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Space-time variation in the composition, richness and abundance of social wasps (Hymenoptera: Vespidae: Polistinae) in a forest-agriculture mosaic in Rio Grande do Sul, Brazil

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ABSTRACT. Wasps, important agents for the control of insect population, have been scantily studied in the Brazilian State of Rio Grande do Sul. Current study investigates monthly variations of social wasps in microhabitats within a forest-agriculture mosaic. Samples were collected between February 2013 and February 2014, through active search and baited traps made from 2 L transparent PET bottles, in five microhabitats, namely, forest, monoculture, polyculture and the edges between the forest fragment and monoculture and polyculture, in the municipality of Doutor Maurício Cardoso. Statistical tests, similarity indices, dominance and constancy as well as PCoA were used for data analysis to group the collection. A total of 953 specimens were collected, distributed across 15 species and seven genera. Abundance differed between microhabitats and the monoculture cultivation was least similar to the other microhabitats. PCoA identified three different groups. Abundance was positively correlated with temperature, negatively correlated with air humidity and was not correlated with wind velocity. Social wasps are able to utilize resources outside the forest fragments, but monocultures may create barriers for their dispersal.

Keywords: forest fragment, landscape, northwest, pesticides, polyculture, seasons.

Variação espaço-temporal da composição, riqueza e abundância de vespas sociais (Hymenoptera: Vespidae: Polistinae) em mosaico de floresta-agricultura no Rio Grande do Sul, Brasil

RESUMO. Vespas são importantes agentes controladores populacionais de outros insetos e são pouco estudadas no Estado do Rio Grande do Sul. Este estudo investigou a variação mensal de vespas sociais em micro-habitats em mosaico floresta-agricultura. As coletas foram realizadas entre fevereiro de 2013 e 2014, por meio de busca ativa e armadilhas atrativas do tipo PET, em cinco micro-habitats no município de Doutor Maurício Cardoso: floresta, monocultura, policultura e suas bordas com o fragmento. Para análise dos dados foram usados testes estatísticos e índices de similaridade, dominância e constância, assim como PCoA para agrupar os meses de coleta. Ao todo, 953 indivíduos foram coletados, distribuídos em 15 espécies e sete gêneros. A abundância diferiu entre micro-habitats, e a monocultura foi menos similar aos demais. A PCoA identificou três grupos diferentes. Abundância foi positivamente correlacionada com a temperatura, negativamente correlacionada com a umidade do ar e não se correlacionou com a velocidade do vento. Vespas sociais são capazes de utilizar recursos fora dos fragmentos florestais, porém monoculturas podem criar barreiras à sua dispersão.

Palavras-chave: fragmento florestal, estações, noroeste, pesticida, policultura, paisagem.

Introduction

Wasps are predatory or parasitoid hymenopterans, natural agents for the control of other arthropod populations (PREZOTO et al., 2006) and pollination agents (CLEMENTE et al., 2012; SOMAVILLA; KÖHLER, 2012). The only Vespidae occurring in Brazil that include social wasps are the Polistinae subfamily, represented by species of the Mischocyttarini and Polistini tribes (independent foundation), and by species of the Epiponini tribe (swarming foundation) (CARPENTER; MARQUES, 2001; HERMES; KÖHLER, 2006). Several studies reported that species of the Mischocyttarini and Polistini tribes are less likely to be successful at founding new nests and, with the exception of a small number of species, achieve little dominance in the environments they inhabit (GOMES; NOLL, 2009; TORRES et al., 2009; OLIVEIRA et al., 2010).

Brazil has the greatest diversity of Polistinae on the planet, with 304 species recorded (CARPENTER; MARQUES, 2001). However, knowledge on Vespidae fauna in Brazil, and particularly in the State of Rio Grande do Sul, is still inadequate. An indication of the paucity of research may be found in Locher et al., (2014) who cite 41 studies surveying the diversity of social wasps in Brazil, only one of which was conducted in Rio Grande do Sul State (HERMES; KÖHLER, 2006).

Agricultural activities cause great biodiversity loss in all groups of the biota, primarily through the suppression and fragmentation of habitats (LEWINSOHN et al., 2005). Further, most remnant biodiversity is concentrated in small forest fragments which, in turn, have been the subject of few studies or conservation initiatives (VIANA; PINHEIRO, 1998). This situation is typical of the remaining natural areas in the State of Rio Grande do Sul and is the result of urbanization and land usage patterns (TRENNEPOHL; MACAGNAN, 2008). Therefore, studies on social wasps in agricultural areas adjacent to forest fragments are relevant to determine the direct or indirect influence of this type of human activity on the taxonomic group and to assess the importance of forest fragments for the conservation and management of biodiversity (AUAD et al., 2010; TANAKA JR.; NOLL, 2011).

Current analysis identifies species of social wasps occurring naturally in agricultural ecosystems in the State of Rio Grande do Sul and investigates patterns of spatial and monthly distribution of social wasps in a range of microhabitats within an agricultural matrix adjacent to a natural forest fragment.

Material and methods

The municipality of Doutor Maurício Cardoso lies in the northwestern region of Rio Grande do Sul State (27°30'32.41"S; 54°21'46.74"W) and is part of the Atlantic Rain Forest Biome. The latter is a phytoecological region classified as a Seasonal Deciduous Forest and highly fragmented to the extent that only 17.97% remains of the original forest cover (CORDEIRO; HASENACK, 2009). The municipality is within the hydrographic basin of the Buricá River, or rather, an area that underwent an intense process of deforestation for crop planting and other related urban and rural installations (TRENNEPOHL; MACAGNAN, 2008). According to Köppen-Geiger, the region climate is Cfa (warm temperate, fully humid, with hot summers).

There are two distinct forms of crop management within the ecosystems selected for current study and also a forest fragment adjacent to them (27°29'3.67"S; 54°20'17.49"W). In the farmed areas, the first type of crop management is conventional, featuring one crop grown at a time, either soy or maize (monoculture), with agrochemicals, while the second type is an alternative form of management, in which several different crops, such as pumpkin, cassava, capsicums, beans, water melons and others are grown concurrently (or polyculture), without any direct application of agrochemicals.

Two different methods were employed in current investigation. Active collection using an insect net limited by time, with sampling duration proportional to the area of each micro-habitat, as follows: Forest (Fo) – three hours and 30 minutes; Monoculture (Mo) – one hour and 40 minutes; Polyculture (Po) – 50 minutes; and the edges between Fo and Mo (EMo) 40 minutes; and between Fo and Po (EPo) – 30 minutes. Collections were conducted between 9h00 am and 4h00 pm, which is the period during which the insects are most active (ELISEI et al., 2008; GOMES; NOLL, 2009), on 2 consecutive days, monthly, from February 2013 to February 2014.

Additionally, baited traps made from 2 L transparent PET bottles were used (SOUZA; PREZOTO, 2006). Each trap had three circular openings, approximately 2 cm in diameter, close to the bottom (10 cm from the base) and contained one of two different substances: (1) 150 mL of natural mango juice (1 kg of fruit liquidized with 250 g of refined sugar and 2 L of water) (adapted from SOUZA; PREZOTO, 2006); or (2) 50 g of raw beef. At each sampling point two traps, each containing a different type of bait, were exposed from 9h00 am to 4h00 pm on the following day, distributed across the microhabitat: one in the polyculture area, two in monoculture edge, two in monoculture, and five in the forest area. No traps were set on the polyculture edge zone due to the fact that its small area would have meant it was not independent from the polyculture traps. Each set of traps was at least 100 m apart from the nearest one and all traps were set at a height of 1.5 m from the ground.

The specimens collected during sampling were stored in pots containing 70% alcohol and identified with dichotomous keys proposed by Carpenter and Marques (2001) and Hermes and Köhler (2004a).

They were also compared with specimens kept at the Santa Cruz do Sul Entomological Collection (CESC). All individuals were deposited and dry-mounted in the CESC (SISBIO authorization: 38735-1).

Data on climate variables, such as temperature, air humidity and wind speed, were retrieved from data of the Brazilian meteorological service, the Instituto Nacional de Meteorologia (INMET), collected by an automatic station in the municipality of Santa Rosa, Rio Grande do Sul, Brazil. Data were analyzed monthly as independent variables determinant of diversity patterns.

Each species' dominance was calculated and expressed as a percentage using the following formula: D= (i/t).100, where i = total number of specimens of a given species and t =total number of specimens of all species collected. These percentages were then categorized as follows: eudominant > 10%; dominant = 5-10%; subdominant = 2-5%; recessive = 1- 2%; rare < 1% (FRIEBE apud LOPES et al., 2007). The constancy of each species was calculated by the following formula: C= p x (100/N), where C= constancy and p= the number of samples in which a given species was recorded; they were categorized as follows: constant > 50%; ancillary = 25 - 50%; accidental < 25% (SOUZA et al., 2014). The Shannon diversity index (H'), the Berger-Parquer dominance index (*d*) and Pielou's evenness index (J') were all calculated (MAGURRAN, 2004). Additionally, the Jaccard and Bray-Curtis similarity indices were used to evaluate the similarity of wasp fauna in the microhabitats investigated (MAGURRAN, 2004). These calculations were all performed with Past v. 3 program (HAMMER et al., 2014). BioEstat 5.3 (AYRES et al., 2007) was used to conduct Kruskal-Wallis non-parametric analysis of variance (H) and Dunn's post-hoc test, to compare and differentiate microhabitats that differed significantly in terms of abundance and were conducted for the results of active sampling only. Jackknife1 and Bootstrap non-parametric estimates of richness (MAGURRAN, 2004) and collection curve were calculated by EstimateS v 9.1 (COLWELL, 2013).

Temporal variations in wasp composition and abundance of species were investigated by the Principal Coordinates Analysis (PCoA), as proposed by Legendre and Legendre (1998). The analysis was conducted using the composition and abundance of wasp species recorded each month, and the degree of significance of the groups formed was tested using the permutation test available in the Multiv program (PILLAR, 1997). Pearson's coefficient was employed to determine correlation between climatic variables and abundance of wasps collected. Moreover, multivariate regression tested the degree of dependence of the abundance of the wasps collected with relation to climatic variables. Data were standardized by logarithmic transformation with BioEstat 5.3, prior to calculating Pearson's coefficients and conducting the multivariate regression analysis (AYRES et al., 2007).

Results

The total number of specimens collected was 953, distributed in seven genera and 15 species. Only three species were classified as eudominant; two were dominant; two were subdominant; four were classified as recessive and four as rare. In terms of frequency, six species were considered constant, four were classified as ancillary and all the other species were accidental (Table 1).

The Epiponini tribe with 572 specimens (60.25%) was the tribe with the greatest number of specimens collected, followed by the Polistini with 370 (38.8%) and the Mischocyttarini with 11 individuals (0.95%). *Agelaia* Lepeletier alone accounted for 67% of the Epiponini and for 40.37% of the total number of specimens collected.

Table 1. Classification of social wasp species with regard to their status of dominance and frequency collected in a deciduous seasonal forest fragment between February 2013 and February 2014, in Doutor Mauricio Cardoso, Rio Grande do Sul, Brazil. N: Abundance.

Species	Acronym	N	Dominance	Constancy
Agelaia multipicta (Haliday, 1836)	AGMU	360	Eudominant	Constant
Polistes versicolor (Olivier, 1792)	POVE	212	Eudominant	Constant
Polistes actaeon Haliday, 1836	POAC	135	Eudominant	Constant
Polybia sp. 1	POSP	56	Dominant	Constant
Polybia ignobilis (Haliday, 1836)	POIG	49	Dominant	Constant
Polybia fastidiosuscula Saussure, 1854	POFA	45	Subdominant	Constant
Agelaia pallipes (Olivier, 1792)	AGPA	24	Subdominant	Ancillary
Polistes simillimus Zikàn, 1951	POSI	14	Recessive	Ancillary
Brachygastra lecheguana (Latreille, 1804)	BRLE	13	Recessive	Ancillary
Polybia scutellaris (White, 1841)	POSC	13	Recessive	Ancillary
Synoeca cyanea (Fabricius, 1775)	SYCY	11	Recessive	Ancillary
Mischocyttarus rotundicollis (Cameron, 1912)	MIRO	9	Rare	Ancillary
Polistes cinerascens Saussure, 1857	POCI	9	Rare	Ancillary
Mischocyttarus cassununga (von Ihering, 1903)	MYCA	2	Rare	Accidental
Protonectarina sylveirae (Saussure, 1854)	PRSY	1	Rare	Accidental

The species accumulation curve was stabilized from the eighth sample session onwards, following the Coleman rarefaction curve. All methods estimated 16 species of social wasps, which is very close to the actual number observed (Figure 1). Diversity may be considered intermediary (H' = 1.87), as well as dominance (*d* = 0.38) and high equitability (J' = 0.69).

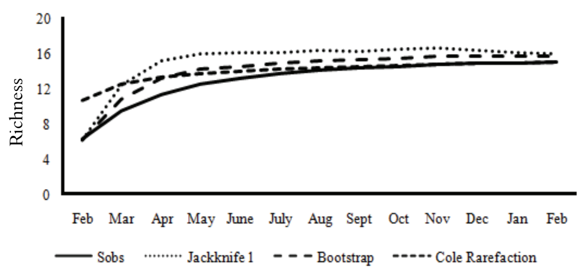

Figure 1. Accumulation curve and species richness estimates of social wasps collected in a fragment of Deciduous Forest in Doutor Mauricio Cardoso, Rio Grande do Sul State, Brazil, between February 2013 and February 2014. Sobs: species observed.

Regarding to the different microhabitats, the monoculture edge exhibited greatest richness (14 species) and abundance, followed by polyculture edge and polyculture with 13 species each, forest with nine, and monoculture with four species (Table 2). Two species were exclusive to one microhabitat: *Mischocyttarus cassununga* (von Ihering, 1903) was represented by two specimens, both collected in the monoculture edge, and one specimen of *Protonectarina sylveirae* (Saussure, 1854) collected in the polyculture area.

Agelaia multipicta (Haliday, 1836) was the most abundant species in monoculture edge, but poorly represented in the other types of cultivation. When only the results of active sampling are taken into account, monoculture was significantly different from the other microhabitats in terms of abundance (H= 26.80; p < 0.001). Both the Jaccard and the Bray-Curtis indices grouped polyculture edge, monoculture edge, polyculture and forest together, isolating them from monoculture (Figure 2).

With regard to temporal variation, December/13, January/14 and February/14 exhibited the greatest abundance, with more than half of all specimens collected, followed by September/13 October/13 November/13, March/13 April/13 May/13 and August/13 (Figure 3). Month by month variation could also be observed to the extent that no specimens were collected during the coldest months - June and July. Although low temperatures were recorded during August, social wasp activity was extant during the month.

PCoA organized the sample points into three groups by wasp activity (Figure 4). The first group illustrates a variation that follows the monthly sequence as temperature falls with the arrival of the coldest months (March, April, May, June and July, 2013: group 1). In contrast, the second group contains a set of months with different climate conditions and the most heterogeneous of the three (February, August, September, October and November, 2013: group 2). The third group comprises the hottest months of the year (December, 2013, January and February, 2014: group 3) and its main descriptors are species of independent foundation (*Polistes* and *Mischocyttarus*). The three groups diverge significantly from each other, according to the permutation test (Q = 16128, p < 0.01).

Table 2. Abundance of social wasps collected with different methodologies in different microhabitats of a Deciduous Forest fragment in Doutor Mauricio Cardoso, between February 2013 and February 2014. EPo: Polyculture edge; EMo: monoculture edge; Po: Polyculture; Mo: Monoculture; Fo: Forest.

Species	Active collection						Baited traps				
	EMo	EPo	Fo	Po	Mo	Total	EMo	Fo	Po	Mo	Total
Agelaia multipicta	68	45	74	13		200	82	71	2	5	160
Agelaia pallipes	1	5		4		10	6	1	6	1	14
Brachygastra lecheguana	1	1		11		13					
Mischocyttarus cassunnunga	1					1	1				1
Mischocyttarus rotundicolis	2	2	3	2		9					
Polistes actaeon	62	45	22	6		135					
Polistes simillimus	4	3		7		14					
Polistes cinerascens	3	4		2		9					
Polistes versicolor	58	58	36	49		201	8			3	11
Polybia fastidiosuscula	24	9	10			43	1	1			2
Polybia ignobilis	9	4	2	25	1	41	6			2	8
Polybia scutellaris	1	3	1	8		13					
Polybia sp. 1	3	27	12	11		53		1	2		3
Protonectarina sylveirae				1		1					
Synoeca cyaneae	2	2		7		11					
Total	239	208	160	146	1	754	104	74	10	11	199

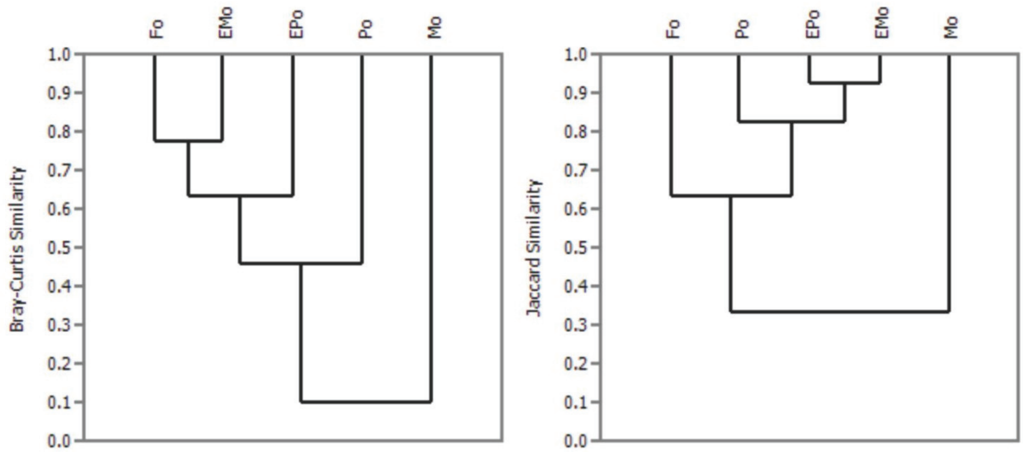

Figure 2. Bray-Curtis and Jaccard similarity indices for social wasps collected in different microhabitats of a fragment Deciduous Forest in Doutor. Mauricio Cardoso, between February 2013 and February 2014. EPo: Polyculture edge; EMo: monoculture edge; Po: Polyculture; Mo: Monoculture; Fo: Forest.

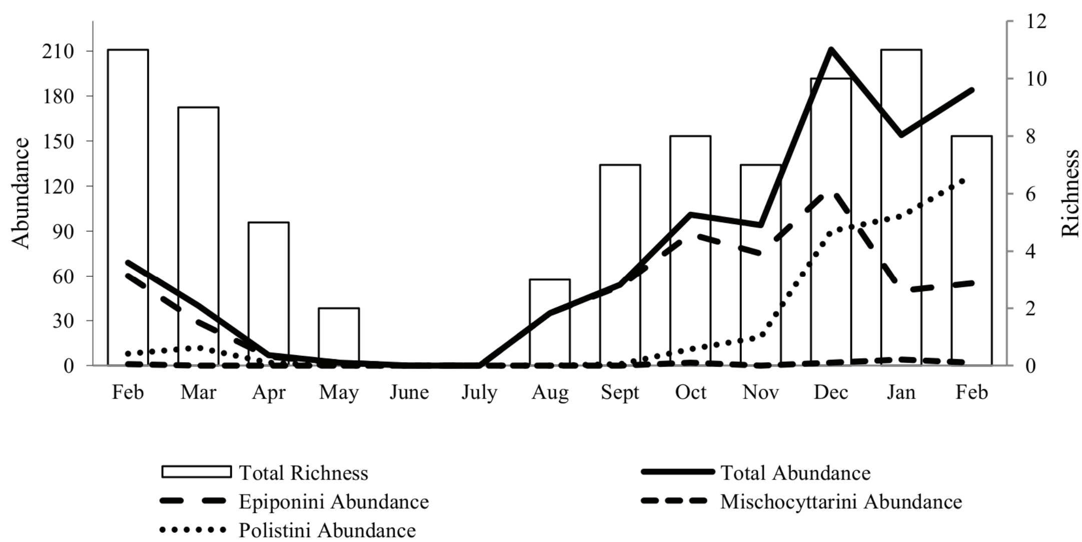

Figure 3. Variation in abundance (total and each tribe) and total richness of social wasps collected in a Deciduous Forest fragment in Doutor Mauricio Cardoso, Rio Grande do Sul State, Brazil, between February 2013 and February 2014.

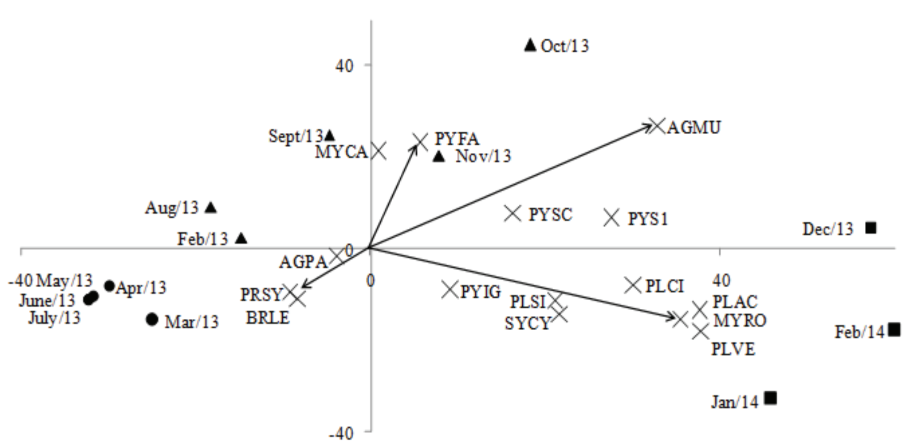

Figure 4. Ordination of sample points by Principal Coordinates Analysis (PCoA), according to the abundance of social wasps collected in a Deciduous Forest fragment in Doutor Mauricio Cardoso, Rio Grande do Sul State, Brazil, between February 2013 and February 2014. ×: wasps species (acronyms in Table 1); ●: group 1; ▲: group 2; ■: group 3.

A positive and significant correlation was detected between abundance of wasps and temperature (r: 0.90; $p < 0.01$). Contrastingly, air humidity was negatively correlated with abundance (r: -0.67; p: 0.01), whereas there was no correlation between abundance and wind velocity (r: 0.33; p: 0.26). There was a relationship between the climatic factors analyzed and the abundance of wasps throughout the year, according to the multivariate regression analysis (F: 8.64; DF 12; $p < 0.01$). The factor with the greatest influence on this variation was temperature (t: 3.47; $p < 0.01$), which accounted for 65% of variation in wasp abundance (R2: 0.65; $p < 0.01$).

Discussion

The diversity observed in the area is similar to that reported in forest fragments in other states (GOMES; NOLL, 2009; SANTOS et al., 2009; TANAKA JR.; NOLL, 2011; SIMÕES et al., 2012). However, as longitude from the equator reduces, the number of species tends to increase (ELPINO-CAMPOS et al., 2007; SANTOS et al., 2009; TANAKA JR.; NOLL, 2011), even in agrosystems (SANTOS et al., 2007, GOMES; NOLL, 2009), which explains the lower diversity observed in current study. The H' index in current study is intermediary due to few species considered eudominant. The index is higher than indices calculated for the three fragments studied by Gomes and Noll (2009) in São Paulo, Brazil, and for two out of four fragments investigated by Tanaka Jr. and Noll (2011), also in São Paulo, Brazil. On the other hand, Santos et al. (2009) only observed lower indices in agricultural systems in the State of Bahia, Brazil, whereas in Campo Sujo and Cerrado Arbóreo indices were higher, suggesting that the type of land management directly influenced overall diversity.

Although swarm founding is not exclusivity of the *Agelaia*, the abundance of the genus registered in current and in other studies indicates that species of this genus find it easy to colonize several different types of microhabitat due to their protected nests, method of foundation and great number of individuals, which gives their colonies greater chances of success (HERMES; KÖHLER, 2004b). Notwithstanding, their abundance is lower in uniform environments as observed in the monoculture zone, and suggests that these species encounter barriers to use resources outside the better-conserved environments. This pattern is the same for *P. fastidiosuscula*, collected only on the edges and forest. With the exception of a small number of studies, *Agelaia* species tend to account for approximately one third or more of the total number of specimens collected (GOMES; NOLL, 2009; AUAD et al., 2010; TANAKA JR.; NOLL, 2011; LOCHER et al., 2014).

The low richness concentration observed in the monoculture evidences the barriers that wasps encounter to use resources from this type of microhabitat, or the lack of appropriate nesting sites. Specimens were only collected in the monoculture when the crop in question (soybean) was flowering. It is worth emphasizing that the presence of just a single vegetable species coupled to the use of insecticides may form barriers to colonization or to the utilization of resources from these microhabitats (TANAKA JR.; NOLL, 2011). Contrastingly, in more complex cultivation, such as silviculture, agroforestry and silvopasture systems, with greater degrees of vertical stratification and lower rates of suppression of vegetation, the greater is the number of species recorded (AUAD et al., 2010; TANAKA JR.; NOLL, 2011). Consequently, the great richness and abundance along the monoculture edge probably occurred as a result of the suppression of vegetation which occurred only twice along the study, with regrowth of vegetation and increase in plant diversity. However, several suppressions were registered on the polyculture edge, forcing the wasp species to take refuge along the edge between the monoculture and the forest fragment. In this case, the edge appears to be an important refuge in the event of local disturbances (LIMA et al., 2010). In current assay, suppression of vegetation was frequent mostly during the autumn, indicating that the vegetation is indispensable to social wasps foraging, especially when the temperature declines with the arrival of winter. These data suggest that the type of land management coupled to low temperatures affects the use of different microhabitats by social wasps.

The increased activity observed during the warmer months is also within what is to be expected according to other studies conducted in different situations (SOUZA et al., 2012; SIMÕES et al., 2012). In more tropical regions, the wet season features greater wasp abundance than the dry season (AUAD et al., 2010; SIMÕES et al., 2012). Only Epiponini individuals were collected during the coldest months in the area under analysis. This may be probably more as a result of their nests being protected and of thermoregulation strategies capable of keeping their temperature stable, regardless of the external temperature (HOZUMI et al., 2010), than because of food availability.

Few individuals were collected on the edges or in the cultivated areas during September, October and November. The above may be primarily due to the inter-harvest period when the vegetation on the edges is impeded to advance into the cultivated areas. This suppression was most intense in the polyculture edge, since polyculture farmers visit their crops more often since they harvest salad vegetable crops more frequently. In contrast, suppression on the monoculture edge was more localized and only occurred in preparation for planting, between different crops. During these months the highest abundance was observed in the forest due to the fact that most trees in the fragment are flowering during the period (ANDREIS et al., 2005). In fact, it is an important detail in the relevance of forest fragments in agricultural matrices, since wasps primarily use the resources available in the forest and only seek resources beyond it when the flowering period of the vegetation in forest has passed. After the coldest months, wasp activity increases in all the microhabitats. This is due to an increase in the availability of food resources, such as nectar; it is also a period during which the activity of other insects starts intensifying (PINHEIRO et al., 2008).

Polistes exhibited a gradual increase in abundance as temperature increases along the months, in contrast to the Epiponini with a faster pattern. This fact indicates that samples should not be collected too intensely during the beginning of spring to avoid the risk of compromising the viability of already reduced species populations, or of causing population disequilibrium, especially with regard to Polistini and Mischocyttarini. One possible alternative would be to distribute sampling effort more uniformly across the months.

Epiponini's peak activity differed from reports by Canevazzi and Noll (2011) who remarked that December and June were the months with least foraging activity by *Polybia paulista*. This is a result of seasonality, which varies little in the state of São Paulo and where even in winter temperatures rarely fall below 20ºC.

The influence of temperature on the activity of wasps does not appear to be exclusively related to the biome or to the geographical state in which studies were conducted. As in the case of current study, temperature was positively related to daily activity of *Polistes simillimus* Zikán, 1951 in the state of Minas Gerais, Brazil (ELISEI et al., 2008), and *Polybia occidentalis occidentalis* (Olivier, 1791) in the state of Bahia, Brazil (RESENDE et al., 2001). In addition to its positive correlation with temperature, air humidity had a negative correlation with the foraging activity of the genus *Polybia* within a range of settings (RESENDE et al., 2001; CANEVAZZI; NOLL, 2011), similar to that reported in current study. While rain may have a strong influence on the species richness observed (SIMÕES et al., 2012), this was not the case since seasonality is not defined by rainfall in the State of Rio Grande do Sul.

The diversity of Vespidae in the State of Rio Grande do Sul is underestimated since few studies have been conducted to investigate these organisms. Although data are still rare, the patterns reported in current assay indicate that small forest fragments constitute important environments for the conservation of social wasps.

As evidenced by diversity recorded throughout the year, the activity of social wasps was primarily influenced by abiotic factors such as temperature and to a secondary degree by biotic factors, such as vegetation cover and richness concentration. Conventional monocultures, such as soybean and corn, do not provide favorable microhabitats for the colonization of social wasps, since they have low microhabitat diversity. In contrast, they may be appropriated for resource utilization, unless there are excesses in the application of insecticides.

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