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Long- and short-term changes in social wasp community structure in an urban area

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Abstract

The success of social wasps in anthropic environments is related to their ability to nest both in vegetation and human constructions, and, as humans modify their own environments, wasps community structure may shift as well. Our aim was to assess the diversity of social wasps and their interactions with nesting substrates seasonally in an urban squares area in Southeastern Brazil, 15 years after the first diversity study in this area. We actively searched for nests in the rainy season between 2014 and 2015 and in the dry season of 2015. Although social wasp species richness did not change since the 2000 assessment (13 species in 5 genera), the abundance decreased substantially. Additionally, wasps showed a general trend of nesting on the man-made materials Metal (n = 115, 60%) and Concrete (n = 106, 36%), especially by the two most common species sampled: *Mischocyttarus cassununga* and *Polistes versicolor*. We suggest that abundance decrease may correspond to the reduction of green areas in the assayed locations. These results support the well-known importance of maintaining green areas in urban environments to promote the growth and conservation of diverse social wasp communities.

Introduction

The social wasps are widely distributed throughout all continents, except Antarctica. In Brazil, they are represented primarily by the Polistinae (Carpenter & Marques, 2001). Brazilian paper wasps inhabit various environments, but show high degrees of association with urban areas, often constructing nests under or inside the walls of buildings (Wenzel, 1998; Alvarenga et al., 2010; Torres et al., 2014; Michelutti et al., 2013).

The importance of studying social wasps and their diversity is emphasized by their ecological roles. For instance, social wasps may act as pollinators when visiting flowers (Clemente et al., 2012), detritivores when foraging on decaying fruits (Barbosa et al., 2014) and animal carcasses (Moretti et al., 2011), and predators when foraging on agricultural pests (e.g., caterpillars) (Elisei et al., 2010). As a result, social wasps are part of a complex intra and interspecific ecological web that is yet to be fully comprehended (Menezes et al., 2014; Virgínio et al., 2016).

The nesting sites chosen by wasps are strongly influenced by predation and the weather (Raposo-Filho & Rodrigues, 1984; Souza et al., 2010). Nesting on man-made substrates, in addition to natural ones, may be a useful strategy for wasp populations since their colonies may have higher developmental success as these locations may allow them to avoid their natural predators and take shelter from harsh weather conditions (Jeanne, 1975; Lima et al., 2000; Alvarenga et al., 2010).

Studies with social wasp behavior and diversity in urban environments have been increasing in number in the last decade (e.g. Alvarenga et al., 2010; Jacques et al., 2012; Naldoski, 2013; Torres et al., 2014; see Barbosa et al., 2016). They show the relation between many species of social wasps and their environments, such as how some species found in urban areas depend exclusively on natural vegetation, whereas other prefer artificial substrates (Alvarenga et al., 2010; Sinzato et al., 2011; Castro et al., 2014; Virgínio et al., 2016). Moreover, as humans continue to change their

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environment, some species seem to change their nesting preferences as well (Torres et al., 2014). Other studies discuss these nesting tendencies in natural and urban areas (Lima et al., 2000; Alvarenga et al., 2010; Maciel and Barbosa, 2015), explaining the advantages of using both natural and man-made substrates. Thus, we need to better understand the ecological relations between wasps and the urban environment.

Previous studies have begun comparing nesting preferences in natural vs. artificial environments. Here, we build on that previous work to survey the diversity of social wasps, using urban locations surveyed in a study published 15 years prior to this one (Lima et al., 2000). We compare the two sets of results to understand long-term changes in the social wasp community structure. We also investigated short-term seasonal changes in the social wasp community structure, by investigating population dynamics across two following seasons and studied the interactions between the species of social wasps and their nesting substrates, trying to establish a link between this relation and the group's seasonality and diversity in order to better understand the ecology of social wasps in urban areas.

Material and Methods

Area of study

The study was carried out in the campus of Universidade Federal de Juiz de Fora (UFJF) (21º46'02.72''S - 43º22'34.9''W 678 m asl), located within the urban perimeter of Juiz de Fora, Minas Gerais state, Southeastern Brazil. The climate in the area is characterized as humid subtropical, with dry winters (May to September) and rainy summers (October to April) (Cwa), according to Köppen-Geiger (Sá-Júnior et al., 2012). The area has been recently classified by Carvalho et al. (2014) as having a predominance of *Pinus elliottii* Engelm., showing a low diversity of plant species, and is considered an emergent ecosystem (Fig 1). It may also be referred to as a novel ecosystem (Maciel & Barbosa, 2015).

Data sampling

Recording the wasp nests took place during one dry season (between December 2014 and February 2015), and one rainy season (between June and July 2015). We actively searched for colonies by inspecting man-made substrates (further classified into: asbestos, concrete, ceramic, metal, plastic, porcelain or stone), rocky outcrops, tree trunk cavities and canopies. When they were located, we photographed colonies, identified the material used as substrate, and collected 1-3 individuals with an entomological net. Individuals were stored in labeled containers with 70% ethylic alcohol for later identification.

For species identification, we used dichotomous keys suggested by Richard (1978), Hermes and Kohler (2004), Silveira (2008), Andena et al. (2009) and Carpenter and Andena (2013). Wasp samples were stored in the Laboratório de Ecologia Comportamental e Bioacústica (LABEC) of UFJF; one individual of each species was dry mounted for the voucher.

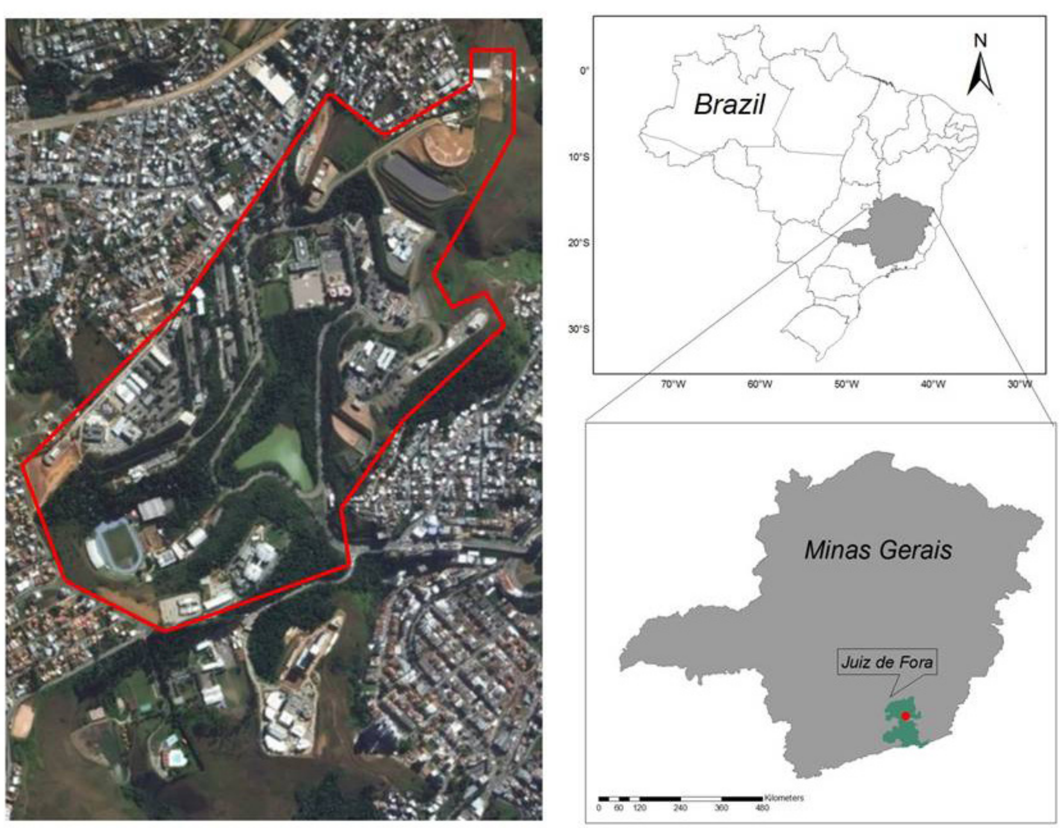

Fig 1. Geographical representation of area of the campus of Universidade Federal de Juiz de Fora, delimited in red, in the urban perimeter of Juiz de Fora, Minas Gerais state, southeastern Brazil.

Data analysis

Species diversity was analyzed for Rainy and Dry season separately and combined using the Shannon (H') diversity index and the H'-based Pielou (J') evenness index. The PAST v.2.17c software (Hammer et al., 2001) was used to perform diversity analyses. G-Test was used to examine the difference in wealth and abundance between seasons; calculations were done with the BioEstat software (v. 5.3).

Each species' dominance was calculated and expressed as a percentage using the following formula: D= (i/T)*100, where i = total number of individuals of a given species and T = total number of individuals of all species collected. These percentages were then categorized as follows: eudominant > 10%; dominant = 5-10%; subdominant = 2-5%; recessive = 1- 2%; or rare < 1% (Friebe, 1983).

In order to assess social wasp species richness in the area for each used method, we calculated the species' rarefaction curves (*sensu* Gotelli & Colwell, 2001) through the software EstimateS 9 using 5000 randomizations. First and 2nd order non-parametric estimators of Jackknife were used to project the maximum species richness that each method and area of study may reach. The software generates 5000 species accumulation curves, randomizing the sampling order; therefore, each point on the curve corresponds to the average of the accumulated richness for the 5000 curves and is associated to a standard deviation value.

To design the bipartite graph among substrates and social wasps on the campus of UFJF, we used every colony in order to build an adjacency matrix for each season: a "quantitative matrix" that regards the frequency of nest-substrate interactions for each wasp species through the R software (v.3.4.3).

In order to assess general changes in the composition of the environment, we obtained satellite photographs of the campus area from the software Google Earth Pro 7.3.0.3832 (32-bit) for the years of 2015 and 2010, which was the oldest record available. Green areas were calculated in the same software using an area delimiting tool. Additional data for previous years was obtained from Vieira et al. (2016).

Results

We identified a total of 13 species from five genera: *Mischocyttarus* Saussurre, 1853, *Polistes* Latreille, 1902, *Polybia* Lepeletier, 1836, *Protopolybia* Ducke, 1905 and *Synoeca* de Saussure, 1852 (Table 1). Species richness was significantly higher during the rainy season (n = 13 species) compared to the dry season (n = 8 species; G-Test = 36.0685; p< 0.0002; Table 1).

The abundance of colonies was also higher during the rainy season (n = 197 colonies) compared to the dry season (n = 86 colonies) (283 total, average = 141.5; G-Test = 366.8213; p< 0.0001).

There were two eudominant species in the area, *Mischocyttarus cassununga* (von Ihering, 1903) and *Polistes versicolor* (Olivier, 1791), and one dominant, *Protopolybia exigua* (de Saussure, 1854). The remaining species were fit into subdominant, recessive or rare (Table 1). Tests with the Jacknife estimators of 1st and 2nd order showed an estimation of 16 and 17 species (respectively) to the campus of UFJF.

Table 1. Species of social wasps sampled and values calculated for Shannon's index, Dominance index and Pielou's index at the campus of Universidade Federal de Juiz de Fora, city of Juiz de Fora, Minas Gerais state, Southeastern Brazil, in the periods between December 2014 and January 2015 (rainy season) and between June and July 2015 (dry season).

Species	Frequency			Dominance	
	Rainy Season	Dry Season	Total		
Mischocyttarus socialis (de Saussure, 1854)	1	0	1	Rare	0,4
Mischocyttarus cassununga (von Ihering, 1903)	100	49	149	Eudominant	52,7
Mischocyttarus drewseni Saussure, 1954	10	3	13	Subdominant	4,6
Mischocyttarus wagnei (Buysson, 1908)	1	0	1	Rare	0,4
Polistes ferreri (de Saussure, 1853)	7	2	9	Subdominant	3,2
Polistes versicolor (Olivier, 1791)	46	16	62	Eudominant	21,9
Polybia fastidiosuscula Saussure, 1854	1	1	2	Rare	0,7
Polybia paulista (Ihering, 1896)	1	1	2	Rare	0,7
Polybia platycephala Richards, 1951	7	0	7	Subdominant	2,5
Polybia sp.	3	2	5	Recessive	1,8
Protopolybia exigua (de Saussure, 1854)	16	12	28	Dominant	9,9
Protopolybia sedula (de Saussure, 1854)	3	0	3	Recessive	1,1
Synoeca cyanea (Fabricius, 1775)	1	0	1	Rare	0,4
Total	197	86	283	-	-
Rainy season	H´= 0,6678	d = 0,5076	J = 0,5995		
Dry season	H´= 0,5682	d = 0,5823	J = 0,6292		
Total	H´= 0,6477	d = 0,5265	J = 0,5814		

These results, along with the species rarefaction curve, are depicted in Figure 2.

Regarding the nesting substrates, social wasps constructed nests on metal the most (115 nests, 40% of the total sampled colonies), followed by concrete (102 nests, 36%). The remainder of the nests (24%) was divided somewhat evenly among the remaining substrates. The eudominant species (*M. cassununga* and *P. versicolor*) have shown flexibility regarding the nesting substrates, found on six and five (respectively) of the eight substrates used by wasps on this study (Figure 3). *P. exigua*, *Protopolybia sedula* (de Saussure, 1854) and *Synoeca cyanea* (Fabricius, 1775), on the other hand, exclusively used vegetation as their substrate. It is worth noting that the use of vegetation as nesting substrate was 43% lower in the dry season than in the rainy season. Such reduction was also recorded for the species richness on this substrate, which decreased from six to only two species in the dry season.

The investigation of the green areas within the campus between 2010 and 2015 showed that in 2010 the total green area was 496,966.9 m^2, which corresponds to 36.9% of the total campus area (1,346,793.80 m^2). The green area in 2015 was reduced to 334,004.8 m^2, corresponding to 24.8% of the total campus area; a reduction of 12.1% of green area. Additionally, Vieira et al. (2016) described a 7.36% reduction of green areas in the campus between 2002 and 2010. By combining these data, we calculate that, between 2002 and 2015, green areas in the campus decreased in 18.56%.

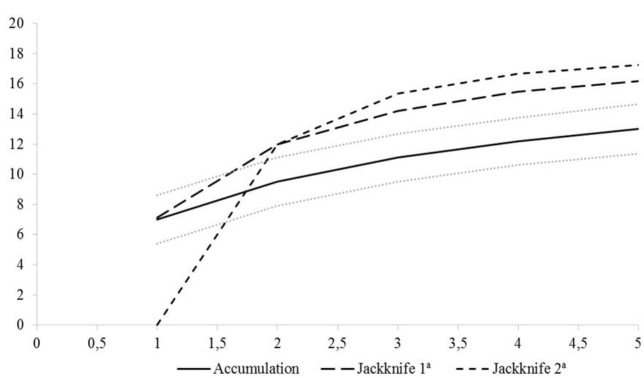

Fig 2. Species Rarefaction Curves estimated from 5000 randomizations for the social wasps sampled in the campus of Universidade Federal de Juiz de Fora city of Juiz de Fora, Minas Gerais state, Southeastern Brazil, in the periods between December 2014 and January 2015 (rainy season) and between June and July 2015 (dry season).

Discussion

Comparing the diversity of wasps sampled in this study with the results found by Lima et al. (2000) in the same area 15 years before provides various insights on how changes in the environmental structure of urban areas may affect the social wasp fauna. In terms of genera richness, both studies had very similar structures since they shared four genera (*Mischocyttarus*, *Protopolybia*, *Polistes* and *Polybia*) and presented a single exclusive genus each (*Protonectarina* in Lima et al., 2000, *Synoeca* in this study). These exclusive genera comprise very small portions of the samples (two colonies of *Protonectarina* and one of *Synoeca*) and show similarities in nesting habits (notably a preference for nesting almost exclusively in vegetation, according to Richards & Richards, 1951; Wenzel, 1998). Their presence may therefore represent rare occurrences rather than an actual change in the richness structure between those 15 years.

The abundance of social wasps, on the other hand, has shown greater differences between the two studies in the area. While Lima et al. (2000) sampled a mean 287.75 colonies per census, we found less than half this value (141.5 per census). This alarming decrease in the wasp populations may be a result of the progressive reduction of vegetation in the studied site. Many tropical wasp species nest exclusively on vegetal substrate, and all benefit indirectly from the surrounding green areas, especially in urban areas (Wenzel, 1998; Alvarenga et al., 2010). Although it cannot be concluded, we suggest that the significant decrease of vegetation (close to 20% in 15 years) may have played a major role in determining social wasp abundance in the area.

Our data seems to be in accordance with the richness of social wasps shown in environments with some degree of similarity to the campus. Jacques et al. (2012) studied an urban area with integrated vegetation in Southeastern Brazil and sampled 21 species; however, only 7 genera and 13 of these species were recorded through the active nest search method, which is similar to our results (13 spp. in five genera). Other diversity studies performed in natural areas show some variation regarding richness; for instance, in the Atlantic Rainforest, these values range between 10 (Arab et al., 2010), 18 (Santos et al., 2007) and 25 (Hermes & Köhler, 2004), highlighting the importance of urban areas, since the value we sampled (n=13) is within their range.

Similar to Lima et al. (2000) we found that the abundance and species richness of social wasps is higher during the rainy season compared to the dry season. This is an evidence of a high colony cycle synchrony degree, as described for some independent-founding wasps (Dantas de Araujo, 1982). However, since 61.5% of the species were also present in the winter, our results agree with Naldoski (2013), who suggests that the complexity of urban environments reduces the impact of seasons on the social wasp cycles.

Despite the differences in abundance and diversity between seasons, the ecological indices had low variation when values were compared across seasons and throughout the year. Jacques et al. (2012) calculated diversity and dominance of social wasps in a different urban area in Southeastern Brazil, and their sample showed higher diversity (H'= 0.9814) and lesser dominance (D= 0.2581) than ours. This results suggests the fauna in the campus of Universidade Federal de Juiz de Fora is strongly dominated by a few species. Indeed, our samples showed two eudominant species (*M. cassununga* and *P. versicolor*) and a dominant one (*Protopolybia exigua*), the rest being subdominant, recessive or rare. The fact that the structure of the index does not significantly differ between seasons suggests that highly dominant species are more adapted to persist throughout harsher (i.e., dryer) environmental conditions.

The species *M. cassununga* and *P. versicolor* may be considered highly synanthropic, since they are more consistently abundant compared to other species (Torres et al., 2014; Castro et al., 2014). In our study, the swarming species (Epiponini tribe) used larger substrate area to attach their large nests. Moreover, the species of the Epiponini tribe were recorded less often on man-made substrates, and some species were restricted to constructing nests on vegetation (Jeanne, 1975; Carpenter & Marques, 2001). In other words, in an environment where green areas are receding (Vieira et al., 2016), species capable of nesting preferably on artificial structures – here depicted by the eudominant *M. cassununga* and *P. versicolor* nesting on metal and concrete (see Figure 3) – are more successful in occupying an urban environment.

Our results show that although the species richness of social wasps in the campus of UFJF has been relatively stable over the last 15 years, modifications on the campus' physical structure, with more buildings and less vegetation, may be affecting the relative abundance of wasps and allowing certain species that are capable of nesting on man-made structures to dominate the community. This is clearly seen in the overall reduction of social wasp abundance over the past 15 years, as well as the decrease of species richness from rainy to dry seasons. Altogether, these results highlight the importance of maintaining green areas in order to promote the growth and conservation of wasp populations.

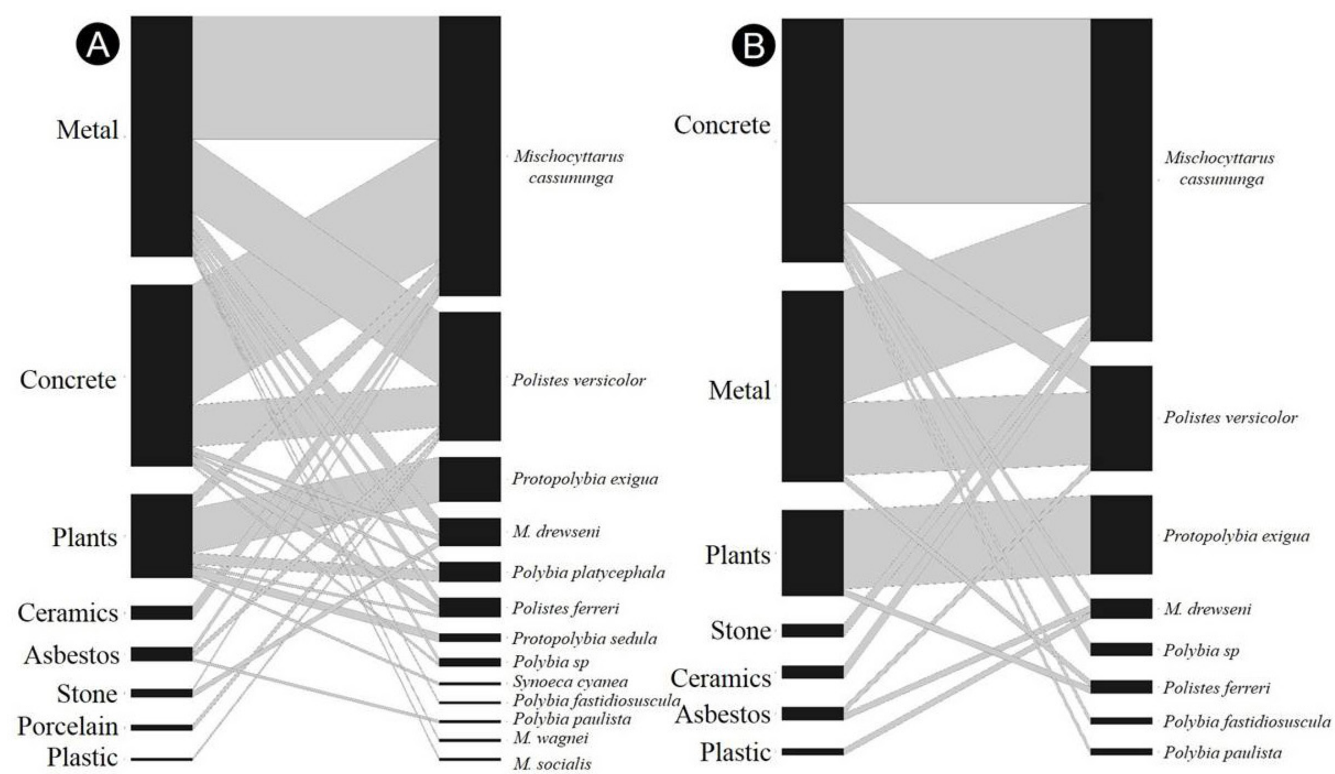

Fig 3. The relation between wasps and different nesting substrates, involving 13 species of social wasps and eight types of substrate on the campus of Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais state, Southeastern Brazil. A - Rainy season (hot/humid) and B - Dry season (cold/dry).

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