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Effect of forest fragment size on Polistinae (Hymenoptera, Vespidae) in a transitional area of Cerrado and Atlantic Forest in south central Minas Gerais state, Brazil

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Abstract. Ecosystem fragmentation negatively affects biological diversity and compromises different environmental services. This situation occurs in two important biomes in Brazil, the Atlantic Forest and the Cerrado. There is little information on the effects of fragmentation on animal taxa, including social wasps. It was hypothesized that fragments that are small in size and subject to anthropogenic pressures have reduced social wasp richness and colony numbers. This study aimed to investigate the effect of forest fragmentation on Polistinae richness and colony number at Atlantic Forest and Cerrado sites in southern central Minas Gerais State, southeastern Brazil. The study was conducted in three fragments, Mata do Baú, Cachoeira da Lajinha, and Cachoeira do Padeiro, from October 2020 to March 2021, using active collection to record social wasp species and colony numbers. A total of 42 species and 80 colonies were recorded in the three fragments. Forest fragment size alone did not influence social wasp communities, but communities were significantly affected by a combination of factors, including fragment size, adjacent vegetation, and anthropogenic pressures. Species richness was higher in Mata do Baú and Cachoeira da Lajinha, which did not differ from each other, than in Cachoeira do Padeiro; however, all fragments had exclusive communities. Therefore, an increase in anthropogenic pressure in any of the three fragments may lead to losses in social wasp species.

Keywords: Atlantic Forest; Conservation Unit; Edge Effect; Gallery Forests; Semideciduous Forests.

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Tropical forests are home to the highest biodiversity in the world (Myers *et al.* 2000; Matos *et al.* 2017; Oliveira-Junior *et al.* 2020), contribute to the regulation of the planet's climate (Anderson-Teixeira *et al.* 2012), and provide environmental services that are vital to the survival of millions of people (Chomitz *et al.* 2007). Unfortunately, tropical forests have suffered a variety of environmental impacts stemming from livestock production, illegal logging (Taubert *et al.* 2018; Veldkamp *et al.* 2020), and road construction (Keller & Largiader 2003), which has led to fragmentation of these ecosystems (Bennett & Saunders 2010; Hansen *et al.* 2020).

Fragmentation results in the isolation of forest remnants (Lord & Norton 1990), affecting environmental services, such as biological control, pollen propagation, and seed dispersal (Viana & Tabanez 1996; Hanski *et al.* 2013), thereby modifying faunal and floral communities (Magnago *et al.* 2014). Furthermore, fragmentation causes significant reductions in the gene flow of a variety of animal groups, such as birds (Bispo *et al.* 2012), amphibians (Condez *et al.* 2009), arachnids (Boas-Junior *et al.* 2020), and insects (Filgueiras *et al.* 2019), including butterflies (Williams *et al.* 2003), beetles (Keller & Largiader 2003), and bees (Knoll & Penatti 2012). There is little information on the effects of forest fragmentation on some taxa, such as social wasps (Morato & Campos 2000; Graça & Somavilla 2018; Bueno *et al.* 2019). Fragmentation of natural environments is one of the major causes of extinction in tropical regions (Olff & Ritchie 2002).

One of the most threatened environments in Brazil is the Atlantic Forest. Considered a global biodiversity hotspot, the Atlantic Forest is home to 50.5% of endangered fauna species of the country, 38.5% of which are endemic (Myers *et al.* 2000; Ribeiro *et al.* 2011). The biome encompasses different phytophysiognomies, such as dense ombrophilous, semideciduous seasonal, deciduous, and mixed forests; *campos de altitude*; mangroves; *restingas*; and pioneer vegetation (Oliveira-Filho 2006). Despite the richness of the biome, only about 12.4% of the original area is conserved (Fundação SOS Mata Atlântica 2021), which is distributed across hundreds of thousands of disconnected forest fragments (Paglia & Pinto 2010; Ribeiro *et al.* 2011; Leão *et al.* 2014).

Atlantic Forest degradation is caused mainly by anthropogenic actions. Such effects have also been observed in the Cerrado, a biome home to 288 endangered species, 126 of which are endemic. The Cerrado holds great importance, also being considered a biodiversity hotspot (Myers *et al.* 2000; ICMBio 2018). The biome has undergone rapid landscape reductions and modifications, mainly because of the advance of agriculture (Queiroz 2009; Hunke *et al.* 2014), having higher deforestation rates than the Amazon (Bolson 2018).

The Atlantic Forest is home to 170 species, while the Cerrado has 137, which corresponds, respectively, to 44.6% and 35.9% (Souza *et al.* 2020a, 2020b) of the 381 social wasps that occur in Brazil (Somavilla *et al.* 2021); therefore, fragmentation and alteration of these ecosystems may negatively affect the wasp fauna of the country. These social insects, commonly known as *marimbondos* our *cabas* in Brazil (Pádua *et al.* 2017), belong to the Hymenoptera, Vespidae, Polistinae, with three of its tribes (Polistini, Mischocyttarini, and Epiponini) occur in the country (Carpenter & Marques 2001), totaling 381 species (Somavilla *et al.* 2021). These social wasps provide different ecological services (Brock *et al.* 2021), acting as biocontrol agents of agricultural pests (Prezoto *et al.* 2019; Elisei *et al.* 2021), pollinators and frequent flower visitors (Brodmann *et al.* 2008; Shuttleworth & Johnson 2009; Gaskett 2011; Clemente *et al.* 2012, 2017), bioindicators (Urbini *et al.* 2006), and sources of compounds for drug production (Brock *et al.* 2021).

The importance of social wasps to terrestrial ecosystems, the high wasp richness in the Atlantic Forest (Souza *et al.* 2020a) and Cerrado (Souza *et al.* 2020b), and the lack of information on the influence of forest fragmentation on social wasp communities are factors that underscore the need to better understand the effect of fragmentation on these Hymenoptera.

Given the above, it was hypothesized that small forest fragments associated with high anthropogenic pressure result in low social wasp richness and colony number. This study aimed to assess the effect of fragmentation on Polistinae richness and colony number in fragments of semideciduous seasonal forests (Atlantic Forest) and gallery forests (Cerrado) in southern central Minas Gerais State, southeastern Brazil.

MATERIAL AND METHODS

The study was conducted in three forest fragments differing in geographical, ecological, and environmental characteristics (see Table 1). Sites were located in the municipalities of Barroso (21°11'13"S 43°58'33"W) and Prados (21°13'33.20"S, 44°2'0.56"W), southern central Minas Gerais State, Campos das Vertentes region, located in the Atlantic Forest biome with Cerrado enclaves, forming a mosaic of vegetation (Carvalho *et al.* 1994; Menini-Neto *et al.* 2004). The sites are described as follows: (1) Mata do Baú, municipality of Barroso, housing remnants of seasonal semideciduous forests of the Atlantic Forest (Oliveira Filho 2006) and Campo Cerrado domains (Souza & Prezoto 2006); (2) Cachoeira do Padeiro, municipality of Barroso, a gallery forest remnant of the Cerrado domain; and (3) Cachoeira da Lajinha, municipality of Prados, a gallery forest fragment of the Cerrado domain (Oliveira-Filho 2006) (Figure 1).

According to data presented in Table 1, it can be said that Mata do Baú has low edge effect (low circularity index) compared with Cachoeira do Padeiro and Cachoeira da Lajinha. These latter sites suffer greater interference from adjacent environments, although Mata do Baú is directly associated with livestock production and eucalyptus plantation. All sites comprise forest remnants at intermediate or advanced stages of regeneration (Menini-Neto *et al.* 2004; Souza 2006; Souza *et al.* 2010). For determination of the circularity index, it was considered that values closer to 1 indicate greater proportion of the central area and consequently lower edge effects (Takikawa *et al.* 2021).

Four field campaigns were conducted, each lasting six consecutive days, from October to December (spring) 2020 and from January to March (summer) 2021. Collections lasted 6 h per day, totaling a sampling effort of 144 h in 24 days per fragment.

The active search method was used for specimen collection and colony counting, as authorized by IBAMA/SISBIO no. 75517-1 (Souza & Prezoto 2006), on pre-existing trails inside each fragment. Entomological nets were used to capture specimens in flight or inside colonies. Collected specimens were sacrificed and stored in 70% alcohol. The material was sent to the Zoology Laboratory of the Federal Institute of Education, Science, and Technology of the South of Minas Gerais, campus Inconfidentes. Samples were subjected to dry preservation and identified with aid from keys dichotomic elaborated by Richards (1978), Carpenter & Marques (2001), or

Table 1. Geographic, ecological, and socioeconomic characteristics of Mata do Baú, Cachoeira da Lajinha, and Cachoeira do Padeiro forest fragments, Minas Gerais State, Brazil, where collections of social wasps (Hymenoptera, Vespidae) were performed.

Characteristic	Mata do Baú	Cachoeira da Lajinha	Cachoeira do Padeiro
Municipality	**Barroso**	**Prados**	**Barroso**
Coordinates	21°12'16.00"S 43°56'3.65"W	21°13'33.20"S 44°2'0.56"W	21°13'14.38"S 43°59'22.87"W
Area (ha)	384.9	32.25	26.43
Phytophysiognomies	Seasonal semideciduous forest and *campo cerrado*	Gallery forest and *campo cerrado*	Gallery forest and *campo cerrado*
Circularity index	0.82	0.44	0.62
Lotic environments	Present	Present	Present
Lentic environments	Present	Absent	Absent
Livestock activity	Present	Absent	Present
Eucalyptus plantations	Present	Absent	Absent
Gullies	Present	Absent	Absent
Adjacent vegetation matrix	*Campo cerrado*, eucalyptus plantations, and pastures	*Campo cerrado* and eucalyptus plantations	*Campo cerrado* and pastures
Distance from other forest fragments	4.5 km from Padeiro and 7.8 km from Lajinha	3.2 km from Padeiro and 7.8 km from Baú	3.2 km from Lajinha and 4.5 km from Baú
Touristic activities	Absent	Present	Present
Fires during the study period	Absent	Absent	Present
Distance from the urban perimeter	2.5 km	4 km	1 km

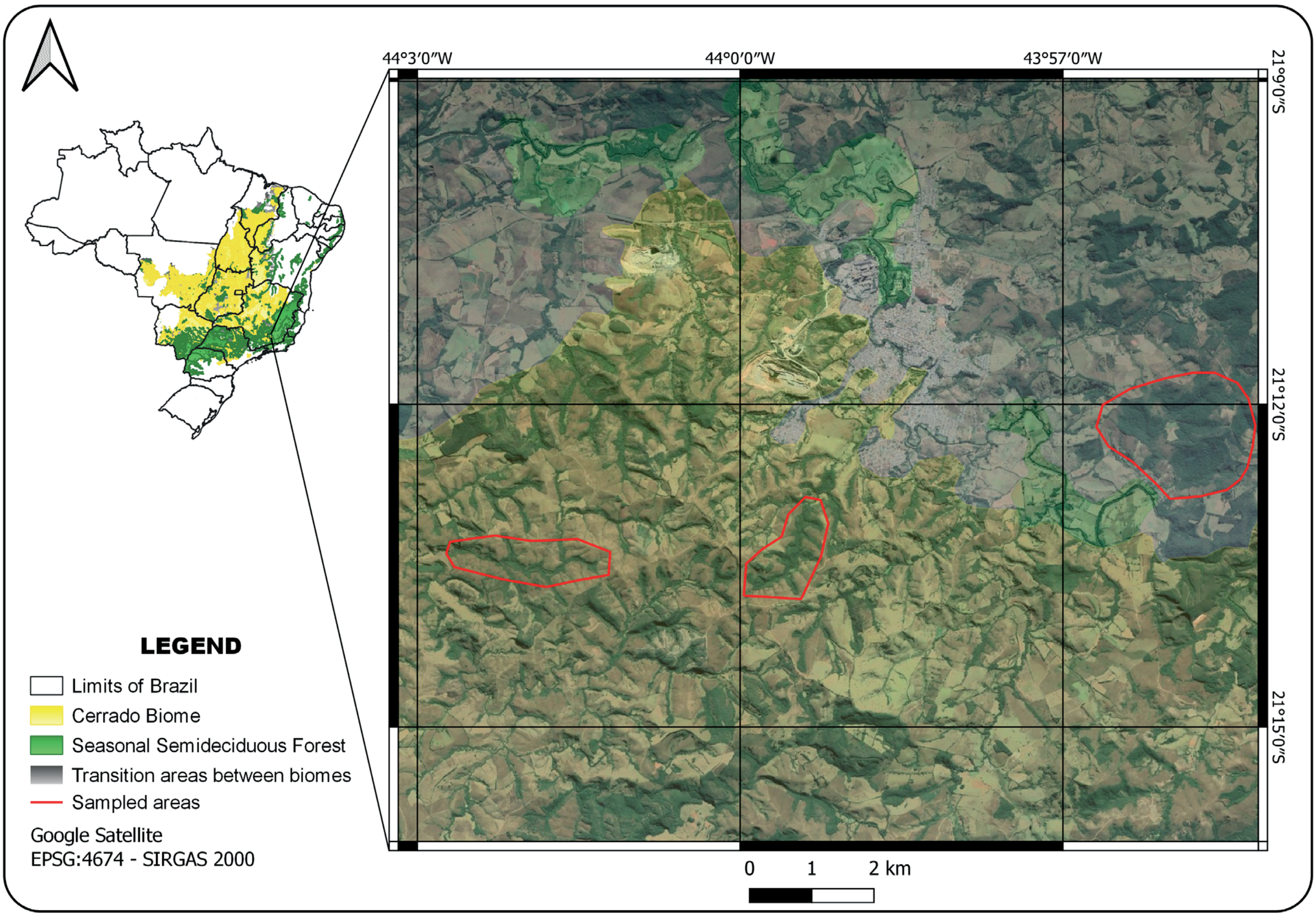

Figure 1. Forest fragments (Mata do Baú, Cachoeira do Padeiro, and Cachoeira da Lajinha) where social wasps were collected in the municipalities of Barroso and Prados, Minas Gerais State, Brazil.

compared with wasps who are deposited in the biological collection of social wasps (CBVS). Specimens that could not be identified were referred to Dr. Orlando Tobias da Silveira, at the Emílio Goeldi Museum, Belém, Pará, Brazil, to confirm identification at a specific level.

To evaluate the hypothesis of the study, two parameters were used, richness and number of colonies, in which the Kruskal-Wallis test was used to verify possible statistical differences. To assess the similarity between the faunas of the fragments, a cluster analysis was performed using the Jaccard similarity matrix, built from presence/absence data. Dendrograms were constructed using the method of unweighted pairs with arithmetic mean. All analyzes were performed using PAST software version 3.24 (Hammer *et al.* 2001).

As the studied fragments are close to each other and inserted in a transition area of Cerrado and Atlantic Forest, forming a vegetation mosaic (Table 1), this variable was disregarded in the study, evaluating only the size and the degree of impact that the area suffer.

RESULTS AND DISCUSSION

A total of 42 species and 80 colonies were collected from three forest fragments (Table 2). The highest species richness was observed in Mata do Baú (n = 33) and Cachoeira da Lajinha (n = 32), whose values did not differ significantly from each other (p = 0.8002, Kruskal-Wallis test). Cachoeira do Padeiro had the lowest species richness (n = 20) compared with Mata do Baú (p = 0.003539, Kruskal-Wallis test) and Cachoeira da Lajinha (p = 0.007479, Kruskal-Wallis test).

This result is a reflection of the high anthropogenic pressure exerted on Cachoeira do Padeiro, mainly caused by forest burning, which destroys colonies, reducing food resources and diversity, as discussed by Clemente *et al.* (2021). Forest fires affect mainly *campo cerrado*, which comprises the adjacent vegetation. It is known that different taxa use adjacent vegetation for foraging and nesting (Antunes 2005; Watson *et al.* 2005); thus, negative impacts in this area may affect forest remnants. Given that social wasps use adjacent environments for foraging and nesting, among other activities (Diniz & Kitayama 1994; Silva-Pereira & Santos 2006), negative impacts on adjacent areas might have negatively affected their richness in the forest remnants of Cachoreira Padeiro.

Such a hypothesis is supported by the occurrence of the edge effect, which affects Cachoreira Padeiro (Table 1). The edge effect is observed at a local scale, altering the environmental characteristics of the remnant, such as humidity, luminosity, and vegetation structure, consequently influencing faunal communities (Rossetti *et al.* 2014; Stangler *et al.* 2015). Thus, it can be said that the presence of pastures as part of the adjacent vegetation matrix negatively influences forest remnants, given that pastures represent poor ecosystems, culminating in a reduction in species richness, as previously observed for social wasps (Auad *et al.* 2010; Klein *et al.* 2015).

Another relevant factor is the low circularity index observed in Cachoeira da Lajinha, which is expected to make the site more susceptible to the edge effect (Table 1), although species richness was not influenced (Table 2). The edge effect might have been mitigated by the low anthropogenic action observed in the surrounding ecosystem compared with Cachoeira do Padeiro (Laurance 2008). When under low anthropogenic pressures, environments that form the adjacent vegetation of forest remnants can offer greater resource availability to animal species (Brotons *et al.* 2003).

Table 2. List of species (1 = presence, 0 = absence) and number of colonies of social wasps recorded in three forest fragments in the municipalities of Barroso and Prados, Minas Gerais State, Brazil.

Species	**Forest fragment**					
	Mata do Baú		**Cachoeira da Lajinha**		**Cachoeira do Padeiro**	
	Richness	**Colonies**	**Richness**	**Colonies**	**Richness**	**Colonies**
Agelaia multipicta (Haliday)	1	0	1	0	1	0
Agelaia pallipes (Olivier)	0	0	1	0	0	0
Agelaia vicina (de Saussure)	1	1	1	0	1	0
Apoica gelida Van der Vecht	1	3	1	5	0	0
Apoica pallens (Fabricius)	1	0	0	0	0	0
Brachygastra augusti (de Saussure)	1	0	1	0	1	1
Brachygastra lecheguana (Latreille	1	0	1	1	1	0
Parachartergus pseudopicalis Willinck	1	0	0	0	0	0
Parachartergus fraternus (Gribodo)	1	0	0	0	0	0
Polybia flavifrons Richards	0	0	1	1	0	0
Polybia chrysothorax (Lechtenstein)	1	0	1	1	0	0
Polybia fastidiosuscula de Saussure	1	1	1	3	1	1
Polybia ignobilis (Haliday)	1	0	1	0	1	0
Polybia jurinei de Saussure	1	0	1	0	1	0
Polybia occidentalis (Olivier)	1	1	1	0	0	0
Polybia sericea (Oliver)	1	0	1	0	1	0
Polybia paulista H. von Ihering	1	1	1	0	1	0
Polybia platycephala Richards	1	0	1	0	1	0
Polybia punctata du Buysson	1	0	1	0	0	0
Protonectarina sylveirae (de Saussure)	1	0	1	0	1	0
Protopolybia sedula (Saussure)	1	4	1	0	1	0
Pseudopolybia vespiceps (de Saussure)	0	0	0	0	1	0
Synoeca cyanea (Fabricius 1775)	1	2	0	0	1	0
Mischocyttarus artifex (Ducke)	0	0	1	1	0	0
Mischocyttarus buyssoni (Ducke)	0	0	1	1	0	0
Mischocyttarus cassununga (R. von Ihering)	1	8	1	4	1	2
Mischocyttarus confusus Zikán	1	2	0	0	0	0
Mischocyttarus drewseni de Saussure	1	2	1	2	1	0
Mischocyttarus ignotus Zikán	1	1	1	7	0	0
Mischocyttarus mirificus (Zikán)	1	2	1	8	1	1
Mischocyttarus rotundicolis (Cameron)	1	0	1	0	0	0
Mischocyttarus saussurei Zikán	1	3	1	1	0	0
Mischocyttarus paraguayensis Zikán	1	1	0	0	0	0
Mischocyttarus parallellogrammus Zikán	1	2	0	0	0	0
Mischocyttarus socialis (de Saussure)	0	0	0	0	1	1
Mischocyttarus wagneri (du Buysson)	1	1	1	1	0	0
Polistes actaeon Haliday	0	0	1	0	0	0
Polistes billardieri de Saussure	0	0	1	0	1	0
Polistes cinerascens Saussure	1	1	1	0	0	0
Polistes pacificus Fabricius 1804	1	0	0	0	0	0
Polistes subsericeus de Saussure	0	0	1	0	0	0
Polistes versicolor (Olivier)	1	0	1	1	1	1
Richness	33		32		20	
Number of colonies		36		37		7
Number of exclusive species per forest fragment	7		6		2	
Number of species common to all three fragments	16					

The structure of adjacent vegetation seems to be as important to social wasp communities as the size and shape of forest fragments, meantime, new studies are necessary for confirming is hypothesis, but in present study, this was evidenced by the fact that Mata do Baú had a larger area and circularity index than Cachoeira da Lajinha (Table 1) but a similar richness of social wasp species, in agreement with the discussions of Bueno *et al.* (2019) and Graça & Somavilla (2018). The authors reported on the negative impact of fragmentation on Polistinae. Thus, it is important to consider not only fragment size and shape but also factors that characterize the ecosystem of the forest remnant and adjacent landscapes when determining the richness, composition, and number of colonies of social wasps (Bennet *et al.* 2004; Watson *et al.* 2005).

It is important to discuss the history of Mata do Baú. In the present study, we recorded 32 species, which was lower than that sampled by Souza & Prezoto (2006) in 2004: the authors reported 38 species. About 15 years later, *campo cerrado* vegetation was replaced in part by eucalyptus plantations, characterized by low richness (Silva *et al.* 2013; Silva-Filho *et al.* 2020), and there was an increase in pasture areas, possibly explaining the reduction in species richness, even though the present study used a lower sampling effort.

Cachoeira do Padeiro showed lower species richness (n = 20) and number of colonies (n = 7), unlike Mata do Baú, with 36 colonies (p = 0.01203, Kruskal-Wallis test) and 33 species. (p = 0.003539, Kruskal-Wallis test). The same occurred when compared to Cachoeira da Lajinha, with 37 colonies (p = 0.00914, Kruskal-Wallis test) and 32 species (p = 0.007479, Kruskal-Wallis test). Thus, the richness and number of colonies of social wasps recorded in Cachoeira do Padeiro showed a significant difference when compared to the other two locations.

Community composition differed between Cachoeira do Padeiro and the two other fragments, which showed high similarity (Figure 2), with nine species in common (Table 2). Cachoeira do Padeiro had only one species in common with Mata do Baú - *Polistes billardieri* de Saussure and Cachoeira da Lajinha - *Synoeca cyanea* (Fabricius). Such a low similarity between Cachoeira do Padeiro and the other sites might be a reflection of the anthropogenic pressures exerted on the site, including forest burning and pasture establishment, which reduces species richness, as discussed in previous studies (Auad *et al.* 2010; De Souza *et al.* 2012; Clemente *et al.* 2021). The size and shape of the fragment, possibly associated with the structure of adjacent ecosystems and human actions (Table 1) influence community composition. This result was observed despite the fact that Mata do Baú and Cachoeira da Lajinha are distant from each other (Table 1) and comprise different forest phytophysiognomies.

Differences in community composition explain the number of unique species in each fragment and the number of species common to all environments (*n* = 16) (Table 2). *Mischocyttarus socialis* (de Saussure) and *Pseudopolybia vespiceps* (de Saussure) were only recorded in Cachoeira do Padeiro. The former species has wide geographical distribution and occupies different ecosystems (Souza *et al.* 2020a, 2020b; Somavilla *et al.* 2021), including agricultural systems (Milani *et al.* 2020), being classified as a generalist species. *P. vespiceps*, by contrast, is not frequent or abundant in inventories (Elpino-Campos *et al.* 2007; Locher *et al.* 2014; Souza *et al.* 2017), occurring mainly in conserved riparian forests (Souza *et al.* 2010). This finding suggests that, although Cachoeira do Padeiro is more subject to negative environmental impacts compared with the other sites, it still represents an ecological support for the species.

Mata do Baú had the highest number of exclusive species (*n* = 7), namely *Apoica pallens* (Fabricius), *Mischocyttarus confusus* Zikán, *Mischocyttarus paraguayensis* Zikán, *Mischocyttarus parallellogrammus* Zikán, *Parachartergus fraternus* Gribodo, *Parachartergus pseudopicalis* Willinck, and *Polistes pacificus* Fabricius. This was the first report of the occurrence of *M. paraguayensis*, *M. parallellogrammus*, and *P. pseudopicalis* in the municipality of Barroso (Souza & Prezoto 2006; Souza *et al.* 2010; Souza *et al.* 2014). The distribution of *M. confusus* is restricted to Atlantic Forest sites in Minas Gerais (Souza *et al.* 2017), and Rio de Janeiro States (Richards 1978; Souza *et al.* 2020a), and has not yet been recorded in conservation units of the state (Oliveira *et al.* 2021). *P. pacificus* occurs at Atlantic Forest sites of Minas Gerais and Rio Grande do Sul States (Richards 1978), as well as in Cerrado areas of Mato Grosso State (Diniz & Kitayama 1998; Souza *et al.* 2020b). Mata do Baú was found to host social wasp species that are restricted to tropical forests in Brazil.

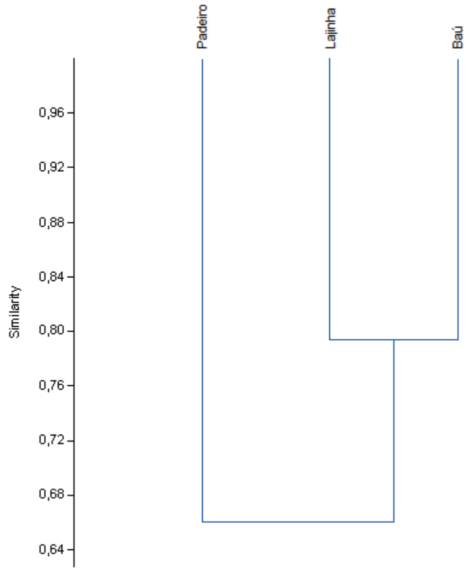

Figure 2. Dendrogram of similarity between social wasps recorded in three forest fragments (Mata do Baú, Cachoeira da Lajinha, and Cachoeira do Padeiro) in the municipalities of Barroso and Prados, Minas Gerais State, Brazil.

Cachoeira da Lajinha had six exclusive species: *Agelaia pallipes* (Olivier), *Polybia flavifrons* Richards, *Mischocyttarus artifex* (Ducke), *Mischocyttarus buyssoni* (Ducke), *Polistes actaeon* Haliday, and *Polistes subsericius* de Saussure. This is the second record of *M. artifex* in southeastern Brazil (Souza *et al.* 2010); the species was previously restricted to the Amazon region (Richards 1978). In the current study, the *M. artifex* colony was found at a gallery forest site, which is similar to riparian forests, where the first occurrence of the species outside the Amazon region was reported (Rio das Mortes, Barroso, near Prados). *M. buyssoni* had only been reported in Minas Gerais State by Richards (1978); thus, this is the first field record of the species (Oliveira *et al.* 2021).

The 16 species common to the three fragments have wide geographical distribution (Richards 1978; Simões *et al.* 2012; Auko *et al.* 2017; Souza *et al.* 2017; Somavilla *et al.* 2021), being found in different ecosystems, explaining why they were recorded at all sites evaluated in this study.

The richness of social wasps in the municipality of Barroso increased from 45 (Souza *et al.* 2017) to 48 species in the current study. This number is high compared with those of other studies carried out in the Atlantic Forest and Cerrado in Brazil (Souza *et al.* 2020a, 2020b). Such findings might be related to the increase in sampling effort in the region over the last two decades (Souza & Prezoto 2006; Souza *et al.* 2014; Souza *et al.* 2020a), demonstrating (i) the importance of inventories that carry out sampling for more than a year, which is the average sampling period observed in other studies, and (ii) how social wasp fauna can be underestimated when there is a lack of research in certain areas, biomes, and regions.

Although Mata do Baú and Cachoeira da Lajinha did not differ in species richness and had more species than Cachoeira do Padeiro, all fragments were found to harbor exclusive communities. Thus, an increase in anthropogenic pressure in any of the three fragments may lead to losses in social wasp species. This possibility is even more worrisome given that the evaluated forest fragments are not part of conservation units (Oliveira *et al.* 2021).

Forest fragment size alone did not influence social wasp communities in the study area, but, possibly, communities were significantly affected by a combination of factors, including fragment size, adjacent vegetation, and anthropogenic pressures. Finally, the results of the present study add to those of previous research and reinforce that fragmentation of environments negatively impacts social wasp communities.

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