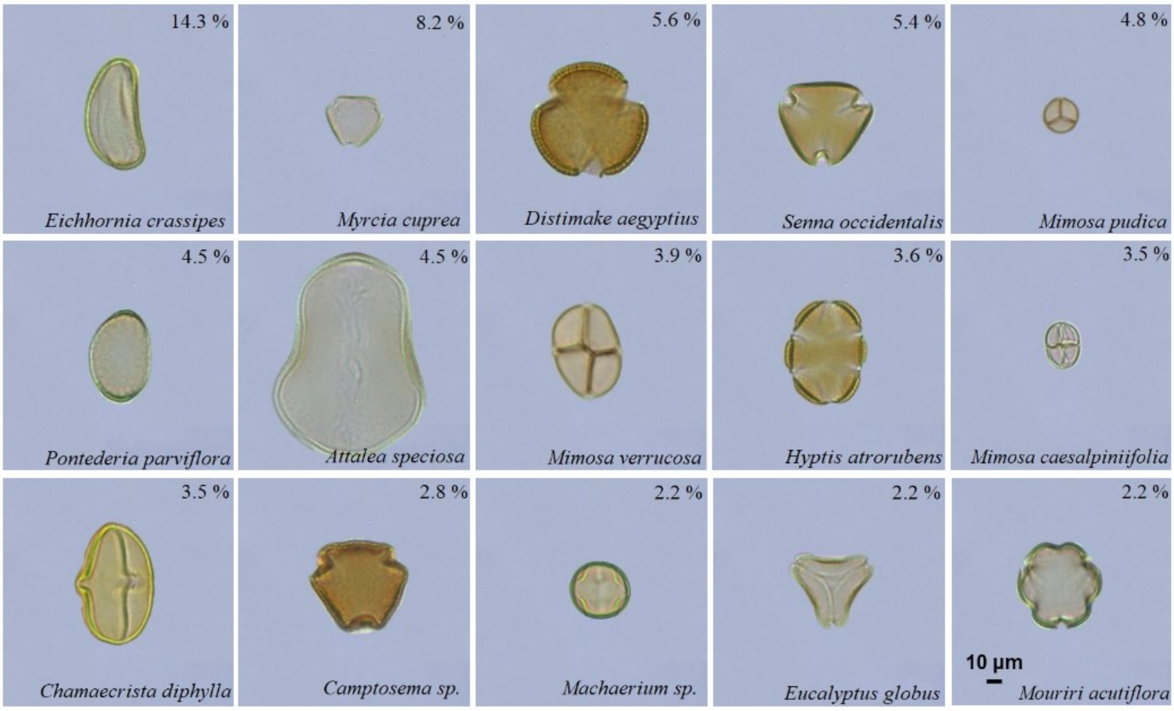


Figure 3. Microphotographs (40x objective; 10 micrometer scale) of the fifteen main pollens, in relative abundance, observed in the pollen slide of honey samples from the bee *Melipona fasciculata* of meliponaries of 13 municipalities of the Baixada Maranhense APA, in eastern Brazilian Amazon. 2019.

The identification and counting of contaminants in honeys, performed in samples without acetolysis, detected the absence of contaminants or foreign elements, and the presence of common elements with the following frequency in the set of 34 honeys: vegetable tissue (53.8%), yeast (23%), Bryophyte spore (9.6%), insect organ: paw or antenna (3.8%) plant part: root (3.8%), monolete fern spore (2%), algae (2%) and Lycophyte (2%).

3.5 Relationships between floral origin and honey productivity

The mean richness of species registered in the slide of honeys from the meliponaries was 17.4 (± 3.5) species, varying from 11 to 26 species while the average abundance of grains counted by honeys was 774 (± 161.5) grains and ranged from 421 to 1,223 grains. Honey productivity had a negative relationship with species richness (r = - 0.36 Pearson, p = 0.032) and with pollen abundance (r = - 0.39 Pearson, p = 0.019).

Honey productivity was positively correlated with shrub richness (r = 0.37 Pearson, R^2 = 0.11, p = 0.029) and negatively correlated with palm abundance (Kendall' tau = - 0.33, R^2 = 0.18, p = 0.008) present in bees' landscapes (see Table 3). There was no relationship between tree species and productivity.

In the modeling of productivity as a function of botanical species, eight species that account for honey productivity ($R^2 = 0.86$; $p < 0.0001$) were selected in model '1'. However, among the eight species, *Cenostigma bracteosum* (Tul.) Gagnon & G.P.Lewis is rare and only occurred in one sample from the meliponary with the greatest productivity (id = 12) with two grains, whereas *Ipomoea carnea* Jacq. only occurred in two meliponaries (id: 2 and 23), with three grains in each. In model '2' we omitted *C. bracteosum* and *I. carnea* and the modeling selected three species (one different from model 1: *Mimosa caesalpiniifolia* Benth), which account for more than half of the variance of honey productivity ($R^2 = 0.54$; $p < 0.0001$).

The species set (considering models 1 and 2) contained nine native botanical species grouped into six families (Table 3). The main botanical family is Fabaceae (44.4%). The life forms of this species set were: shrubs (44.4%), trees (33.3%), palms (11.1%), and herbs (11.1%). As to the floral resources of these species for the bees, all were nectariferous and polliniferous species; two were highly polliniferous.

Table 3. Coefficients of independent model obtained with RDA and multiple linear model of honey yield (Y) of *Melipona fasciculata* as a function of 77 species, obtained by melissopalynology in eastern Brazilian Amazon, Brazil. Model 2 omitted rare species.

Yield	explanatory variables: botanical species[¥]	family	score rda / coef lm	
			model 1	**model 2**
	Cenostigma bracteosum Tul., N/P, shrub, savanna	Fabaceae	0.394 / 7.159	*omitted*
	Tibouchina aspera Aubl., N/P, tree, savanna	Melastomataceae	0.388 / 0.478	0.506 / 0.004
	Ipomoea carnea Jacq., N/P, shrub, anthropic	Convolvulaceae	0.258 / 3.791	*omitted*
Y ~	*Neptunia plena* (L.) Benth, N/P, herb, wetland	Fabaceae	-0.621 /-1.111	-0.723 /-0.023
	Anacardium occidentale L., N/P, tree, savanna	Anacardiaceae	-0.507 /-2.635	-
	Attalea speciosa Mart. ex Spreng, N/P*, palm, anthropic	Arecaceae	-0.423 /-1.063	-
	Psychotria carthagenensis Jacq., N/P, shrub, wetland	Rubiaceae	-0.149 /-2.547	-
	Plathymenia sp., N/P, tree, savanna	Fabaceae	-0.003 /-1.334	-
	Mimosa caesalpiniifolia Benth, N/P*, shrub, savanna	Fabaceae	-	0.245 / 0.009
		R² adj.	**0.86**	**0.54**
		p	**<0,0001**	**<0,0001**

[¥] Botanical species; resources for bees (N - nectariferous, P - polliniferous, P* - too much pollen); life form; habitat; R^2 adj. is r square adjusted; p is significance level, score rda is biplot scores for constraining variables, coef lm is multiple linear regression coefficients.

4 Discussion

The Amazon is the largest and most biodiverse Brazilian biome, but has the lowest number of laws and public policies related to pollinators (Hipólito et al., 2021), while in recent years deforestation, forest fragmentation and land use change have intensified (Silva Junior et al., 2020). Although there are several studies on the effect of landscape on the production of *Apis meliffera* honey (Sponsler and Johnson, 2015; Donkersley, 2019), detailed studies on the landscapes and productivity of stingless honeybees are scarce (Jaffé et al., 2015). The Environmental Preservation Area (APA) of Baixada Maranhense is a natural laboratory for elucidating how the landscape influences the honey productivity of *M. fasciculata*.

M. fasciculata is a tropical bee, endemic in the north, northeast, and center of Brazil, in the Amazon and Cerrado biomes (Camargo and Pedro, 2013). It has a life expectance varying between 25 and 105 days and starts foraging around 25–33 days after emergence. Climatic and floristic characteristics of the region determine behavior and foraging activity (Kerr et al., 1996; Vit et al., 2013; Gostinski et al., 2018). In a study using radio-frequency identification tags (Oliveira et al., 2021) identified that most of the *M. fasciculata* bees (65%) drifted to another hive nearby (not necessarily associated with orientation mistakes) and that factors such as temperature, humidity, and solar irradiation influenced the rates of drifting behavior and affected foraging activity. Authors also identified that *M. Fasciculata* forages during the entire day, but prefer the morning (peak activity per colony at 9:00 am). Indeed, the species is very susceptible to climatic variation and small fluctuations can impact their lifespan and implicate extranidal activities (Oliveira et al., 2021). In our study, climate variables were not significant to explain honey productivity, probably because of a small variation between sites. However, in the context of climate change, it is fundamental to understand the impact of climatic variables on stingless bee behavior and extranidal activity.

Meliponiculture in the APA has a familial character, is conducted by people with advanced age, many years engaged in the activity and an important network of contacts. The beekeeper's experience indicated by the network of contacts, the number of boxes and handling helped to account for the variation in productivity (Jaffé et al., 2015). However, the honey productivity of the studied meliponaries is low and of greater variability (1,302 ± 928.7ml.bx^{-1}) when compared to the average productivity of 2,430 ml in a similar ecosystem in the state of Pará (Venturieri et al., 2003).

Our analyses revealed that the variation in honey productivity is related to the configuration of the landscapes around the meliponaries, the floral origin and the profile and management of the beekeepers. These factors also affect the food and medicinal quality of honey (de Oliveira Alves, 2013), which will be revealed in future physicochemical and sensory analyses. The analysis of honey contaminants indicated only natural elements of the working ecosystem of the bees and the absence of foreign bodies, which validates our samples, the sampling method, and values the APA beekeepers for their management and hygiene (Barth, 2004).

4.1 Landscapes related to greater honey productivity

In the APA, the highest honey productivity is associated with landscapes with greater coverage of natural grassland fields and permanent water, and with associated species. However, the identification of the floral origin by melissopalynology indicated that these honeys have lower richness and abundance of pollen, which suggests an abundant nectar supply in these landscapes.

The natural grassland field is a very old and stable non-forest ecosystem that, in the geomorphological evolution of the Baixada Maranhense, was formed between 9,000 and 5,000 years ago (Lima et al., 2020). Areas of natural grassland field are similar to areas in early succession, they are open, have high solar radiation, great richness and abundance of herbaceous, shrub and grassland species with much flowering (Kohler et al., 2008; Neumüller et al., 2020), which guarantees a high nectariferous potential and honey production for *M. fasciculata*. Our results confirm that high honey productivity is positively related to shrubs and some trees. However, there are very few botanical records on the APA natural grassland field vegetation (Pinheiro, 2020) to correlate to our data. Therefore, further research should assess the floristic aspect and phytosociology related to this ecosystem. Studies on landscape structure indicate that the most efficient pollination and foraging services occur where there are hedges, alleys, strips or forest corridors interspersed with open fields, because they facilitate formation of the "cognitive map", communication and social flight guidance of the bees due to the three-dimensional structure of the landscape, as opposed to the absence of these structures (Donkersley, 2019; Kheradmand and Nieh, 2019).

The positive effect of permanent water is due on the one hand to the water essential resource, which ensures greater productivity of local ecosystems, as well as the presence of nectariferous aquatic plants, especially *Eichhornia crassipes*, the most abundant species in the set of analyses and the primary one in 30% of the analyzed honeys (Table 5 in SM). Also, the availability of permanent water in the Amazonian dry period favors honey productivity (de Oliveira Alves, 2013).

4.2 Landscapes related to lower honey productivity

The lower honey productivity in the APA is associated with landscapes possessing greater coverage of mature forest, pastures and mosaic. Although these landscape classes have a negative effect on honey productivity, which leads us to reject our original hypothesis, these honeys contain greater abundance and richness of pollen, with up to 26 species. These data suggest a higher frequency of pollen foraging and a greater contribution of these meliponaries in ecosystem services of pollination and maintenance of gene flows, especially in fragmented forest areas, compensating for the restriction of seed dispersal due to distance (Sujii et al., 2021). Furthermore, in mature tropical forests present the possibility of complex and diversified webs and greater competition for resources with other species of native bees (Vit et al., 2013).

The negative relationship with pastures and mosaic, land cover that includes shifting agriculture and small pastures (Capanema et al., 2019), is most likely related to the dynamics of fire use in the landscape (Junior et al., 2016; Peralta et al., 2017), where culturally fire is used for pasture clearing and slash-and-burn practice (Júnior et al., 2008). The fire and smoke from forest fires trigger signals proportional to the size of the danger to the hive that is transmitted among bees; in the short term they interfere with the olfactory sense in general and in the long term hamper foraging and harm the plant-bee relationship (Cho et al., 2021).

The botanical species with the greatest negative effect on honey productivity is *Attalea speciosa* (babassu), a highly polliniferous palm, typical of the palm forest, and very abundant in anthropized environments. *A. speciosa* is not a good supplier of nectar, but it is home to wild *M. fasciculata* nests and other native insects (Anderson et al., 1988). Babassu has high social and economic importance in the region led by women babassu palm breakers, the largest traditional forest products extractive group in Brazil (Porro et al., 2011).

4.3 Relations between floral origin and honey productivity

The diversity of land-use classes and landscape configuration of the APA reveal a plasticity in the behavior of *M. fasciculata* and may indicate a range of tolerance, or an effort to adapt to forest fragmentation (Lichtenberg et al., 2017). The richness of botanical species identified in this study highlights the strong local adaptation of this bee species, which depending on the situation may adopt generalist (Ribeiro et al., 2019) or specialist (Antonini et al., 2006) behavior. The ecological appearance hypothesis (Feeny, 1976) explains that animal foraging takes place preferentially in the most “apparent” and easy-to-find plants, which can result in a specialization of foraging depending on the abundance and ease of finding floral resources. In all the studied meliponaries, the sampling methodology controlled the temporal and spatial foraging frequency variation of different landscapes and flora compositions as it evaluated the annual accumulation of pollen and nectar in a determined area - reflecting on honey productivity and floral origin.

Our study provides an important dimensioning of pollination ecosystem services associated with meliponiculture in the APA, and confirms the synergy between this activity, conservation and restoration of landscapes in this region. We identified a set of 77 botanical species (84% native) associated with *M. fasciculata*, distributed in landscapes with different configurations of land use and land cover. In practice, these results indicate a complex relationship of interdependence between people, hives, waters and ecosystems, where the benefits of nature for people are multiple, and the families that raise their bees are equally important for nature (Spangenberg et al., 2014). The work of Melipona beekeepers for the conservation of biodiversity in the APA must be valued and recognized, as an economic and sociocultural activity based on local nature, which guarantees ecological management that is very important for future generations.

5. Conclusion

Landscape composition has an important effect on the honey productivity of the stingless bee *Melipona fasciculata* in the APA of Baixada Maranhense, in the Eastern Amazon. In landscapes with higher percentage and density of natural grassland field patches, percentage of permanent water and a specific composition of native shrub botanical species is where there is greater honey productivity, but lower species richness and pollen abundance in honey. Meliponaries in landscapes with greater mature forest cover present lower honey productivity, but have honeys with greater richness and abundance of native species, indicating more pollination ecosystem services in these landscapes.

6 Acknowledgments

The authors are grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES), to the professors Dr. Márcia Maria Corrêa Rêgo and Patricia Maia Correia de Albuquerque for having made available the Laboratory of Studies on Bees - LEA, to Dr. Liana Anderson and Dr. Luiz Aragão from INPE/TREES for access to their team and suggestions, Diego Sousa Campos and Janderson Rocha Silva for support in spatial analysis, Nadja Maria Guedes Farfan, Luciana dos Santos Aires and Gilvânia Sousa Pereira for support in the field and laboratory. In particular, the authors thank the stingless beekeepers from Baixada Maranhense who participated in the survey.

References

Albuquerque, P.M., Gostinski, L. F., Rego, M.M.C, Carreira, L., 2013. Flores e Abelhas: a interação da tiúba (*Melipona fasciculata*, Meliponini) com suas fontes florais na Baixada Maranhense. EDUFMA, São Luís.

Albuquerque, U.P., Cunha, L.V.F.C. da, Lucena, R.F.P., Alves, R.R.N. (Eds.), 2014. Methods and Techniques in Ethnobiology and Ethnoecology, Springer Protocols Handbooks. Humana Press. https://doi.org/10.1007/978-1-4614-8636-7

Almeida, L.Q., Welle, T., Birkmann, J., 2016. Disaster risk indicators in Brazil: A proposal based on the world risk index. International Journal of Disaster Risk Reduction 17, 251–272. https://doi.org/10.1016/j.ijdrr.2016.04.007

Alvares, C.A., Stape, J.L., Sentelhas, P.C., de Moraes Gonçalves, J.L., Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 711–728. https://doi.org/10.1127/0941-2948/2013/0507

Anderson, A.B., Overal, W.L., Henderson, A., 1988. Pollination Ecology of a Forest-Dominant Palm (Orbignya phalerata Mart.) in Northern Brazil. Biotropica 20, 192–205. https://doi.org/10.2307/2388234

Antonini, Y., Costa, R.G., Martins, R.P., 2006. Floral preferences of a neotropical stingless bee, *Melipona quadrifasciata* Lepeletier (Apidae: Meliponina) in an urban forest fragment. Brazilian Journal of Biology 66, 463–471. https://doi.org/10.1590/S1519-69842006000300012

Barth, O.M., 2004. Melissopalynology in Brazil: a review of pollen analysis of honeys, propolis and pollen loads of bees. Scientia Agricola 61, 342–350. https://doi.org/10.1590/S0103-90162004000300018

Borcard, D., Gillet, F., Legendre, P., 2011. Numerical Ecology with R, Use R! Springer-Verlag, New York. https://doi.org/10.1007/978-1-4419-7976-6

Borges, R.C., Padovani, K., Imperatriz-Fonseca, V.L., Giannini, T.C., 2020. A dataset of multi-functional ecological traits of Brazilian bees. Sci Data 7, 120. https://doi.org/10.1038/s41597-020-0461-3

Brancalion, P.H.S., Garcia, L.C., Loyola, R., Rodrigues, R.R., Pillar, V.D., Lewinsohn, T.M., 2016. Análise crítica da Lei de Proteção da Vegetação Nativa (2012), que substituiu o antigo Código Florestal: atualizações e ações em curso. Natureza & Conservação 14, e1–e16. https://doi.org/10.1016/j.ncon.2016.03.004

Camargo, J.M.F., Pedro, S.R.M., 2013. Meliponini Lepeletier, 1836. In Moure, J. S., Urban, D. & Melo, G. A. R. (Orgs). Catalogue of Bees (Hymenoptera, Apoidea) in the Neotropical Region - online version.

Capanema, V., Sanches, I., Escada, M., 2019. Comparação entre os produtos temáticos de uso e cobertura da terra do Terraclass Amazônia e Mapbiomas: teste de aderência entre classes. https://doi.org/10.13140/RG.2.2.33070.74561

Carreira, L.M.M., Barth, O.M., 2003. Atlas de pólen da vegetação de cangas da Serra de Carajás, Coleção Adolpho Ducke. Goeldi Editoração, Belém, Pará.

Carreira, L.M.M., Silva, M.F. da, Lopes, J.R.C., Nascimento, L.A.S., 1996. Catálogo de Pólen das Leguminosas da Amazônia Brasileira, Coleção Adolpho Ducke. Laïs Zumero.

Celentano, D., Rousseau, G.X., Muniz, F.H., Varga, I. van D., Martinez, C., Carneiro, M.S., Miranda, M.V.C., Barros, M.N.R., Freitas, L., Narvaes, I. da S., Adami, M., Gomes, A.R., Rodrigues, J.C., Martins, M.B., 2017. Towards zero deforestation and forest restoration in the Amazon region of Maranhão state, Brazil. Land Use Policy 68, 692–698. https://doi.org/10.1016/j.landusepol.2017.07.041

Chase, M.W., Christenhusz, M.J.M., Fay, M.F., Byng, J.W., Judd, W.S., Soltis, D.E., Mabberley, D.J., Sennikov, A.N., Soltis, P.S., Stevens, P.F., 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society 181, 1–20. https://doi.org/10.1111/boj.12385

Cho, Y., Jeong, S., Lee, D., Kim, S.-W., Park, R.J., Gibson, L., Zheng, C., Park, C.-R., 2021. Foraging trip duration of honeybee increases during a poor air quality episode and the increase persists thereafter. Ecology and Evolution 11, 1492–1500. https://doi.org/10.1002/ece3.7145

de Oliveira Alves, R.M., 2013. Production and Marketing of Pot-Honey, in: Vit, P., Pedro, S.R.M., Roubik, D. (Eds.), Pot-Honey: A Legacy of Stingless Bees. Springer, New York, NY, pp. 541–556. https://doi.org/10.1007/978-1-4614-4960-7_40

Donkersley, P., 2019. Trees for bees. Agriculture, Ecosystems & Environment 270–271, 79–83. https://doi.org/10.1016/j.agee.2018.10.024

Fernandes, R.T., Rosa, I.G., Conti-Silva, A.C., 2020. Honey from Tiúba stingless bees (*Melipona fasciculata*) produced in different ecosystems: physical and sensory studies. Journal of the Science of Food and Agriculture 100, 3748–3754. https://doi.org/10.1002/jsfa.10415

Feeny, P., 1976. Plant Apparency and Chemical Defense, in: Wallace, J.W., Mansell, R.L. (Eds.), Biochemical Interaction Between Plants and Insects, Recent Advances in Phytochemistry. Springer US, Boston, MA, pp. 1–40. https://doi.org/10.1007/978-1-4684-2646-5_1

González-Miret, M.L., Terrab, A., Hernanz, D., Fernández-Recamales, M.Á., Heredia, F.J., 2005. Multivariate Correlation between Color and Mineral Composition of Honeys and by Their Botanical Origin. J. Agric. Food Chem. 53, 2574–2580. https://doi.org/10.1021/jf048207p

Gostinski, L.F., Oliveira, F.F., Contrera, F.A.L., Albuquerque, P.M.C. de, 2018. Nicho trófico e partição de fontes polínicas por duas espécies de *Melipona* (HYMENOPTERA, APIDAE) na Amazônia oriental. Oecologia Australis 22. https://doi.org/10.4257/oeco.2018.2204.08

Härtel, S., Steffan-Dewenter, I., 2014. Ecology: Honey Bee Foraging in Human-Modified Landscapes. Current Biology 24, R524–R526. https://doi.org/10.1016/j.cub.2014.04.052

Hesselbarth, M.H.K., Sciaini, M., With, K.A., Wiegand, K., Nowosad, J., 2019. landscapemetrics: an open-source R tool to calculate landscape metrics. Ecography 42, 1648–1657. https://doi.org/10.1111/ecog.04617

Hipólito, J., Coutinho, J., Mahlmann, T., Santana, T.B.R., Magnusson, W.E., 2021. Legislation and pollination: Recommendations for policymakers and scientists. Perspectives in Ecology and Conservation 19, 1–9. https://doi.org/10.1016/j.pecon.2021.01.003

Jaffé, R., Pope, N., Carvalho, A.T., Maia, U.M., Blochtein, B., Carvalho, C.A.L. de, Carvalho-Zilse, G.A., Freitas, B.M., Menezes, C., Ribeiro, M. de F., Venturieri, G.C., Imperatriz-Fonseca, V.L., 2015. Bees for Development: Brazilian Survey Reveals How to Optimize Stingless Beekeeping. PLOS ONE 10, e0121157. https://doi.org/10.1371/journal.pone.0121157

Junior, C.H.L.S., Freire, A.T.G., Rodrigues, T.C.S., Viegas, J.C., Bezerra, D. da S., 2016. Dinâmica das queimadas na baixada maranhense. InterEspaço: Revista de Geografia e Interdisciplinaridade 2, 355–375. https://doi.org/10.18766/2446-6549/interespaco.v2n5p355-375

Júnior, N.N.P., Murrieta, R.S.S., Adams, C., 2008. A agricultura de corte e queima: um sistema em transformação The slash-and-burn agriculture: a system in transformation 3, 22.

Katsanos, D., Retalis, A., Michaelides, S., 2016. Validation of a high-resolution precipitation database (CHIRPS) over Cyprus for a 30-year period. Atmospheric Research 169, 459–464. https://doi.org/10.1016/j.atmosres.2015.05.015

Kerr, W., Carvalho, G., Nascimento, V., 1996. Abelha Uruçu: Biologia, Manejo e Conservação. Belo Horizonte.

Kerr, W.E., Carvalho, G.A., Silva, A.C. da, Assis, M. da G.P. de, 2001. Aspectos pouco mencionados da biodiversidade amazônica. Parcerias Estratégicas 6, 20–41.

Kheradmand, B., Nieh, J.C., 2019. The Role of Landscapes and Landmarks in Bee Navigation: A Review. Insects 10, 342. https://doi.org/10.3390/insects10100342

Kohler, F., Verhulst, J., Klink, R.V., Kleijn, D., 2008. At what spatial scale do high-quality habitats enhance the diversity of forbs and pollinators in intensively farmed landscapes? Journal of Applied Ecology 45, 753–762. https://doi.org/10.1111/j.1365-2664.2007.01394.x

Lichtenberg, E.M., Mendenhall, C.D., Brosi, B., 2017. Foraging traits modulate stingless bee community disassembly under forest loss. Journal of Animal Ecology 86, 1404–1416. https://doi.org/10.1111/1365-2656.12747

Lima, K.C., Perez Filho, A., Lima, K.C., Perez Filho, A., 2020. Evolução geomorfológica de planícies costeiras no holoceno. Mercator (Fortaleza) 19. https://doi.org/10.4215/rm2020.e19010

Marchant, R., 2002. Do rare species have any place in multivariate analysis for bioassessment? Journal of the North American Benthological Society 21, 311–313. https://doi.org/10.2307/1468417

Martin, L., Suguio, K., Flexor, J.M., Bittencourt, A., Vilas-Boas, G., 1980. Le quaternaire marin brésilien (littoral pauliste, Sud fluminense et bahianais) 30.

Melhem, Cruz-Barros, M.A.V., Correa, A.M.S., Makino-Watanabe, H., Silvestre-Capelato, M.S.F., Esteves, V.L.G., 2003. Variabilidade polinica em plantas de Campos do Jordao (São Paulo, Brasil). Boletim do Instituto de Botanica 16, 9–104.

Myerscough, M.R., Khoury, D.S., Ronzani, S., Barron, A.B., 2017. Why Do Hives Die? Using Mathematics to Solve the Problem of Honey Bee Colony Collapse, in: Anderssen, B., Broadbridge, P., Fukumoto, Y., Kamiyama, N., Mizoguchi, Y., Polthier, K., Saeki, O. (Eds.), The Role and Importance of Mathematics in Innovation, Mathematics for Industry. Springer, Singapore, pp. 35–50. https://doi.org/10.1007/978-981-10-0962-44

Neumüller, U., Burger, H., Krausch, S., Blüthgen, N., Ayasse, M., 2020. Interactions of local habitat type, landscape composition and flower availability moderate wild bee communities. Landscape Ecol 35, 2209–2224. https://doi.org/10.1007/s10980-020-01096-4

Nowosad, J., Stepinski, T.F., 2019. Information theory as a consistent framework for quantification and classification of landscape patterns. Landscape Ecol 34, 2091–2101. https://doi.org/10.1007/s10980-019-00830-x

Nunes-Silva, P., Costa, L., Campbell, A.J., Arruda, H., Contrera, F.A.L., Teixeira, J.S.G., Gomes, R.L.C., Pessin, G., Pereira, D.S., de Souza, P., Imperatriz-Fonseca, V.L., 2020. Radiofrequency identification (RFID) reveals long-distance flight and homing abilities of the stingless bee *Melipona fasciculata*. Apidologie 51, 240–253. https://doi.org/10.1007/s13592-019-00706-8

Oksanen, J., Blanchet, G., Friendly, M., Kindt, R., 2020. vegan: Community Ecology Package. R package version 2.5-7.

Oliveira, R.C., Contrera, F.A.L., Arruda, H., Jaffé, R., Costa, L., Pessin, G., Venturieri, G.C., de Souza, P., Imperatriz-Fonseca, V.L., 2021. Foraging and Drifting Patterns of the Highly Eusocial Neotropical Stingless Bee *Melipona fasciculata* Assessed by Radio-Frequency Identification Tags. Frontiers in Ecology and Evolution 9.

Peralta, G., Stevani, E.L., Chacoff, N.P., Dorado, J., Vázquez, D.P., 2017. Fire influences the structure of plant–bee networks. Journal of Animal Ecology 86, 1372–1379. https://doi.org/10.1111/1365-2656.12731

Pinheiro, C.U.B., 2020. Coletas botânicas na zona costeira do estado do Maranhão, nordeste do Brasil. Revista Brasileira de Geografia Física 13, 3006–3024. https://doi.org/10.26848/rbgf.v13.6.p3006-3024

Pioker-Hara, F.C., Drummond, M.S., Kleinert, A. de M.P., 2014. The Influence of the Loss of Brazilian Savanna Vegetation on the Occurrence of Nests of Stingless Bees (Apidae: Meliponini). Sociobiology 61, 393–400. https://doi.org/10.13102/sociobiology.v61i4.393-400

Porro, N., Veiga, I., Mota, D., 2011. Traditional communities in the Brazilian Amazon and the emergence of new political identities: the struggle of the quebradeiras de coco babaçu—babassu breaker women. Journal of Cultural Geography 28, 123–146. https://doi.org/10.1080/08873631.2011.548487

RCPol – Rede de Catálogos Polínicos Online [WWW Document], 2020. URL http://rcpol.org.br/pt/home/ (accessed 9.15.20).

R Core Team, 2020. R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing. Vienna, Austria.

Ramsar, 2000. Baixada Maranhense Environmental Protection Area. Ramsar Sites Information Service. [WWW Document]. URL https://rsis.ramsar.org/ris/1020 (accessed 9.10.20).

Ribeiro, M.H.M., Luz, C.F.P. da, Albuquerque, P.M.C. de, 2019. Palynology as a tool for distinguishing geopropolis samples from stingless bee species in the Maranhense Amazon, Brazil. Journal of Apicultural Research 58, 16–36. https://doi.org/10.1080/00218839.2018.1494890

Roubik, D.W., 2006. Stingless bee nesting biology. Apidologie 37, 124–143. https://doi.org/10.1051/apido:2006026

Silva Junior, C.H.L., Heinrich, V.H.A., Freire, A.T.G., Broggio, I.S., Rosan, T.M., Doblas, J., Anderson, L.O., Rousseau, G.X., Shimabukuro, Y.E., Silva, C.A., House, J.I., Aragão, L.E.O.C., 2020. Benchmark maps of 33 years of secondary forest age for Brazil. Scientific Data 7, 269. https://doi.org/10.1038/s41597-020-00600-4

Souza, C.M., Z. Shimbo, J., Rosa, M.R., Parente, L.L., A. Alencar, A., Rudorff, B.F.T., Hasenack, H., Matsumoto, M., G. Ferreira, L., Souza-Filho, P.W.M., de Oliveira, S.W., Rocha, W.F., Fonseca, A.V., Marques, C.B., Diniz, C.G., Costa, D., Monteiro, D., Rosa, E.R., Vélez-Martin, E., Weber, E.J., Lenti, F.E.B., Paternost, F.F., Pareyn, F.G.C., Siqueira, J.V., Viera, J.L., Neto, L.C.F., Saraiva, M.M., Sales, M.H., Salgado, M.P.G., Vasconcelos, R., Galano, S., Mesquita, V.V., Azevedo, T., 2020. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. Remote Sensing 12, 2735. https://doi.org/10.3390/rs12172735

Spangenberg, J.H., Görg, C., Truong, D.T., Tekken, V., Bustamante, J.V., Settele, J., 2014. Provision of ecosystem services is determined by human agency, not ecosystem functions. Four case studies. International Journal of Biodiversity Science, Ecosystem Services & Management 10, 40–53. https://doi.org/10.1080/21513732.2014.884166

Sponsler, D.B., Johnson, R.M., 2015. Honey bee success predicted by landscape composition in Ohio, USA. PeerJ 3, e838. https://doi.org/10.7717/peerj.838

Sujii, P.S., Tambarussi, E.V., Grando, C., de Aguiar Silvestre, E., Viana, J.P.G., Brancalion, P.H.S., Zucchi, M.I., 2021. High gene flow through pollen partially compensates spatial limited gene flow by seeds for a Neotropical tree in forest conservation and restoration areas. Conserv Genet 22, 383–396. https://doi.org/10.1007/s10592-021-01344-3

Venturieri, G.C., Leão, K.L., Rêgo, E. de S., Venturieri, G.A., 2018. Honey production of the “uruçu-cinzenta” stingless bee (*Melipona fasciculata*) after offering cerumen in natural form or as artificially made pots. Journal of Apicultural Research 57, 129–134. https://doi.org/10.1080/00218839.2017.1339520

Venturieri, G.C., Raiol, V. de F.O., Pereira, C.A.B., 2003. Avaliação da introdução da criação racional de *Melipona fasciculata* (Apidae: Meliponina), entre os agricultores familiares de Bragança - PA, Brasil. Biota Neotropica 3, 1–7. https://doi.org/10.1590/S1676-06032003000200003

Vit, P., Pedro, S.R.M., Roubik, D. (Eds.), 2013. Pot-Honey: A legacy of stingless bees. Springer-Verlag, New York. https://doi.org/10.1007/978-1-4614-4960-7

Waddell, E.H., Banin, L.F., Fleiss, S., Hill, J.K., Hughes, M., Jelling, A., Yeong, K.L., Ola, B.B., Sailim, A.B., Tangah, J., Chapman, D.S., 2020. Land-use change and propagule pressure promote plant invasions in tropical rainforest remnants. Landscape Ecol 35, 1891–1906. https://doi.org/10.1007/s10980-020-01067-9

The effect of landscape composition on stingless bee (*Melipona fasciculata*) honey productivity in a wetland ecosystem of Eastern Amazonia, Brazil

Supplementary Material - SM

Table 4. Pollen types (77) identified in *Melipona fasciculata* honeybee samples by plant species in the 34 studied landscapes of APA Baixada Maranhense, in eastern Brazilian Amazon, Brazil, in 2019.

Plant species	Resource[£]	Life form	Origin	Habitat	P(%)[¥]
MONOCOTS					
ARECACEAE					
Attalea speciosa Mart. ex Spreng	N/P*	palm	native	anthropic	4.426
Euterpes sp.	N/P*	palm	native	forest	0.500
Mauritia flexuosa L.	P*	palm	native	forest	0.060
Syagrus sp.	N/P*	palm	native	anthropic	0.078
CYPERACEAE					
Cyperus luzulae (L.) Rottb. ex Retz.	A	aq herb	native	anthropic	0.967
Eriophorum vaginatum L.	A	herb	exotic	wetland	0.493
POACEAE					
Poaceae	A	herb	-	grassland	0.015
PONTEDERIACEAE					
Eichornia crassipes Mart. (Solms)	N	aq herb	native	wetland	11.401
Pontederia parviflora Alexander	N	aq herb	native	wetland	4.583
EUDICOTS					
AMARANTHACEAE					
Alternanthera brasiliana (L.) Kuntze	N/P	herb	native	anthropic	2.183
Amaranthus sp.	N/P	herb	exotic	anthropic	0.007
ANACARDIACEAE					
Anacardium occidentale L.	N/P	tree	native	savanna	0.265
ASTERACEAE					
Baccharis sp.	N/P	shrub	native	anthropic	0.011
Mikania cordifolia (L.f) Willd.	N/P	vine	native	anthropic	0.146
Vernonia polyanthes (Spreng.) Less.	N	shrub	exotic	grassland	0.093
BEGONIACEAE					
Begonia sp.	P	herb	native	anthropic	0.034
BIGNONIACEAE					
Adenocalymma sp.	N/P	vine	native	savanna	0.045
Arrabidaea sp.	N/P	vine	native	anthropic	0.011
Tabebuia sp.	N	tree	native	anthropic	0.030
BURSERACEAE					
Protium leptostachyum Cuatrec.	N	tree	native	forest	1.101
CECROPIACEAE					
Cecropia sp.	P	tree	native	anthropic	0.220
CONVOLVULACEAE					
Ipomoea carnea Jacq.	N/P	shrub/vine	native	anthropic	0.022
Distimake aegyptius (L.) A.R. Simões & Staples	N/P	creeper	native	anthropic	5.534
Merremia sp.	N/P	vine	exotic	anthropic	0.713
DILLENIACEAE					
Curatella sp.	P	shrub	native	grassland	0.022
EUPHORBIACEAE					
Croton heliotropiifoluis Kunth	N	shrub	native	savanna	0.026
Sebastiania sp.	N/P	shrub	native	grassland	0.187
FABACEAE					
Anadenanthera macrocarpa (Benth.)	P	tree	native	savanna	0.037
Andira anthelmia (Vell.) Benth.	N/P	tree	exotic	anthropic	1.896
Bauhinia forficata Link.	P	shrub	exotic	anthropic	0.011
Bowdichia sp.	P	shrub	native	savanna	1.956

Cenostigma bracteosum Tul. Gagnon & G.P.Lewis	N/P	shrub	native	savanna	0.007
Camptosema sp.	NA	vine	native	grassland	2.877
Campsiandra sp.	NA	tree	native	forest	0.224
Centrosema pubescens Benth.	N/P*	vine	native	grassland	0.896
Coursetia sp.	NA	shrub	native	savanna	0.007
Chamaecrista diphylla (L.) Greene	N/P*	herb	native	anthropic	3.512
Crotalaria retusa L.	N	shrub	exotic	anthropic	1.008
Cynometra sp.	NA	tree	native	forest	0.209
Desmodium incanum DC.	N/P	herb	exotic	anthropic	0.026
Dicorynia sp.	NA	tree	native	grassland	0.034
Dioclea sp.	NA	vine	native	anthropic	0.011
Inga cayennensis Sagot ex Benth	N/P*	tree	native	anthropic	0.019
Machaerium sp.	N	shrub	native	anthropic	2.788
Martiodendron parviflorum (Amshoff) R. Koeppen	NA	tree	native	forest	1.821
Mimosa verrucosa Benth	N/P*	shrub	native	forest	3.896
Mimosa caesalpiniifolia Benth	N/P*	shrub	native	savanna	3.523
Mimosa pudica L.	P	Herb	native	anthropic	4.795
Myrocarpus frondosus Allem	P	tree	exotic	forest	1.034
Neptunia plena (L.) Benth	N/P	herb	native	wetland	1.956
Newtonia sp.	NA	tree	exotic	forest	0.019
Piptadenia phyllostachya Benth	N/P	tree	native	forest	0.011
Plathymenia sp.	N/P	tree	native	savanna	0.063
Phyllocarpus sp.	NA	tree	native	forest	0.011
Schrankia leptocarpa DC.	N/P	herb	native	anthropic	0.355
Senna occidentalis (L.)	N/P	shrub	native	anthropic	5.620
Schizolobium amazonicum Huber ex Ducke	N/P*	tree	native	anthropic	0.970
Stryphnodendron adstringens (Mart.) Coville	N/P	tree	native	savanna	1.564
Stylosanthes sp.	N/P*	herb	native	savanna	0.011
Zollernia sp.	N/P*	shrub	native	forest	0.015
LAMIACEAE					
Hyptis atrorubens Poit.	N	herb	native	anthropic	3.575
Hyptis sp.	N	herb	native	anthropic	0.821
MALPIGHIACEAE					
Peixotoa jussieuana A.Juss	NA	shrub	native	savanna	0.179
MELASTOMATACEAE					
Miconia alata (Aubl.) DC	N/P	shrub	native	grassland	0.086
Mouriri acutiflora Naudin.	N/P	tree	native	forest	2.407
Tibouchina aspera Aubl.	N/P	tree	native	savanna	1.952
MYRTACEAE					
Eugenia flavescens DC.	N/P*	shrub	native	savanna	0.194
Eucalyptus globulus Labill.	N/P	tree	exotic	anthropic	2.228
Myrcia cuprea (O.Berg) Kiaersk	N/P	shrub	native	forest	8.121
Psidium guajava L.	N/P*	tree	native	anthropic	1.907
PASSIFLORACEAE					
Passiflora glandulosa Cav.	P	creeper	native	forest	0.007
RUBIACEAE					
Borreria tenella (Kunth) Cham & Schultde	N/P*	herb	native	grassland	0.202
Borreria verticillata (L.) G. Mey	N/P*	shrub	native	anthropic	1.720
Psychotria carthagenensis Jacq.	N/P	shrub	native	wetland	0.037
SAPINDACEAE					
Paullinia pinnata L.	N	vine	native	anthropic	0.179
Serjania Lethalis A.St.-Hil	N	vine	native	savanna	1.123
SOLANACEAE					
Solanum paniculatum L.	P	shrub	native	anthropic	0.907

£ Resources (N: nectariferous, P: polliniferous, *: excess pollen, NA: information not available, A: anemophilous). ¥ P (%): relative pollen frequency in the 102 studied bee boxes;

Table 5. Analysis of the floral origin in honey of *Melipona fasciculata* of 34 meliponaries (id) in APA of Baixada Maranhense, eastern Brazilian Amazon, Brazil, in 2019. Pollen type 1, 2, 3, 4 specifies the main pollen of nectariferous species and its relative abundance.

id	Classification	Pollen type 1	Pollen type 2	Pollen type 3	Pollen type 4
13	Heterofloral	*Attalea speciosa* 37 %	*Hyptis atrorubens* 17 %	*Mouriri acutiflora* 10 %	*Protium leptostachium* 9 %
20	Heterofloral	*Tibouchina aspera* 33 %	*Mouriri acutiflora* 27 %	*Hyptis atrorubens* 24 %	*Protium leptostachium* 9 %
19	Heterofloral	*Mimosa pudica* 29 %	*Eucalyptus globulus* 23 %	*Andira antelmia* 18 %	*Hyptis sp.* 15 %
24	Heterofloral	*Eichhornia crassipes* 33 %	*Pontederia parviflora* 27 %	*Myrcia cuprea* 19 %	*Attalea speciosa* 13 %
23	Heterofloral	*Eichhornia crassipes* 30 %	*Alternanthera brasiliana* 17 %	*Myrcia cuprea* 13 %	*Pontederia parviflora* 11 %
28	Heterofloral	*Camptosema sp.* 22 %	*Attalea speciosa* 22 %	*Stryphnodendron adstringens* 13 %	*Distimake aegyptius* 9 %
30	Heterofloral	*Centrosema pubescens* 42 %	*Distimake aegyptius* 19 %	*Mouriri acutiflora* 13 %	*Eichhornia crassipes* 12 %
22	Heterofloral	*Mimosa caesalpiniifolia* 29 %	*Stryphnodendron adstringens* 19 %	*Neptunia plena* 17 %	
2	Heterofloral	*Distimake aegyptius* 32 %	*Myrcia cuprea* 20 %	*Mouriri acutiflora* 19 %	
4	Heterofloral	*Distimake aegyptius* 43 %	*Distimake sp.* 12 %	*Eugenia flavescens* 10 %	
5	Heterofloral	*Myrcia cuprea* 44 %	*Distimake aegyptius* 34 %	*Distimake sp.* 14 %	
8	Heterofloral	*Machaerium sp.* 47 %	*Myrcia cuprea* 27 %	*Hyptis atrorubens* 15 %	
6	Heterofloral	*Myrcia cuprea* 36 %	*Psidium guajava* 22 %	*Hyptis sp.* 13 %	
34	Heterofloral	*Distimake aegyptius* 44 %	*Myrcia cuprea* 34 %	*Machaerium sp.* 15 %	
33	Heterofloral	*Andira anthelmia* 32 %	*Psidium guajava* 28 %		
7	Heterofloral	*Myrcia cuprea* 45 %	*Distimake aegyptius* 31 %		
25	Heterofloral	*Eichhornia crassipes* 43 %	*Pontederia parviflora* 36 %		
27	Heterofloral	*Machaerium sp.* 28 %	*Serjania lethalis* 24 %		
29	Heterofloral	*Eichhornia crassipes* 36 %	*Alternanthera brasiliensis* 18 %		
1	Monofloral	*Machaerium sp.* 48 %			
3	Monofloral	*Peixotoa jussieuana* 48 %			
9	Monofloral	*Hyptis atrorubens* 79 %			
10	Monofloral	*Hyptis atrorubens* 55 %			
11	Monofloral	*Alternanthera brasiliana* 48 %			
12	Monofloral	*Myrcia cuprea* 53 %			
14	Monofloral	*Eichhornia crassipes* 50 %			
15	Monofloral	*Eichhornia crassipes* 55 %			
16	Monofloral	*Eichhornia crassipes* 52 %			
17	Monofloral	*Eichhornia crassipes* 62 %			
18	Monofloral	*Eichhornia crassipes* 58 %			
21	Monofloral	*Distimake aegyptius* 65 %			
26	Monofloral	*Eichhornia crassipes* 50 %			
31	Monofloral	*Schizolobium amazonicum* 49 %			
32	Monofloral	*Pontederia parviflora* 51 %			

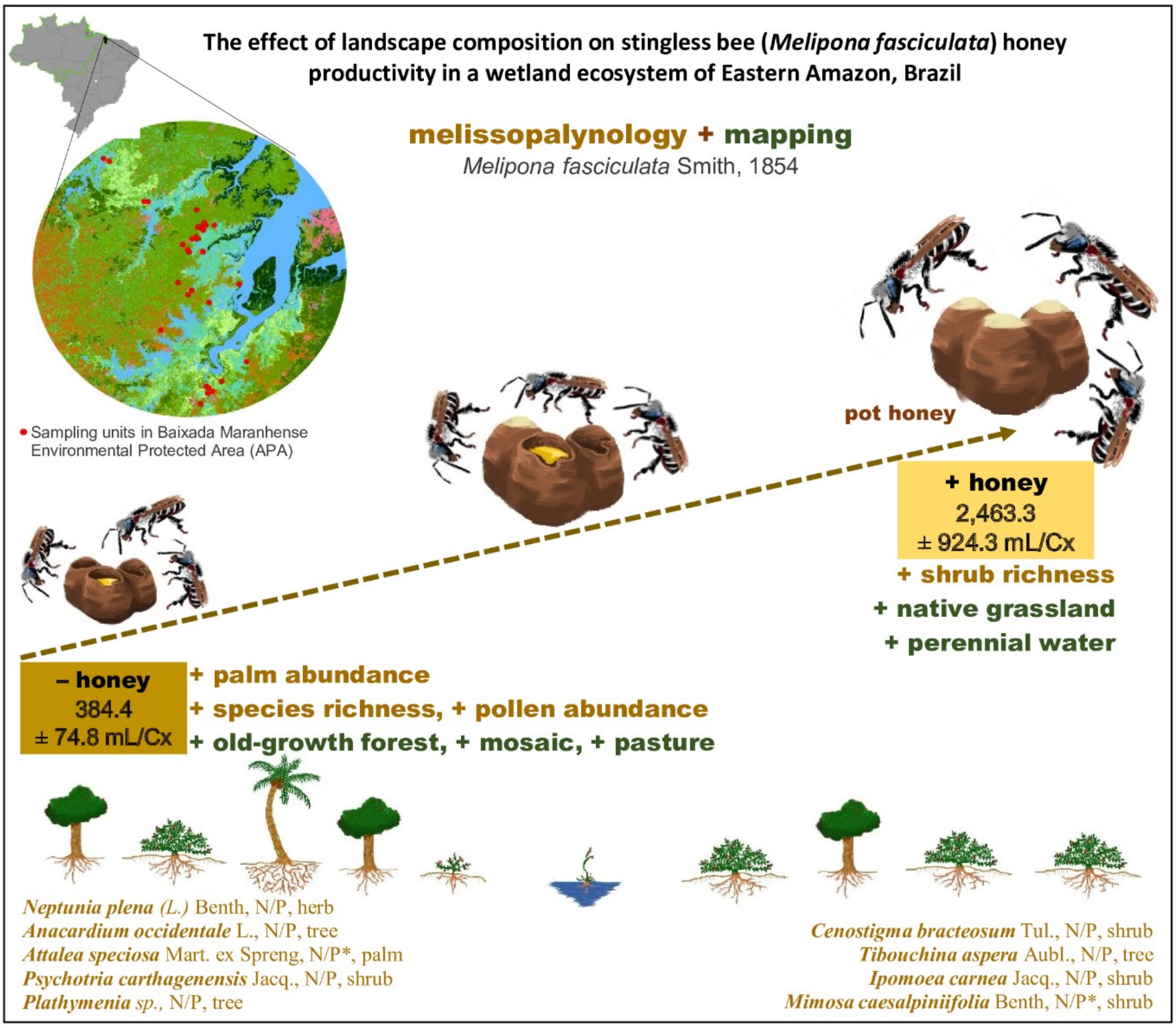
Table 6. Fifteen main botanical species and its occurrence (%) in the 34 meliponaries (id) in APA of Baixada Maranhense, eastern Brazilian Amazon, Brazil, in 2019.

specie	occurrence, classification, number (id)	source of resources and habitat
Eichhornia crassipes Mart. (Solms)	19 occurrences (56 %) ● Monofloral: 14, 15, 16, 17, 18, 26 ● Heterofloral: 23, 24, 25, 29 ● Low frequency: 2, 4, 7, 21, 22, 28, 30, 31, 32	nectariferous, aquatic, native, inhabits lakes, rivers and flooded fields.
Myrcia cuprea (O. Berg) Kiaersk	30 occurrences (88 %) ● Monofloral: 13 ● Heterofloral: 2, 5, 6, 7, 8, 23, 34 ● Low frequency: 1, 3, 4, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 22, 24, 25, 26, 27, 28, 29, 31, 32	nectariferous and polyniferous, shrub, native, inhabits forests or fields.
Distimake aegyptius (L.) A.R. Simões & Staples	21 occurrences (61 %) ● Monofloral: 21 ● Heterofloral: 2, 4, 5, 7, 30, 34 ● Low frequency : 6, 11, 13, 14, 16, 17, 18, 19, 20, 22, 24, 27, 28, 31	nectariferous and polyniferous, liana, native, inhabits anthropic or savannah environment.
Senna occidentalis (L.) Link	27 occurrences (79 %) ● Alta frequência: 1, 3, 5, 6, 7, 8, 10, 11, 20, 29, 31 ● Low frequency: 2, 9, 14, 15, 16, 17, 18, 19, 22, 23, 24, 26, 27, 30, 32, 33	it provides only pollen, which influences the physiology and survival of bees, shrub, native, from anthropogenic or savanna environment.
Mimosa pudica L.	30 occurrences (88 %) ● Monofloral: 0 ● Heterofloral: 19, 33 ● Low frequency: 1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30, 32, 34	polyniferous and nectariferous, herbaceous, native, inhabits anthropogenic or savannah environment.
Pontederia parviflora Alexander	15 occurrences (44 %) ● Monofloral: 32 ● Heterofloral: 24, 25 ● Low frequency: 4, 5, 8, 11, 14, 16, 17, 23, 26, 29, 30, 34	nectariferous, aquatic herb, native, inhabits anthropogenic or savannah environment.
Attalea speciosa Mart. ex Spreng	27 occurrences (79 %) ● Monofloral: 13 ● Heterofloral: 28 ● Low frequency: 1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 32	very polyniferous and nectariferous, palm tree, native, inhabits anthropogenic or savannah environment. Plant characteristic of Maranhão and APA.
Mimosa verrucosa Benth	20 occurrences (59 %) ● Alta frequência: 12, 14, 17, 18, 20, 32, 33 ● Low frequency: 1, 4, 9, 10, 11, 13, 16, 19, 21, 24, 25, 27, 34	very polyniferous and nectariferous, native, inhabits forest environment or wetlands.
Hyptis atrorubens Poit	9 occurrences (26 %) ● Monofloral: 9, 10 ● Heterofloral: 8, 13, 20 ● Low frequency: 22, 27, 29, 33	nectariferous and polyniferous, shrub, native, inhabits forest or native grassland environment.
Chamaecrista diphylla (L.) Greene	16 occurrences (47 %) ● Alta frequência: 1, 2, 4, ● Low frequency: 3, 6, 7, 9, 10, 11, 12, 13, 17, 28, 29, 31, 32	nectariferous and polyniferous, herb, native, inhabits anthropic environment or wetland.
Mimosa caesalpiniifolia Benth	21 occurrences (62 %) ● Monofloral: 0 ● Heterofloral: 2, 3, 4, 9, 18, 20, 22, 28, 31 ● Low frequency: 1, 6, 7, 10, 12, 13, 16, 19, 24, 25, 26, 30	nery poliniferous, shrub, native, inhabits savanna environment.
Camptosema sp.	13 occurrences (38 %) ● Monofloral: 0 ● Heterofloral: 17, 28, 33, 34 ● Low frequency: 13, 15, 16, 22, 23, 24, 25, 26, 32	unknown floral resource, liana, native, inhabits native grassland.
Mouriri acutiflora Naudin	12 occurrences (35 %) ● Monofloral: 0 ● Heterofloral: 2, 13, 20 ● Low frequency: 1, 3, 9, 10, 11, 19, 30, 31, 33	nectariferous and polyniferous, tree, native, inhabits forest environment or wetland.
Machaerium sp.	11 occurrences (32 %) ● Monofloral: 1 ● Heterofloral: 8, 27 ● Low frequency: 2, 5, 7, 13, 23, 24, 29, 31, 34	nectariferous and polyniferous, shrub, native, inhabits anthropic or savannah environment.
Eucalyptus globulus Labill	23 occurrences (67 %) ● Monofloral: 0 ● Heterofloral: 19 ● Low frequency: 3, 5, 6, 7, 9, 10, 11, 12, 13, 14, 16, 17, 18, 20, 21, 22, 27, 28, 29, 31, 32, 34	nectariferous and polyniferous, tree, exotic, inhabits anthropic environment.

*● monofloral: > 45 %, ● heterofloral: plant composition 9 % - 45 %, ● low frequency: < 9 %, ● high frequency: > 9 %, (Barth, 2004).

APÊNDICE B - Figura resumo para revista Journal of Apicultural Research

Figura 4. Figura resumo para revista Journal of Apicultural Research, parte do artigo: o efeito da composição da paisagem na produtividade do mel de abelhas sem ferrão (*Melipona fasciculata*) em um ecossistema de zonas úmidas da Amazônia Oriental, Brasil.



N - nectariferous; P - polliniferous; * - too much pollen; mosaic - includes shifting agriculture, sand formations, small pastures and villages.

APÊNDICE D - Figuras extras da execução da pesquisa

Figuras ilustrativas das atividades da pesquisa:

Figura 1. Alguns dos meliponicultores envolvidos na pesquisa. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

Figura 2. Esquema de localização e mapeamento das paisagens utilizadas pelas abelhas na pesquisa. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

Figura 3. Esquema de análise das variáveis do artigo sobre produtividade de mel de *Melipona fasciculata*. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

Figura 4. Esquema de análise das variáveis do artigo sobre características físico-química de mel de *Melipona fasciculata*. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

Figura 5. Diversos momentos da etapa de campo da pesquisa. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

Figura 1. Alguns meliponicultores (as) envolvidos na pesquisa. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

Figura 2. Esquema de localização e mapeamento das paisagens da abelha utilizados na pesquisa. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

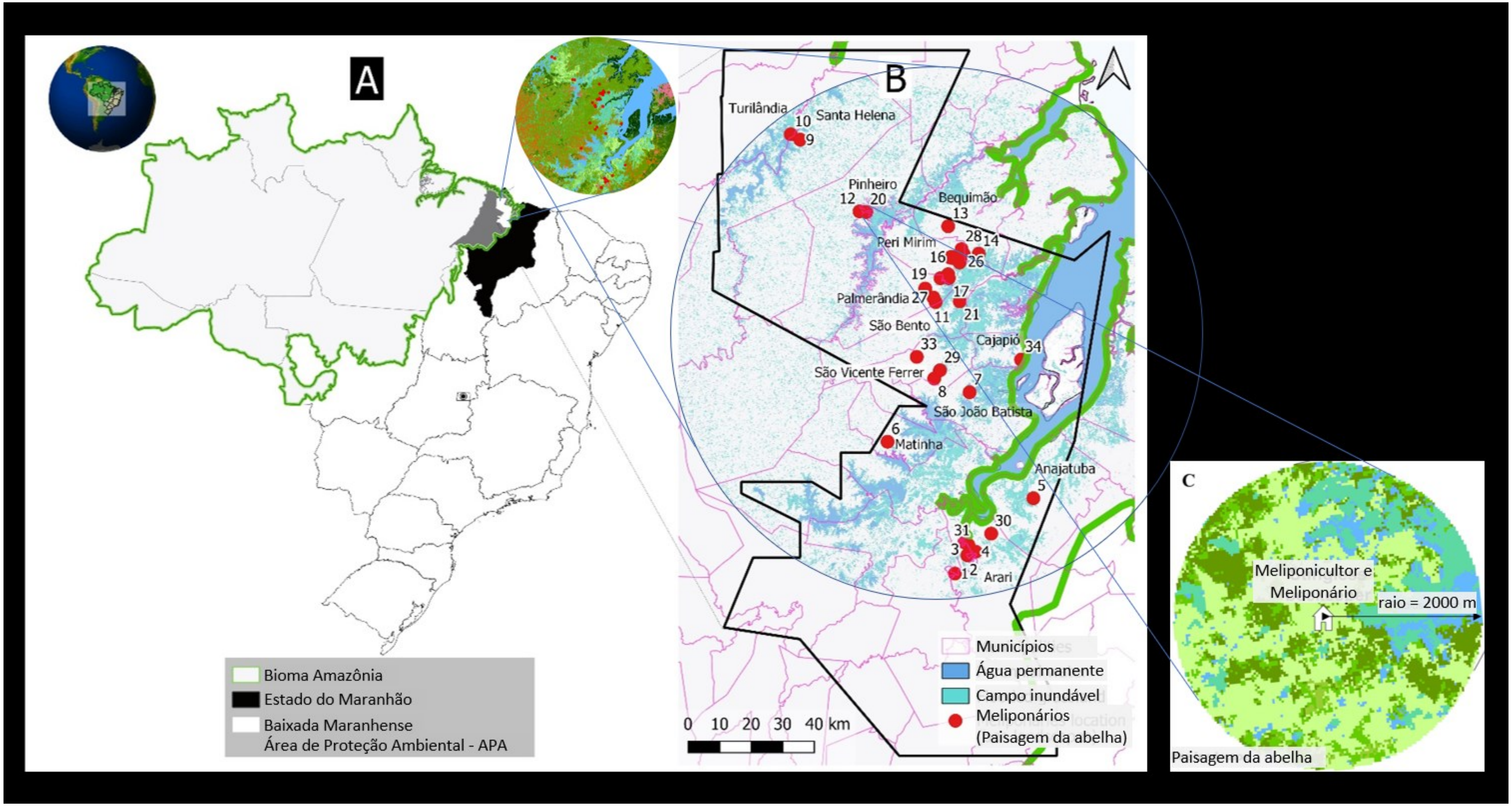


Figura 3. Esquema de análise das variáveis do artigo sobre produtividade de mel de *Melipona fasciculata*. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

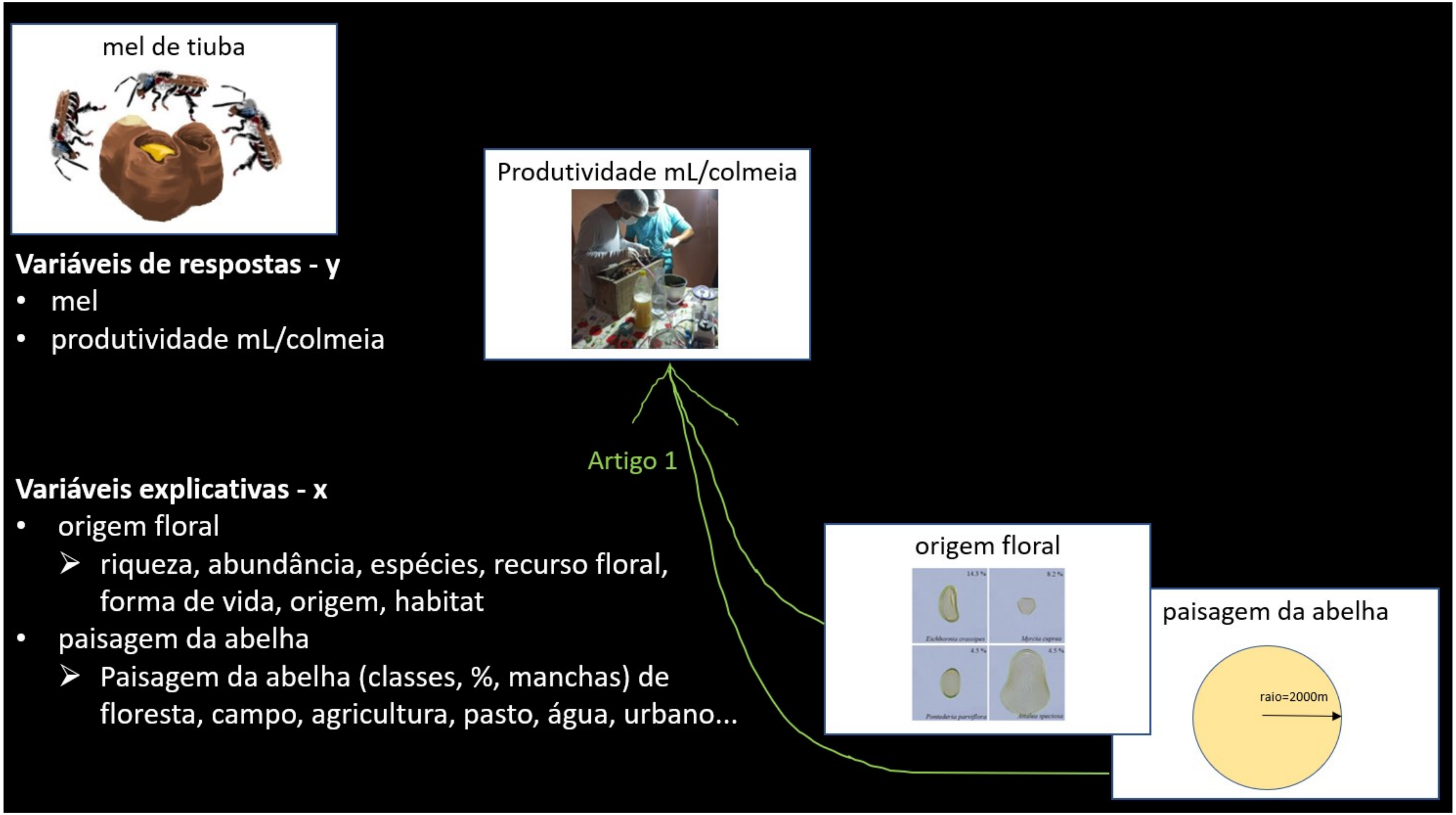


Figura 4. Esquema de análise das variáveis do artigo sobre características físico-química de mel de *Melipona fasciculata*. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018.

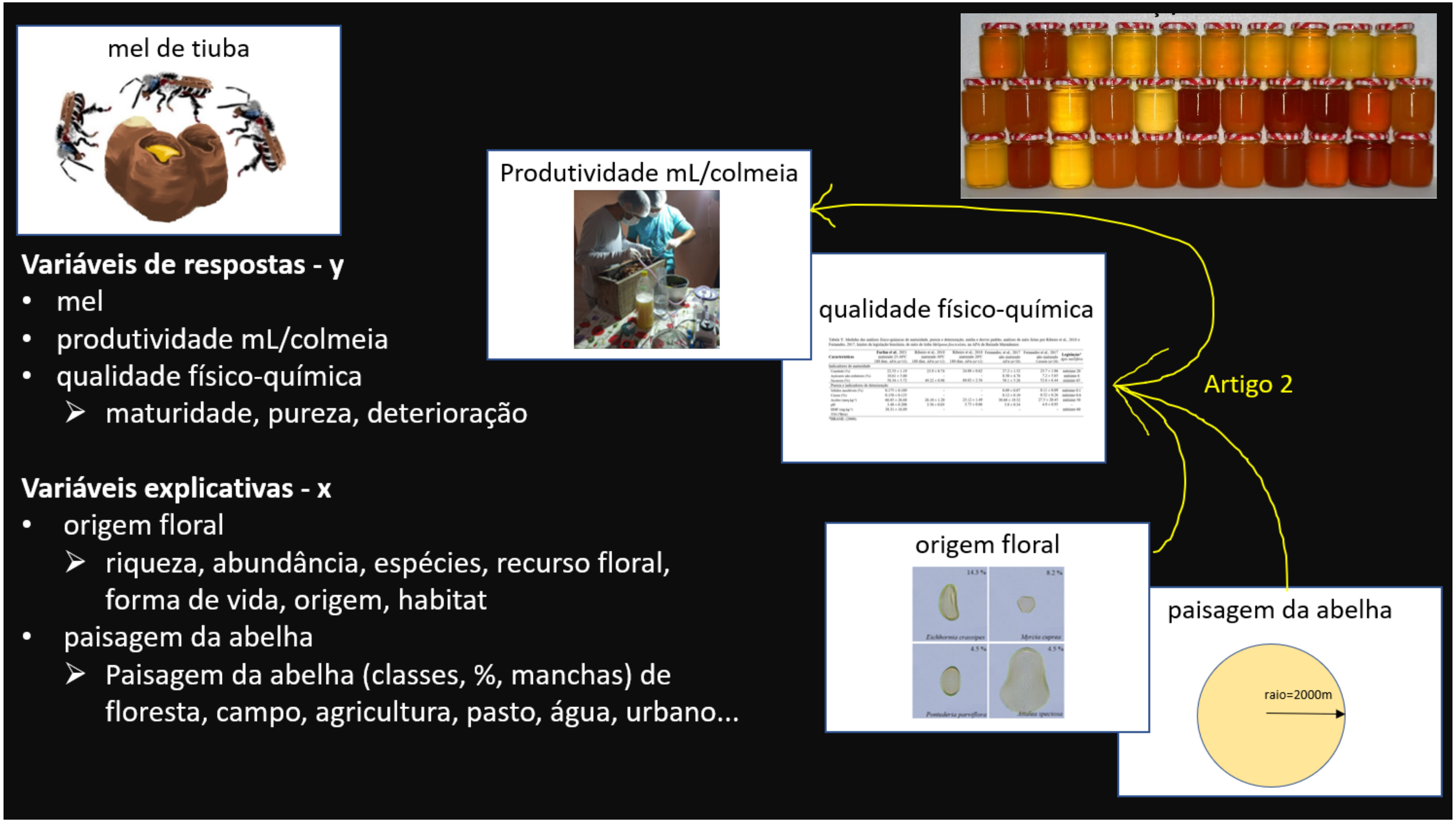


Figura 5. Diversos momentos da etapa de campo da pesquisa. APA da Baixada Maranhense, estado do Maranhão, Brasil, em 2018