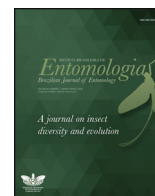




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Biology, Ecology and Diversity

## Seasonal population abundance of the assembly of solitary wasps and bees (Hymenoptera) according to land-use in Maranhão state, Brazil



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### ABSTRACT

Solitary wasps and bees (Hymenoptera) play a key role in ecosystem and agroecosystem functioning. Crops may benefit from biological pest control and pollination carried out by predatory solitary wasps and solitary bees, respectively. Here, we aimed at evaluating the abundance and faunistic compositions of solitary wasps and bees in respect to land-use (pasture, alley cropping, young fallow and old fallow) over an entire year using trap nests in the Brazilian northeastern state of Maranhão. Land-use did not influence the abundance of solitary wasps and bees, however, levels of dominance, abundance and frequency of the species *Pachodynerus guadulpensis* Saussure, *Isodontia* sp. 1, *Isodontia* sp. 2, *Trypoxylon nitidum* Smith and *Megachile* cfr. *franea* Schrottky varied with land-use. The abundance of wasps and bees varied over the period of the year with populations peaking in January (bees), and June and July (wasps). Relative humidity explained most of the variation for the abundance of wasps while temperature explained higher portions of the variance for the abundance of bees. There was an interaction between period of the year and land-use for the abundance of wasps (but not for bees). We concluded that total population abundance of solitary wasps and bees were not affected by the land-use however, levels of dominance, abundance and frequency of some species of these hymenopterans changed according to land-use. Also, relative humidity and temperature were important environmental variables explaining the abundances of wasps and bees.

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### Introduction

Solitary wasps and bees (Insecta: Hymenoptera) are important components in ecosystem and agroecosystem functioning (Tylianakis et al., 2005; Buschini and Woiski, 2008). Predatory solitary wasps play a key role in reducing crop pests such as Lepidoptera larvae (Tylianakis et al., 2005) or Orthoptera nymph (Soares et al., 2001). However, some species of solitary wasps also feed on beneficial arthropods like spiders (Santoni and Del Lama, 2007). Solitary bees are efficient pollinators of native and cultivated plants and their decline may have a negative impact on crop yields (Klein et al., 2003; Kremen et al., 2007; Ricketts et al., 2008; Giannini et al., 2015). These hymenopterans are also bioindicators since they are sensitive to environmental disturbance like changes in the microclimate and in food resources availability (Klein et al., 2002; Tylianakis et al., 2004, 2005, 2006; Buschini and Woiski, 2008).

Several factors may affect populations of solitary wasps and bees, such as prey abundance, floral resources diversity, and availability of places for nesting and microclimatic conditions (Klein et al., 2002; Tylianakis et al., 2006). Different types of land-use present distinct patterns of biotic and abiotic factors, which are essential for solitary wasps and bees and therefore may affect the distribution and density of these hymenopterans (Klein et al., 2002; Tylianakis et al., 2006; Batista Matos et al., 2013; Stangler et al., 2015). Thus, distinct land-use types spread throughout a region may complement each other, and contribute to the maintenance of populations of solitary wasps and bees and, consequently to maintain the ecological services provided by these insects (Tscharntke et al., 2005, 2007; Kremen, 2005). Temporal variation in abiotic factors such as air humidity and temperature as well as seasonal availability of resources may influence many arthropod populations including solitary wasps and bees (Guedes et al., 2000; Tylianakis et al., 2005; Teodoro et al., 2009; Stangler et al., 2015). Herein, we evaluated the effects of land-use on the abundance and faunistic compositions of wasps and bees that nest in pre-existing cavities in pasture, alley cropping, young fallow and old fallow, over

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a whole year. We used data from a previous study (Batista Matos et al., 2013), which elucidated the effects of land use on patterns of species richness and composition of these hymenopterans. The following questions were addressed: (1) Population abundance of solitary wasps and bees change according to land-use? (2) Temperature and air relative humidity variations affect the abundances of these insects? (3) The species dominance, abundance and frequency of the assemblies of these hymenopterans vary according to land-use?

## Material and methods

### Study area

The experiment was conducted in study sites located around the municipality of Miranda do Norte (3°36'S, 44°34'W, elevation 44 m), Maranhão state, in northeastern Brazil. The mean temperature in this region is 27 °C and the mean annual rainfall is 1.615 mm, with marked rainy (January–May) and dry (June–December) seasons. The natural vegetation was completely replaced by staple crops and pasture cultivated mainly by smallholders. Secondary vegetation fragments (fallows) of different sizes and successional stages are interspersed into a crop and pasture matrix (Batista Matos et al., 2013).

Four land-use types commonly found in the study region were selected: (1) pastures of non-managed signal grass (*Brachiaria brizantha* Hochst Stapf) with sparsely distributed babassu palms (*Attalea speciosa* Mart. ex. Spreng); (2) alley croppings of 8–9 years old and characterized by alleys of the leguminous tree species *Leucaena leucocephala* (Lam.) R. de Wit.) and *Clitoria fairchildiana* R. Howard between which crops like rice, maize, beans and cassava are grown during the rainy season; (3) young fallows with approximately 8 years old and mostly dominated by *Mimosa caesalpinifolia* Benth shrubs; and (4) old fallows with ca. 20 years and characterized by babassu and *tucum* palms (*Astrocaryum vulgare* Mart.) in addition to leguminous trees like *Dioclea latifolia* Benth and *Bauhinia* spp. Firewood and timber removal of valuable tree species are common in both young and old fallows. We selected four study sites (with at least 1 ha) for each land-use type, totaling 16 study sites. The minimal distance between study sites was around 400 m (Batista Matos et al., 2013).

### Trap nests and sampling

Trap nests are tubular spaces prepared for sampling solitary wasps and bees species which nest in pre-existing cavities (Tscharrntke et al., 1998; Tyljanakis et al., 2004; Buschini and Woiski, 2008; Sobek et al., 2009; Batista Matos et al., 2013). Each trap nest consisted of 15 internodes of dry bamboo, with inner diameters ranging from 2 to 20 mm and approximately 20 cm in length, wrapped with a wire. Four trap nests were installed in each study site in the corners of a square (5 m × 5 m) located at least 30 m away from the edge, totaling 64 trap nests (960 internodes) in all study sites. Each trap nest was tied to a wooden post with a wire (1.5 m from the ground). Sticky glue (Isca Cola, Ijuí, Brasil) was applied monthly around the wire to prevent ants and other crawling arthropods from entering the internodes. Samplings were monthly conducted during an entire year (December 2008–November 2009) by collecting nested internodes and replacing them for empty ones. The nested internodes were diagonally placed in carton boxes (20 cm × 5 cm) in the laboratory and observed daily until the emergence of adult insects. Afterwards, the hymenopterans were separated in morphospecies and sent for identification. Voucher specimens were deposited in the collection of the department of Zoology of the Universidade Federal Paraná, Curitiba, Paraná state, Brazil.

### Environmental variables

The abiotic environmental factors temperature and relative humidity were monthly recorded in each study site under standardized conditions (on sunny days between 8:00 and 14:00) throughout an entire year by placing a digital thermohygrometer (910.15chp, Alla Brazil) above ground in the middle of the quadrat for 5 min.

### Statistical analyses

Repeated Measures ANOVAs were used to determine the effect of land-use types on the abundance of solitary wasps and bees throughout the year using Statistica 8.0. One-way ANOVAs followed by post hoc Fisher LSD test ( $P < 0.05$ ) were carried out to investigate differences among land-use types within each month.

Faunistic analyses of the community of solitary wasps and bees were further carried out for each land-use type, using the software ANAFU developed by ESALQ/USP (Lofego and Moraes, 2006). These analyses consisted on the calculation of: [i] dominance, according to the method of Kato (Laroca and Mielke, 1975), where species presenting frequency higher than  $1/S$ , where  $S$  is the total number of species in the community, are considered dominant (D) while species presenting frequencies smaller than  $1/S$  are considered non-dominant (ND); [ii] abundance, considered as the total number of individuals from each species per sample unit and classified as rare (r) when the species abundance is below the confidential interval (CI) calculated for the mean at 1% probability, disperse (d) when the species abundance is between the inferior limits of the mean CI at 5% and 1% probability, common (c) when the species abundance is between the inferior and superior limits of the mean CI at 5% probability, abundant (a) when the species abundance is between the superior limits of the mean CI at 5% and 1% probability, very abundant (va) when the species abundance is higher than the superior limit of the mean CI at 1% probability, and [iii] frequency, considered as the percentage of individuals of one species in relation to the total number of specimens and classified, according to the CI of the mean at 5% as low frequent (LF) when the frequency is lower than the inferior limit of the mean CI, frequent (F) when the frequency is between the inferior and superior limits of the mean CI, very frequent (VF) when the frequency is higher than the superior limit of the mean CI. The software submits the outliers to a residue analysis and the additional classifications for dominance (super dominance [SD]), abundance (super abundance [sa]) and frequency (super frequency [SF]) may apply. For further explanations on the calculations of the parameters above see Silveira Neto et al. (1976) and Lofego and Moraes (2006).

Hierarchical partitioning analyses were utilized to evaluate the relative contribution of the abiotic environmental variables temperature and relative air humidity on the abundance of solitary wasps and bees using the software R (Mc Nally and Walsh, 2004) with “hier.part” and “gtools” packages (R 2.10.1, R Development Core Team, 2010). This analysis estimates the percentage of explained variance of each variable in joint and independent contributions with all other variables, considering all possible models in a multivariate regression (Mc Nally, 1996, 2000; Heikkinen et al., 2005). Data were  $\log(x + 1)$  transformed whenever necessary.

## Results

A total of 17 wasp species (Chrysididae, Crabronidae, Leucospidae, Mutillidae, Pompilidae, Sphecidae and Vespidae) and 8 bees species (Apidae and Megachilidae) (Table 1) were collected. Vespidae was the most abundant wasp family with 821 specimens (5 species), followed by Crabronidae with 529 specimens (3 species),

**Table 1**

Solitary wasp and bee species (Hymenoptera) collected in the four land-use types over a whole year.

Family	Species	Total
Vespidae	<i>Pachodynerus guadulpensis</i> Saussure	614
	<i>Pachodynerus nasidens</i> Latreille	120
	<i>Monobia angulosa</i> Saussure	77
	<i>Zethus toltecus</i> de Saussure	9
	<i>Minixi brasillianum</i> Saussure	1
Sphecidae	<i>Isodontia</i> sp. 1	145
	<i>Isodontia</i> sp. 2	80
	<i>Isodontia</i> sp. 5	13
	<i>Isodontia</i> sp. 4	11
	<i>Isodontia</i> sp. 3	1
Crabronidae	<i>Trypoxylon nitidum</i> Smith	336
	<i>Trypoxylon cincreum</i> Cameron	192
	<i>Liris</i> sp.	1
Chrysididae	<i>Chrysis</i> sp. (gr. <i>intricans</i> ) <sup>a</sup>	21
Mutillidae	Sphaerophthalminae (subfamily) <sup>a</sup>	1
Leucospidae	<i>Leucospis egaia</i> Walker <sup>a</sup>	1
Pompilidae	<i>Priochilus</i> sp.	1
Megachilidae	<i>Megachile</i> cfr. <i>framea</i> Schrottky	197
	<i>Hypanthidium maranhense</i> Urban	22
	<i>Megachile curvipes</i> Smith	10
	<i>Megachile brethesi</i> Schrottky	5
	<i>Megachile sejuncta</i> Cockerell	4
	<i>Coelioxys</i> sp. <sup>a</sup>	16
Apidae	<i>Euglossa</i> sp.	4
	<i>Xylocopa suspecta</i> Moure	2

<sup>a</sup> Parasitoid species of trap nesting wasps and bees (not included in the analyses).

Sphecidae with 250 specimens (5 species), and Pompilidae with 1 specimen (1 species). Megachilidae was the most abundant family of bees with 254 individuals (6 species) compared to Apidae with 6 individuals (2 species).

Wasps from the family Chrysididae (*Chrysis* sp. group. *intricans*; 21 specimens), Mutillidae (Sphaerophthalminae sp.; 1 specimen), Leucospidae (*Leucospis egaia* Walker; 1 specimen) and a single species from the family Megachilidae (*Coelioxys* sp.; 16 specimens) are parasitoid wasps and bees and, therefore were not included in the statistical analyses. The parasitoids represented only 2% of the total of individuals collected.

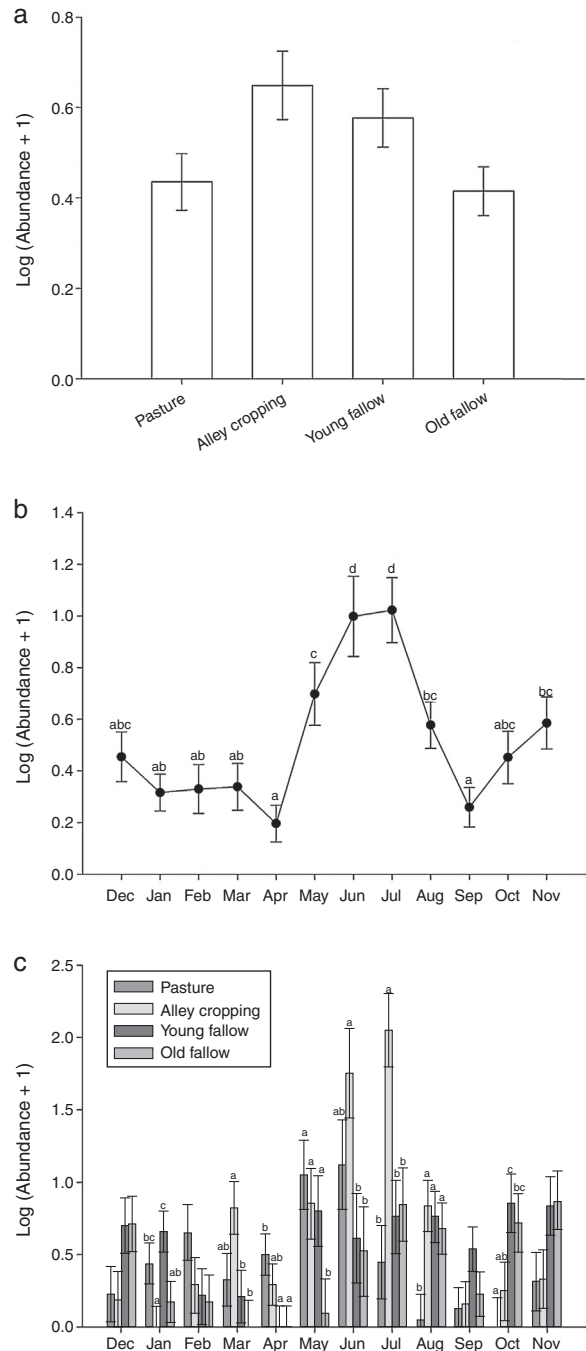
#### Effects of land-use and temporal variability on the abundance of hymenopterans

The abundance of solitary wasps was not affected by land-use type over the one-year study ( $F_{3,60} = 2.657$ ,  $P = 0.056$ ) (Fig. 1a). The month of the year influenced the abundance of wasps ( $F_{11,660} = 7.327$ ,  $P < 0.0001$ ) with a population peak in June and July (Fig. 1b). The interaction between the land-use type and month of the year for the abundance of wasps was significant in the months of January ( $F_{3,60} = 4.152$ ,  $P = 0.009$ ), March ( $F_{3,60} = 3.727$ ,  $P = 0.016$ ), April ( $F_{3,60} = 2.882$ ,  $P = 0.43$ ), May ( $F_{3,60} = 3.017$ ,  $P = 0.037$ ), June ( $F_{3,60} = 3.324$ ,  $P = 0.025$ ), July ( $F_{3,60} = 7.850$ ,  $P = 0.0002$ ), August ( $F_{3,60} = 4.053$ ,  $P = 0.011$ ), and October ( $F_{3,60} = 3.866$ ,  $P = 0.0135$ ) (Fig. 1c).

The abundance of solitary bees was not affected by land-use type over the one-year study ( $F_{3,60} = 1.108$ ,  $P = 0.353$ ) (Fig. 2a). The month of the year affected the abundance of bees ( $F_{11,660} = 2.863$ ,  $P = 0.001$ ) with a more pronounced population peak in January (Fig. 2b). There was no interaction between land-use type and month of the year ( $F_{33,660} = 1.340$ ,  $P = 0.099$ ) to the abundance of solitary bees (Fig. 2c).

#### Faunistic composition of wasps and bees

The levels of dominance, abundance and frequency for most species of solitary wasps and bees were not affected by the land-use type (Table 2). Nevertheless, levels of dominance, abundance

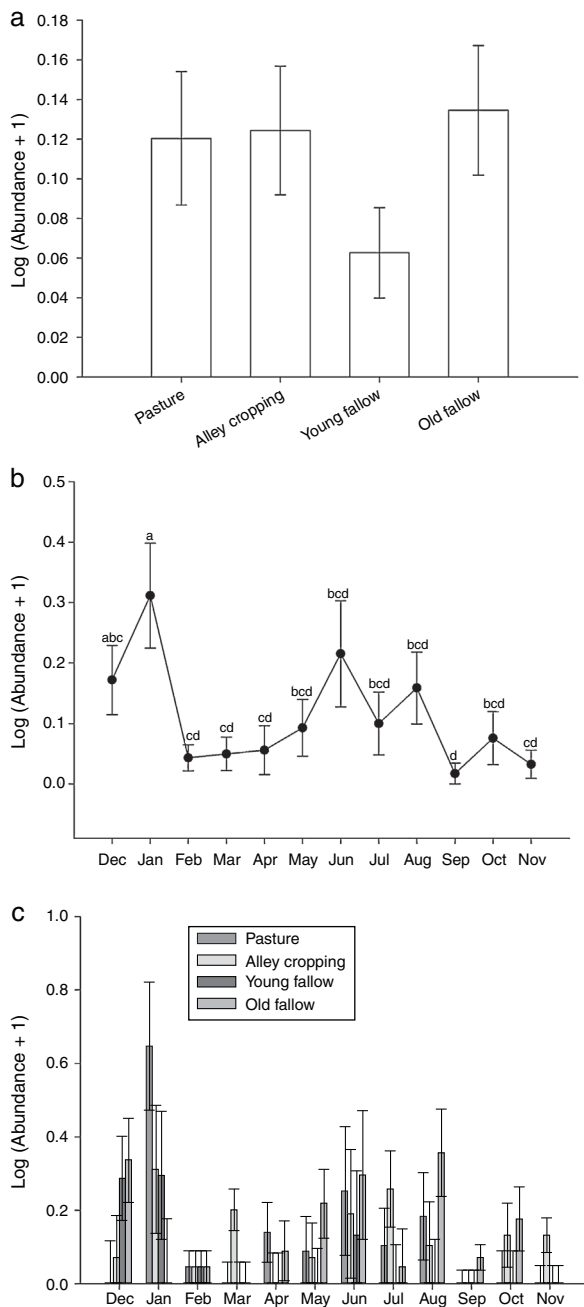


**Fig. 1.** Abundance of solitary wasps according to land-use (a), month (b) and interaction between land-use and month (c). Repeated measures ANOVA followed by post hoc Fisher LSD tests ( $P < 0.05$ ). Means  $\pm$  SE are given.

and frequency changed with land-use for the wasp species *Pachodynerus guadulpensis* of Saussure, *Isodontia* sp. 1, *Isodontia* sp. 2, *Trypoxylon nitidum* Smith, and the bee species *Megachile* cfr. *framea* Schrottky.

#### Abiotic environmental variables effects on the abundance of wasps and bees

Most of the variance for the abundance of wasps (61.16%) and bees (64.66%) was explained by the independent effects of the variables. Relative humidity had a greater independent contribution (41.67%) in comparison to temperature (19.48%) for the abundance



**Fig. 2.** Abundance of solitary bees according to land-use (a), month (b) and interactions between land-use and month (c). Repeated measures ANOVA followed by post hoc Fisher LSD tests ( $P < 0.05$ ). Means  $\pm$  SE are given.

of solitary wasps. Conversely, temperature (49.07%) had a higher independent contribution than relative humidity (15.59%) for the abundance of bees.

## Discussion

Population abundances of the assembly of solitary wasps and bees were not affected by the land-use. However, levels of dominance, abundance and frequency of *P. guadulpensis*, *Isodontia* sp. 1, *Isodontia* sp. 2, *T. nitidum* (wasps) and *M. cfr. framea* (bee) changed over land-use type. The wasp species *Pachodynerus guadulpensis* changed from common and frequent in pasture to super dominant, super abundant and super frequent in alley cropping and dominant, very abundant and very frequent in young and old fallow. The wasp

*Isodontia* sp. 1 was common and frequent in pasture, alley cropping and young fallow but very abundant and very frequent in old fallow. *Isodontia* sp. 2 which was only disperse and low frequent in pasture changed to common and frequent in alley cropping and young fallow and very abundant and very frequent in old fallow. Another wasp, *Trypoxylon nitidum*, changed from very abundant and very frequent in pasture and alley cropping to common and frequent in young and old fallows. The bee *Megachile cfr. framea* changed from common and frequent in pasture, alley cropping and young fallow to very abundant and very frequent in old fallow. Therefore, the population levels of these hymenopterans were affected by different habitats in the study region. Several habitats may offer greater amount of niches and possibilities of resource exploitation (Silva et al., 2008). For instance, fallows may provide resources that are scarce in cultivated areas such as permanent vegetation coverage, shelter and nesting places and alternative sources of pollen and nectar to species that interact with the crops (Tschardt et al., 2007; Sobek et al., 2009). Crop settings, on the other hand, usually have a high abundance of preys and floral resources in certain times of the year which may favor arthropod populations (Tschardt et al., 2005, 2007). Thus, different types of land-use in a region may complement each other, contributing to the maintenance of insects such as solitary wasps and bees and, consequently, potentially maintaining the environmental services provided by them (Tschardt et al., 2005, 2007; Kremen, 2005).

The wasp species *P. guadulpensis*, *Isodontia* sp.1 and *Isodontia* sp. 2 provide their nests with Lepidoptera larvae and Orthoptera nymphs (Buschini and Buss, 2010; Soares et al., 2001) and may, therefore help in the biological control of crop pests. *Trypoxylon nitidum*, however, provide its nest with spiders (Santoni and Del Lama, 2007), and high populations of this wasp may hamper natural pest control played by arachnids. The bee species *M. cfr. framea* may be a crop pollinator because the species from the genera *Megachile* found in Brazil have been highlighted for their potential to increase seed production in Leguminosae, and in several ornamental, medicinal and edible plants (Garófalo et al., 2004). Bees of the family Apidae such as *Euglossa* and *Xylocopa* have also been reported as crop pollinators in Brazil (Giannini et al., 2015).

The population densities of solitary wasps and bees varied throughout the months of the year with populations peaking in June and July during the dry season (wasps) and in January during the rainy season (bees). However, we acknowledge that the time scale of this study is short (one-year). Seasonal changes in temperature and relative humidity are known to affect the population density of several species of arthropods (Philpott et al., 2006; Teodoro et al., 2009), including solitary wasps and bees (Tylanakis et al., 2005). In the region where the study was carried out, the mean temperature is higher and the relative air humidity is lower in the dry season (June to December) comparing with the rainy season (January to May). However, the importance of these environmental variables in explaining the abundance of solitary wasps and bees seems to be taxon-specific. Relative humidity was more important than temperature for the abundance of wasps while the opposite was observed for bees.

Overall, the abundance of wasps was higher in alley croppings during March, June and July. The seasonal variation in the availability of resources, as well as the temperature and humidity, in different habitats may also influence insect populations, especially when important resources become available in different periods of the year (Wolda, 1988; Tylanakis et al., 2005). For instance, Klein et al. (2002) studied the response of solitary wasps and bees communities to land-use in Indonesia and found that the abundance of solitary eumenine wasps was higher in more anthropized land-use types such as intensive managed agroforests. Such results may be explained by high amounts of prey found in those agroforests, which seemed to affect more the abundance of solitary

**Table 2**  
Faunistic analyses of solitary wasps and bees according to land-use over an entire year.

	Vespidae					Sphecidae					
	<i>P. guadulpensis</i>	<i>P. nasidens</i>	<i>M. angulosa</i>	<i>Z. toltecus</i>	<i>M. brasillianum</i>	<i>Isodontia</i> sp. 1	<i>Isodontia</i> sp. 2	<i>Isodontia</i> sp. 5	<i>Isodontia</i> sp. 4	<i>Isodontia</i> sp. 3	
<i>Pasture</i>											
# of individuals	73	13	50	–	–	30	11	–	–	–	
Dominance <sup>a</sup>	D	D	D	–	–	D	D	–	–	–	
Abundance <sup>b</sup>	c	c	c	–	–	c	d	–	–	–	
Frequency <sup>c</sup>	F	F	F	–	–	F	LF	–	–	–	
<i>Alley cropping</i>											
# of individuals	361	74	–	–	–	23	19	9	–	–	
Dominance	SD	D	–	–	–	D	D	D	–	–	
Abundance	sa	c	–	–	–	c	c	d	–	–	
Frequency	SF	F	–	–	–	F	F	LF	–	–	
<i>Young fallow</i>											
# of individuals	137	33	19	–	–	54	20	–	11	–	
Dominance	D	D	D	–	–	D	D	–	D	–	
Abundance	va	C	c	–	–	c	c	–	d	–	
Frequency	VF	F	F	–	–	F	F	–	LF	–	
<i>Old fallow</i>											
# of individuals	43	–	8	9	1	38	30	4	–	1	
Dominance	D	–	D	D	ND	D	D	ND	–	ND	
Abundance	va	–	c	c	r	va	va	d	–	r	
Frequency	VF	–	F	F	LF	VF	VF	LF	–	LF	
	Crabronidae		Pompilidae		Megachilidae				Apidae		
	<i>T. nitidum</i>	<i>T. cinereum</i>	<i>Liris</i> sp.	<i>Priochilus</i> sp.	<i>M. cfr. framea</i>	<i>H. maranhense</i>	<i>M. curvipes</i>	<i>M. brethesi</i>	<i>M. sejuncta</i>	<i>Euglossa</i> sp.	<i>X. suspecta</i>
<i>Pasture</i>											
# of individuals	162	–	–	–	65	–	3	4	–	–	–
Dominance <sup>a</sup>	D	–	–	–	D	–	ND	ND	–	–	–
Abundance <sup>b</sup>	va	–	–	–	c	–	d	d	–	–	–
Frequency <sup>c</sup>	VF	–	–	–	F	–	LF	LF	–	–	–
<i>Alley cropping</i>											
# of individuals	133	13	–	–	70	–	–	–	–	1	–
Dominance	D	D	–	–	D	–	–	–	–	ND	–
Abundance	va	c	–	–	c	–	–	–	–	r	–
Frequency	VF	F	–	–	F	–	–	–	–	LF	–
<i>Young fallow</i>											
# of individuals	31	87	–	–	23	9	–	–	–	–	–
Dominance	D	D	–	–	D	D	–	–	–	–	–
Abundance	c	va	–	–	c	r	–	–	–	–	–
Frequency	F	VF	–	–	F	LF	–	–	–	–	–
<i>Old fallow</i>											
# of individuals	10	92	1	1	39	13	7	1	4	3	2
Dominance	D	D	ND	ND	D	D	D	ND	ND	ND	ND
Abundance	c	va	r	r	va	c	c	r	d	d	r
Frequency	F	VF	LF	LF	VF	F	F	LF	LF	LF	LF

<sup>a</sup> Dominance: SD, super dominant; D, dominant; ND, not dominant.

<sup>b</sup> Abundance: sa, super abundant; va, very abundant; a, abundant; c, common; d, disperse; r, rare.

<sup>c</sup> Frequency: SF, super frequent; VF, very frequent; F, frequent; LF, low frequent.

eumenine wasps than amenable microclimatic conditions of temperature and humidity found in less intensive land-uses. Batista Matos et al. (2013) found that patterns of species richness and composition of solitary wasps and bees were contingent on land-use emphasizing the importance of secondary forest fragments such as fallows along with agriculture habitats for the conservation of solitary wasps and bees. Here, we complement the study by Batista Matos et al. (2013) by demonstrating that although land-use did not influence total population abundance of solitary wasps and bees, levels of abundance, dominance and frequency of some species of these hymenopterans vary with land-use.

### Conflicts of interest

The authors declare no conflicts of interest.

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