Sociobiology
An international journal on social insects

RESEARCH ARTICLE - WASPS

Species Richness and Abundance of Social Wasps (Vespidae: Polistinae) Associated with Shaded Cocoa Agroforests (*Theobroma cacao* L.) in Southern Bahia State, Brazil

José Victor A. Ferreira[1], José C. Morante-Filho[1], Alexandre Somavilla[2], Danielle Storck-Tonon[3], Maíra Benchimol[1]

1 - Applied Ecology and Conservation Lab, Universidade Estadual de Santa Cruz, Ilhéus-BA, Brazil
2 - Instituto Nacional de Pesquisas da Amazônia, Coordenação de Biodiversidade, Manaus-AM, Brazil
3 - Programa de Pós-Graduação em Ambiente e Sistemas de Produção Agrícola (PPGASP), Universidade do Estado de Mato Grosso, Tangará da Serra-MT, Brazil

Article History

Edited by
Marcel G. Hermes, UFLA, Brazil
Received 28 June 2024
Initial acceptance 19 September 2024
Final acceptance 05 December 2024
Publication date 30 December 2024

Keywords
Agricultural system, agroecosystem, biological control, biodiversity-friendly, new species records, taxonomic diversity.

Corresponding author
José V. A. Ferreira
Applied Ecology and Conservation Lab.
Universidade Estadual de Santa Cruz
Km 16 - Rodovia Ilhéus Itabuna
Salobrinho, Ilhéus-BA, Brasil.
CEP: 45662-900
E-Mail: ferreirajvabio@gmail.com

Abstract

Traditional cocoa agroforests of southern Bahia in Brazil, locally known as "cabrucas", are highly relevant for sheltering forest species, being thus recognized as a biodiversity-friendly agricultural system. However, despite their role in biodiversity conservation, little is known about the ability of cocoa agroforests to maintain social wasp assemblages in human-modified landscapes. Here, we present the first list of social wasp species recorded in shaded cocoa agroforests in southern Bahia. In total, we collected 25 species of social wasps belonging to nine genera, representing 20% of the known species richness for the entire northeastern region of Brazil. In particular, *Angiopolybia pallens* (Lepeletier), *Agelaia angulata* (Fabricius), and *Agelaia centralis* (Cameron) were the most abundant species, with 186, 70, and 36 individuals, respectively. Notably, we report six previously unrecorded species from Bahia state: *Agelaia flavipennis* (Ducke), *Polybia emaciata* Lucas, *Polybia quadricincta* (Saussure), *Agelaia angulicollis* (Spinola), *Parachartegus smithii* (Saussure) and *Protopolybia acutiscutis* (Cameron). Of these six species, three are recorded for the first time in the Northeast region of Brazil and two for the Atlantic Forest biome. Based on our findings, we emphasize that cocoa agroforests can contribute to maintaining the diversity of social wasps in human-modified landscapes.

Introduction

Brazil, a country with high biodiversity, is home to more than 90,000 described species of insects (Rafael et al., 2024). However, a considerable portion of this diversity remains unknown or restricted to specific regions of the country, as is the case of social wasps of the subfamily Polistinae, alongside Eumeninae and Masarinae, which encompasses the three subfamilies of Vespidae occurring in Brazil. Overall, 1,050 species of Polistinae wasps are recognized worldwide, with about a third of these species (381) recorded in Brazil (Somavilla et al., 2021).

Given that social wasps are predatory insects (Michelutti et al., 2017), particularly Lepidoptera immatures, these organisms play an important role in regulating trophic chains in natural systems (Brock et al., 2021). In addition, social wasps also perform a fundamental role in natural biological control, especially insect pests in agricultural systems (Prezoto et al., 2019; Southon et al., 2019). Despite being relatively well-studied insects, which means that these wasps' evolutionary, behavioral, and ecological biology are reasonably well-known (Prezoto et al., 2021), there are still many gaps in the geographic distribution of social wasps. Even in highly diverse biomes that concentrate most studies

on social wasps, such as the Atlantic Forest, there are regions where the taxonomic diversity of these insects remains poorly explored or even unknown (Souza et al., 2020; dos Santos et al., 2020).

One of the possible limitations in understanding the geographic distribution of social wasps is associated with the fact that natural habitat is primarily the focus of most species' inventories, which limits the understanding of species diversity in other environments (Somavilla et al., 2019; Somavilla et al., 2020). However, surveying wasp species associated with agricultural systems may be relevant for understanding the species diversity patterns in anthropogenic areas and identifying species of agricultural interest. In addition, several insect species are associated with agricultural areas, which comprise a significant extent of human-modified landscapes worldwide (Melo et al., 2013; Somavilla et al., 2016; Ferreira et al., 2020). Along with life-history attributes, the ability of native species to use agricultural areas depends on the crop system and its local level of intensification, factors that can affect resource availability for most insect species (Oakley & Bicknell, 2022).

Shaded cocoa agroforests (*Theobroma cacao* L.) of southern Bahia in Brazil are agroecosystems exhibiting high value for biodiversity maintenance in human-modified landscapes (Cassano et al., 2009). Historically, cocoa has been cultivated in a system popularly known as cabruca, where cocoa trees are planted under the shade of large trees. Thus, the association of emergent trees with cocoa trees creates high structural complexity systems, making them highly relevant for biodiversity conservation (Cassano et al., 2009). However, in the 1980s, after the incidence of the witch's broom fungus (*Moniliophthora perniciosa*), there was an expansion of intensive cocoa cultivation areas, such as cocoa monocultures or full-sun cocoa production (Alger & Caldas, 1994; Gama-Rodrigues et al., 2021), with negative impacts on biodiversity (Niether et al., 2020; Ferreira et al., 2020). Despite this, cocoa production in the cabruca system still represents one of the region's main economic activities, covering a total of ~11% of the 83 cocoa-producing municipalities in southern Bahia state (Mapbiomas, 2023).

These agroforests maintain a higher amount of large canopy trees to provide shade for cocoa trees, creating, therefore, greater structural complexity of the vegetation and consequently providing high resource availability (Cassano et al., 2009). In addition, the role of these agroforests in biodiversity conservation may be even more relevant if we consider that these agroecosystems are located in the Atlantic Forest, a biodiversity hotspot (Myers et al., 2000) highly threatened by deforestation, which has destroyed about 80% of its original vegetation (Vancine et al., 2024). However, the species diversity of social wasps associated with these agroforests remains unknown. Therefore, surveys of wasp species in this type of agricultural system can enhance our understanding of the actual geographic distribution of these insects in Brazil and assess the value of agroforests for wasp conservation in human-modified landscapes.

In our study, we aimed to identify which species of social wasps are associated with the shaded cocoa agroforests in southern Bahia, a region retaining high species diversity and endemism for various floristic and faunal groups within the Brazilian Atlantic Forest (Martini et al., 2007; Dias et al., 2014).

Material and methods

Study Area

Our study was conducted in the southern region of Bahia state, Brazil, specifically in the municipalities of Arataca, Belmonte, Canavieiras, Ilhéus, Itapebi, Mascote, Santa Luzia, Una, and Uruçuca (Fig 1; Table S1). The region is in the Atlantic Forest biome, considered a global biodiversity hotspot (Myers et al., 2000), being characterized by a hot and humid climate, with average annual temperatures of 24°C and annual precipitation ranging from 1700 to 2000 mm (Gouvêa, 1969). Given the changes in land use over the last few decades, the region is currently composed of a mosaic of environments consisting mainly of remnants of forests, cattle pastures, and shaded cocoa agroforests (Cabral et al., 2021).

Social wasp collection

We sampled social wasps in 30 cocoa agroforests from December 2022 to February 2023, a single field campaign per agroforest. The agroforests were selected to meet the objectives of the "Eco-nomia das Cabrucas" project, whose sites were chosen to ensure a gradient of forest cover on a landscape scale, which the forest cover ranged from 4.4% to 79.4%, within a radius of 1,000 m surrounding of each agroforest. Each agroforest was spaced at least 2 km apart to ensure sampling independence, covering a total area of 5,386 km². In each agroforest, we established a transect of approximately 50 m, located about 100 m from the nearest edge. Along the transect (Fig 1A), we deployed three flight interception traps of the Townes Malaise model, spaced approximately 50 m apart (Fig 1B). Additionally, we installed six 500 ml plastic bottle traps (Fig 1C) containing three types of attractive baits: guava juice, orange juice, and sardine solution. The bottle traps were installed at about 1.5 m above the ground, spaced approximately 10 m apart from each other, and the different baits were distributed alternately (Fig 1A). We used industrialized guava and orange juices with a concentration of 50% and 35% natural juice, respectively, according to the manufacturer's specifications. The sardine solution comprised 125 g of crushed sardines and oil diluted in 1 L of water (methodology adapted from Souza et al. 2015). All traps remained installed for an uninterrupted period of about 72 hours. The specimens collected were identified using the identification keys proposed by Somavilla and Carpenter (2021) and Richards (1978) and also through comparisons with previously identified species from the Invertebrate Collection of the National Institute for Amazonian Research (INPA), where the material is deposited. The collections were carried out following the Brazilian legislation, under

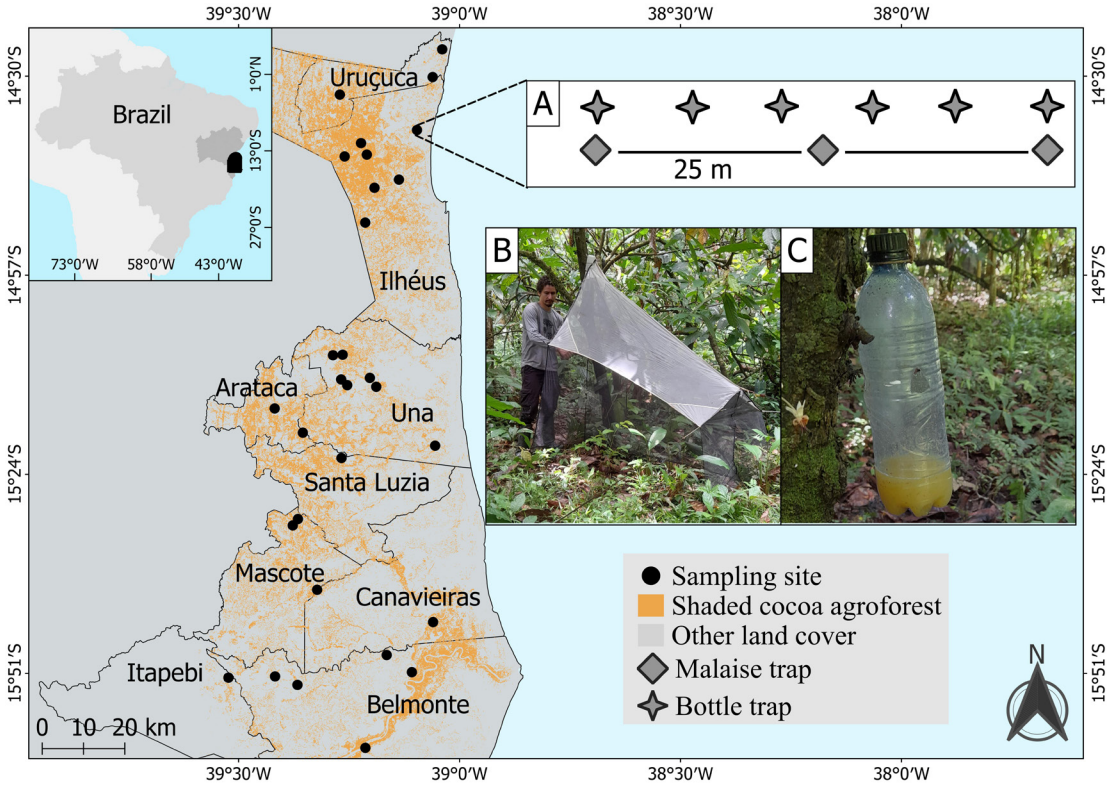

Fig 1. Location of the 30 cocoa agroforests sampled in nine municipalities in southern Bahia state, Brazil. The map was constructed using QGIS software 3.34.1 (QGIS Development Team 2023), based on the raster of shaded cocoa agroforest cover in the south of Bahia (Mapbiomas Cacau, 2023). Diagram (A) representing the distribution pattern of the Malaise traps (B) and bottle traps (C) in each sampled agroforest.

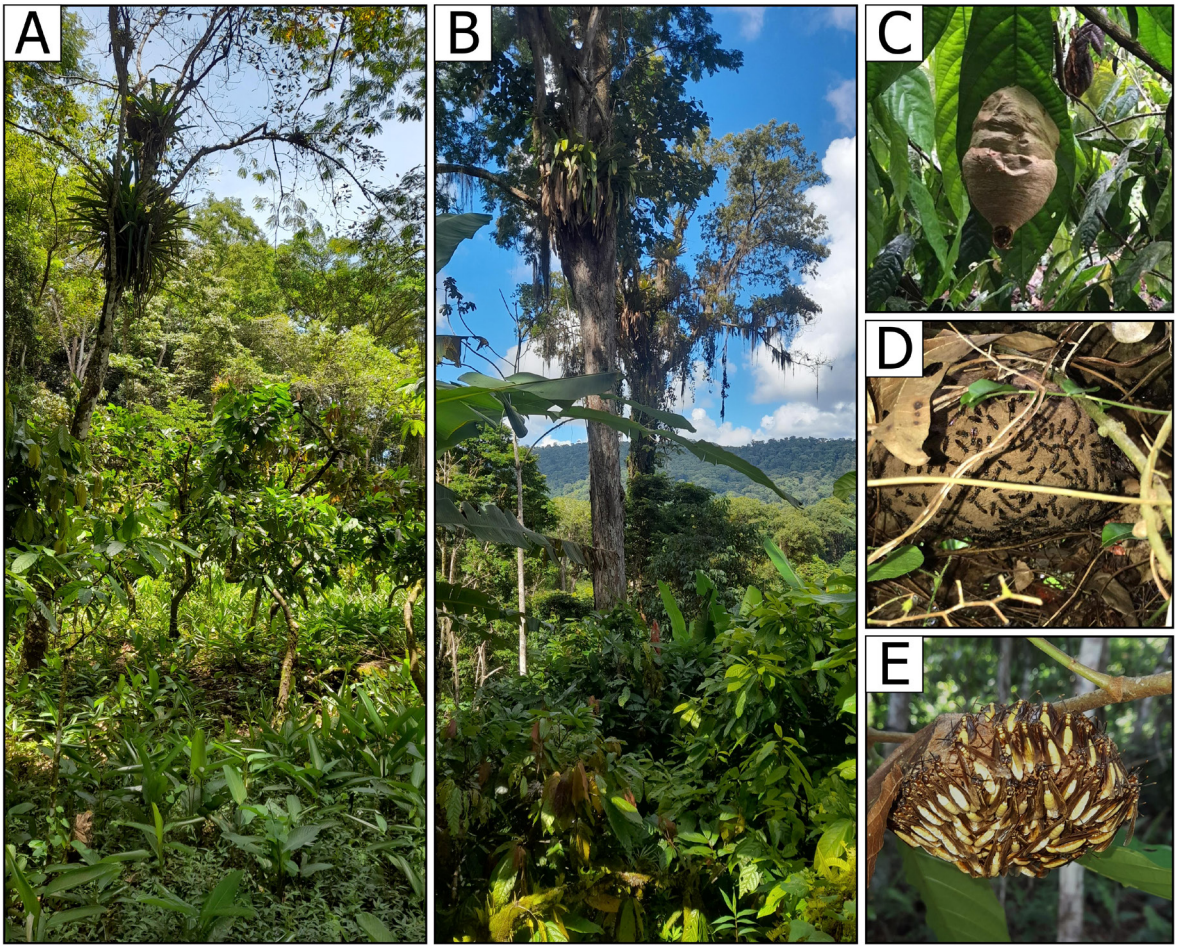

Fig 2. Shaded cocoa agroforests typically observed in southern Bahia, Brazil (A and B). Social wasp nests recorded in surveyed agroforests during our data collection: (C) *Angiopolybia pallens* (Lepeletier, 1836), (D) *Polybia* sp. Lepeletier, 1836 and (E) *Apoica pallens* (Fabricius, 1804).

authorization (SISBIO 83493-1) issued by the Chico Mendes Institute for Biodiversity Conservation (ICMBio), together with permission from the landowners.

Data analysis

Using the *iNEXT* package (Hsieh et al., 2016), we constructed a curve with the extrapolated species richness to assess whether increasing the sampling effort (i.e., the number of sampled cocoa agroforests) would lead to higher species richness. We employed a presence-absence matrix and extrapolated species richness to twice our sampling effort (i.e., 60 agroforest sites). Estimating the extrapolated species richness and the respective graph plotting were done using the R software (Team R Core 2018).

Results

In total, we collected 363 specimens of social wasps representing nine genera and 25 species (Table 1). In particular, *Polybia* Lepeletier, 1836, *Ageleia* Lepeletier, 1836, *Mischocyttarus* Carpenter, 1993, and *Protopolybia* Ducke, 1905, comprised the genera with the highest number of species, with 10, five, three, and two species, respectively. In contrast, *Angiopolybia* Araujo, 1946, *Apoica* Lepeletier, 1836, *Leipomeles* Möbius, 1856; and *Metapolybia* Ducke, 1905, each presented a single species. We also observed that *Angiopolybia pallens* (Lepeletier, 1836), *Agelaia angulata* (Fabricius, 1804), *Agelaia centralis* (Cameron, 1907), *Polybia rejecta* (Fabricius, 1798), and *Polybia occidentalis* (Olivier, 1792) showed the highest number of individuals recorded in the cocoa agroforests, with 186, 70, 36, 19, and 12 wasps, respectively (Table 1). Together, these species accounted for 20% of the species richness observed and 89% of all individuals collected in all surveyed agroforests. We recorded, for the first time, six species for the Bahia state – *Agelaia flavipennis* (Ducke, 1905), *Polybia emaciata* Lucas, 1879, *Polybia quadricincta* Saussure, 1854, *Agelaia angulicollis* (Spinola, 1851), *Parachartegus smithii* (Saussure, 1854) and *Protopolybia acutiscutis* (Cameron, 1906), the first three being recorded for the first time in the Northeast region of Brazil and two for the Atlantic Forest biome. Based on the species accumulation curve (Fig 3), increasing sampling effort can lead to a sharp increase in the species richness (36.2 species, confidence interval: lower = 24.1 and upper = 48.4). Although we did not search for social wasp nests, during our collections, we observed three nests of different species established in agroforests: *Angiopolybia pallens*, *Polybia* sp., and *Apoica pallens* (Fabricius, 1804) (Fig 2C, D and E), emphasizing the capacity of this system to offer suitable sites and conditions for the establishment of these wasps' nests.

Table 1. Social wasp species recorded in 30 cocoa agroforests located in southern Bahia state, Brazil. New records for the (*) state of Bahia and (**) the Atlantic Forest.

Specie	Bottle trap	Malaise trap	Abundance (%)
Agelaia angulata (Fabricius, 1804)	9	61	70 (19.3)
Agelaia angulicollis (Spinola, 1851) */**		1	1 (0.3)
Agelaia centralis (Cameron, 1907)	6	30	36 (9.9)
Agelaia flavipennis (Ducke, 1905) *	3		3 (0.8)
Agelaia vicina (Saussure, 1854)		3	3 (0.8)
Angiopolybia pallens (Lepeletier, 1836)	149	37	186 (51.2)
Apoica pallens (Fabricius, 1804)	1		1 (0.3)
Leipomeles dorsata (Fabricius, 1804)		6	6 (1.7)
Metapolybia cingulata (Fabricius, 1804)		1	1 (0.3)
Mischocyttarus bahiensis Zikán, 1949		1	1 (0.3)
Mischocyttarus labiatus (Fabricius, 1804)		1	1 (0.3)
Mischocyttarus santacruzi Raw, 2000		1	1 (0.3)
Parachartegus smithii (Saussure, 1854) *		1	1 (0.3)
Polybia (*Myraptera*) sp.1 White, 1941	2		2 (0.6)
Polybia belemensis Richards, 1970		1	1 (0.3)
Polybia dimidiata (Olivier, 1792)		1	1 (0.3)
Polybia emaciata Lucas, 1879 *		1	1 (0.3)
Polybia flavifrons Smith, 1857		4	4 (1.1)
Polybia jurinei Saussure, 1854	1	2	3 (0.8)
Polybia occidentalis (Olivier, 1792)		12	12 (3.3)
Polybia quadricincta Saussure, 1854 *		1	1 (0.3)
Polybia rejecta (Fabricius, 1798)	2	17	19 (5.2)
Polybia ruficeps Schrottky, 1902	2		2 (0.6)
Protopolybia acutiscutis (Cameron, 1906) */**	1	1	2 (0.6)
Protopolybia exigua (Saussure, 1854)		4	4 (1.1)
Abundance	**176**	**187**	**363**
Species richness	**10**	**21**	**25**

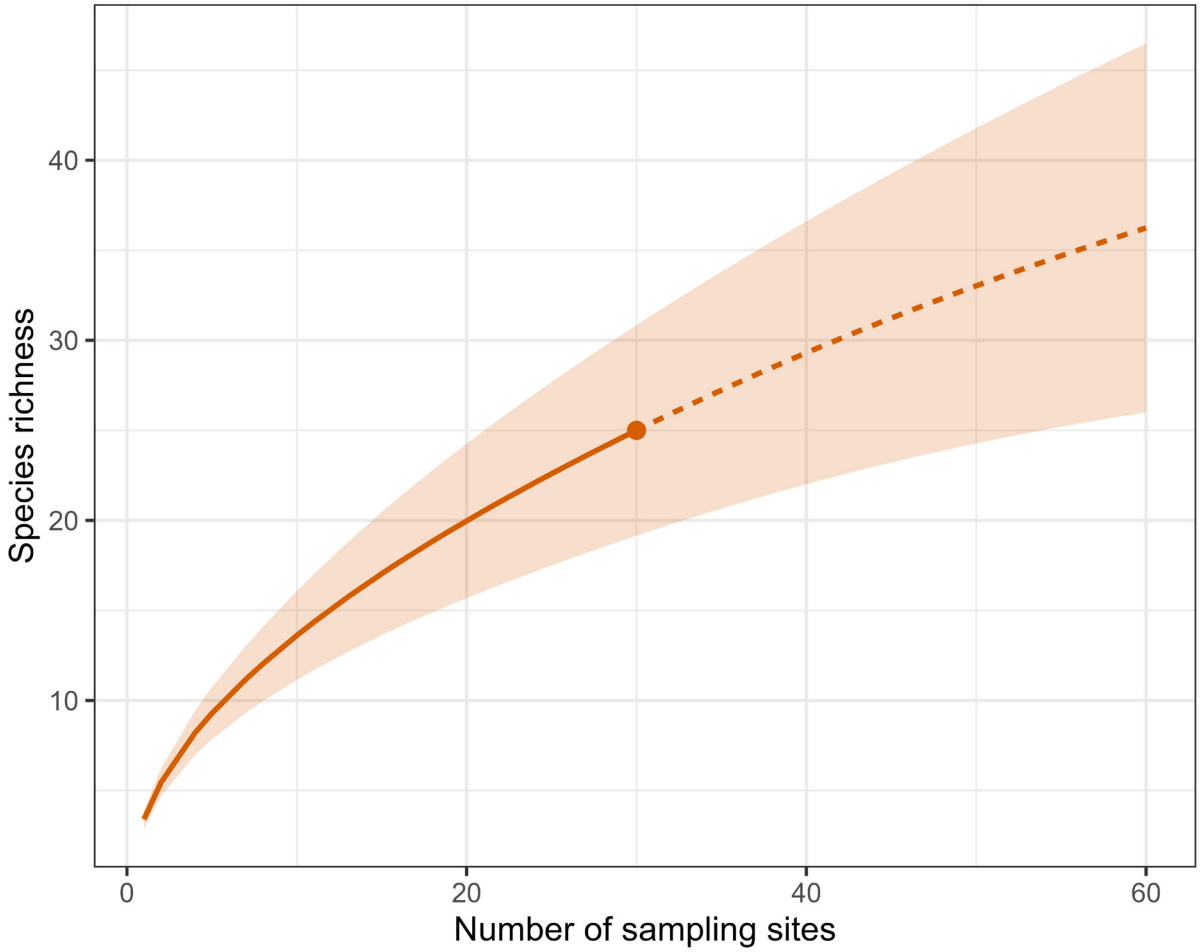

Fig 3. Species richness curve of social wasps observed (solid line) and extrapolated (dashed line) based on the number of sampling sites (i.e., 60 cocoa agroforests). The dot represents the total richness observed in the 30 sampled agroforests, and the shadow represents a 95% confidence interval.

Discussion

As far as we know, this is the first study to describe the assembly of social wasps associated with shaded cocoa agroforests in Brazil. Our study recorded a considerable species number (n = 25), especially compared to another study conducted in native forest remnants near our studied region (Aragão & Andena, 2016). In this previous study, the authors recorded 26 social wasp species over one year of sampling using three collection methods (attractive solution, light trap, and Malaise trap). In addition to the similar number of species observed between the studies, only 10 (40%) of the 25 species observed in cocoa agroforests were shared by these forest fragments (Aragão & Andena, 2016). This suggests that, in addition to the southern region of Bahia possibly having a high richness of social wasps, in which only two studies recorded a total of 41 species, the cocoa agroforests typical of this region potentially contribute to the species pool at a regional level.

A bibliographic survey of research about social wasps from the northeastern region of Brazil identified that 15 (~58%) of the 26 regional studies were conducted in the Bahia state (dos Santos et al., 2020). Based on these studies, 86 species of social wasps were documented for the state, representing 70% of the species known in the northeastern region of Brazil. This high species richness observed for Bahia may be associated with its vast territorial extension, Brazil's fifth largest state, and the high diversity of biomes within its territory: Caatinga, Cerrado, and Atlantic Forest (IBGE, 2024). Our study, therefore, recorded one-third of the known species for the Bahia state and one-fifth of the species recorded in northeastern Brazil. On a broader scale, a survey of Polistinae species recorded in the different phytophysiognomies of the Atlantic Forest identified a total of 170 species (Souza et al., 2020). Considering the scale of this survey and the diversity of habitats, which included everything from agroecosystems to important refuges for biodiversity, such as National Parks, cocoa agroforests presented a representative species richness, corresponding to 15% of the species richness recorded for the Atlantic Forest. Thus, as well as being the first inventory of social wasp species in cocoa agroforests in Brazil, our study suggests the potential importance of these agricultural systems for conserving Polistinae wasps in human-modified landscapes.

Regarding the general pattern observed of wasp assembly, the observed predominance of species of the tribe Epiponini was expected, given that this tribe has more than 250 species distributed in 19 genera, being the most endemic of the Neotropical region (Somavilla et al., 2021). In addition, Epiponini species are widely distributed throughout Brazil and recorded in all states of the country (Barbosa et al., 2016). However, despite the high proportion of species recorded in our study, we acknowledge the limitation regarding our sampling effort. Since sampling effort strongly influences species richness (Azovsky, 2011), maintaining traps in the field for longer periods or sampling more sites would increase the number of observed species, as evidenced by the estimated species number. For example, we did not collect any species from the Polistini tribe, genus *Polistes*. This result is unexpected since this tribe contains many species, is widely distributed in Brazil, and is relatively common in anthropized environments (Prezoto et al., 2021). We also acknowledge that other collection methods, such as active searching, should be used to better represent social wasp species in a community (Silveira, 2002). Therefore, we suggest that future studies expand the number of sampled agroforests or increase sampling efforts within agroforests, which could contribute to new species records for this agricultural system.

Our study documented the first records of six social wasp species for the Bahia state, with three recorded for the first time in the country's northeastern region. Among these new records, *A. flavipennis*, *P. smithii*, *P. emaciata*, and *P. quadricincta* were already expected to occur in Bahia since these species have been widely recorded in different biomes and Brazilian states (CTFB 2024). On the other hand, the occurrence of *A. angulicollis* and *P. acutiscutis* is more restricted in Brazil. In the case of both species, knowledge of their distribution had previously been restricted to the north of the country, except for records for Mato Grosso and Maranhão (Prezoto et al., 2021), especially for the Amazon biome. Given the absence of *A. angulicollis* and *P. acutiscutis* in the various studies conducted in the Amazon region, in large forest fragments (Somavilla et al., 2015; Gomes et al., 2020), urban fragments (Graça & Somavilla, 2019) or even agroecosystems (Somavilla et al., 2016), we can consider that both species are indeed rare. Therefore, in addition to contributing to the knowledge of the social wasp assemblage associated with cocoa agroforest, our study expands knowledge regarding species' geographical distribution and occurrence, including species rarely observed in social wasp inventories.

In general, our findings highlighted two points that deserve attention. Firstly, despite social wasps being a well-studied group with numerous studies on their behavior, ecology, and evolution (Prezoto et al., 2021), the distribution of these insect species in Brazil still presents sampling gaps (Barbosa et al., 2016). In particular, most research is still concentrated in the southeast region of Brazil, with a limited number of surveys being conducted in the northeast region (Barbosa et al., 2016). For example, the state of Sergipe does not present any published studies to date on social wasps (dos Santos et al., 2020). Second, our results demonstrated that, compared to forest remnants near our study area (Aragão & Andena, 2016), cocoa agroforests exhibit a considerable number of social wasp species. As well as providing food resources, shaded cocoa agroforests offer favorable conditions for establishing social wasp nests, as observed during our collections. Therefore, this agricultural system can act as a supplementary habitat for these insects, with important implications for species conservation and also for intensifying the provision of ecosystem services such as biological control provided by wasps (Brock et al., 2021). Despite the recognized importance of cocoa agroforests for biodiversity conservation (Cassano et al., 2009), the relevance of these systems for conservation is still underestimated, especially if we consider that these agroforests are located in the Atlantic Forest, one of the hotspots with the highest levels of habitat loss and degradation (Myers et al., 2000). Moreover, the Bahia state still presents high rates of deforestation of the Atlantic Forest (SOS et al., 2021), jeopardizing the maintenance of its biodiversity. In this harsh scenario, agroforests can act as an important refuge for native species, including social wasps. Therefore, we suggest that future studies on social wasps should focus on conducting inventories in poorly studied regions, such as Northeast Brazil, surveying both natural habitats and anthropogenic areas like agricultural systems. This information will help us understand the geographic distribution of species and enhance our understanding of the role of agricultural systems in maintaining native forest species in human-modified landscapes.

Author's Contributions

JVAF: Conceptualization, methodology, project administration, funding acquisition, formal analysis, writing-original draft, writing-review & editing.
JCM-F: Conceptualization, methodology, supervision, project administration, funding acquisition, writing-review & editing.
AS: Conceptualization, methodology, writing-original draft, writing-review & editing.
DS: Methodology, supervision, writing-review & editing.
MB: Methodology, supervision, project administration, funding acquisition, writing-review & editing.

Data availability

The datasets generated and/or analyzed during the current study are available upon request to the corresponding author.

Acknowledgments

We thank Dr. Mônica Josene Barbosa Pereira for kindly lending us some Malaise traps. We want to thank the farm owners for permitting us to conduct our research, as well as the team responsible for selecting the study areas: Martin

Cervantes, Marina Figueiredo, Laís Rodrigues, Rebeca Sampaio, Paloma Resende, and Matheus Torres. We thank the team that assisted us in the fieldwork: Carla Rocha, Eduarda Caroline, Elimardo Bandeira, Júlia Ellen, Leonardo M. de Abreu, and Maria Lavanholle. Finally, we would like to thank our colleagues and professors from the Applied Ecology and Conservation Lab (LEAC/UESC) for their discussions and contributions throughout the development of this study. This research was funded by The Rufford Foundation (nº 36668-1), Fundo Brasileiro para Biodiversidade (FUNBIO, nº 039/2022), along with the Humanize Institute and Eurofins, Idea Wild, and the Pró-Reitoria de Pesquisa e Pós-Graduação (PROPP nº 073.6764.2021.0013306-41) at the Universidade Estadual de Santa Cruz (UESC). JVAF obtained a graduate scholarship from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES). This manuscript was written while JVAF was on a research stay at the Yaakunah K'aax Reserve, Mexico, funded by CAPES. Maíra Benchimol (304189/2022-7) and José Carlos Morante-Filho (303302/2022-4) obtained the productivity grant from the National Council for Scientific and Technological Development (CNPq). This study is part of the 'Eco-nomia das cabrucas' project (publication number #15), coordinated by Maira Benchimol and Deborah Faria, and funded by the Brazilian Council for Research and Technology (CNPq), the Research Support Foundation of the State of Bahia (FAPESB, grant number INC0006/2019), which support the National Institute of Science and Technology in Interdisciplinary and Transdisciplinary Studies in Ecology and Evolution (INCT IN-TREE).

References

Alger, K. & Caldas, M. (1994). The declining cocoa economy and the Atlantic Forest of Southern Bahia, Brazil: Conservation attitudes of cocoa planters. The Environmentalist, 14: 107-119. https://doi.org/10.1007/BF01901304

Aragão, M. & Andena, S.R. (2016). The social wasps (Hymenoptera: Vespidae: Polistinae) of a fragment of Atlantic Forest in southern Bahia, Brazil. Journal of Natural History, 50: 1411-1426. https://doi.org/10.1080/00222933.2015.1113317

Azovsky, A.I. (2011). Species-area and species-sampling effort relationships: Disentangling the effects. Ecography, 34: 18-30. https://doi.org/10.1111/j.1600-0587.2010.06288.x

Barbosa, B.C., Detoni, M., Maciel, T.T. & Prezoto, F. (2016). Studies of social wasp diversity in Brazil: Over 30 years of research, advancements and priorities. Sociobiology, 63: 858-880. https://doi.org/10.13102/sociobiology.v63i3.1031

Brock, R.E., Cini, A. & Sumner, S. (2021). Ecosystem services provided by aculeate wasps. Biological Reviews, 96: 1645-1675. https://doi.org/10.1111/brv.12719

Cabral, J.P., Faria, D. & Morante-Filho, J.C. (2021). Landscape composition is more important than local vegetation structure for understory birds in cocoa agroforestry systems. Forest Ecology and Management, 481: 118704. https://doi.org/10.1016/j.foreco.2020.118704

Cassano, C.R., Schroth, G., Faria, D., Delabie, J.H. & Bede, L. (2009). Landscape and farm scale management to enhance biodiversity conservation in the cocoa producing region of southern Bahia, Brazil. Biodiversity and Conservation, 18: 577-603. https://doi.org/10.1007/s10531-008-9526-x

CTFB. (2024). Catálogo Taxonômico da Fauna do Brasil. http://fauna.jbrj.gov.br/fauna/listaBrasil/br/gov/jbrj/fauna/web/listaBrasil/taxa/consultarPublico/bem-vindo-consulta-publica.jsp#tabs-1. (Accessed date: June 2024).

Dias, I.R., Medeiros, T.T., Nova, M.F.V. & Solé, M. (2014). Amphibians of Serra Bonita, Southern Bahia: A new hotpoint within Brazil's Atlantic Forest hotspot. Zookeys, 130: 105-130. https://doi.org/10.3897/zookeys.449.7494

Ferreira, A.S., Peres, C.A., Dodonov, P. & Cassano, C.R. (2020). Multi-scale mammal responses to agroforestry landscapes in the Brazilian Atlantic Forest: The conservation value of forest and traditional shade plantations. Agroforestry Systems, 94: 2331-2341. https://doi.org/10.1007/s10457-020-00553-y

Ferreira, J.V.A., Storck-Tonon, D., da Silva, R.J., Somavilla, A., Pereira, M.J.B. & da Silva, D.J. (2020). Effect of habitat amount and complexity on social wasps (Vespidae: Polistinae): Implications for biological control. Journal of Insect Conservation, 24: 613-624. https://doi.org/10.1007/s10841-020-00221-7

Gama-Rodrigues, A.C., Müller, M.W., Gama-Rodrigues, E.F. & Mendes, F.A.T. (2021). Cacao-based agroforestry systems in the Atlantic Forest and Amazon Biomes: An ecoregional analysis of land use. Agricultural Systems, 194: 103270. https://doi.org/10.1016/j.agsy.2021.103270

Gomes, B., Lima, C., Silva, M. & Noll, F. (2020). High number of species of social wasps (Hymenoptera, Vespidae, Polistinae) attests the great biodiversity of Western Amazon: a survey from Rondônia, Brazil. Sociobiology, 67: 112-120. https://doi.org/10.13102/sociobiology.v67i1.4478

Gouvêa, J.B.S. (1969). Contribuição à Geomorfologia do Sul da Bahia. Área dos baixos cursos dos rios Pardo e Jequitinhonha. Itabuna.

Graça, M.B. & Somavilla, A. (2019). Effects of forest fragmentation on community patterns of social wasps (Hymenoptera: Vespidae) in Central Amazon. Austral Entomology, 58: 657-665. https://doi.org/10.1111/aen.12380

Hsieh, T.C., Ma, K.H. & Chao, A. (2016). iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods in Ecology and Evolution, 7: 1451-1456. https://doi.org/10.1111/2041-210X.12613

IBGE. (2024). Instituto Brasileiro de Geografia e Estatística. https://brasilemsintese.ibge.gov.br/territorio.html. (Accessed date: November 2024).

Mapbiomas Cacau. (2023). Mapeamento do Cultivo Sombreado de Cacau no Sul da Bahia. https://brasil.mapbiomas.org/en/mapbiomas-cacau/. (Accessed date: June 2024).

Martini, A.M.Z., Fiaschi, P., Amorim, A.M. & Paixão, J.L. (2007). A hot-point within a hot-spot: A high diversity site in Brazil's Atlantic Forest. Biodiversity and Conservation, 16: 3111-3128. https://doi.org/10.1007/s10531-007-9166-6

Melo, F.P.L., Arroyo-Rodríguez, V., Fahrig, L., Martínez-Ramos, M. & Tabarelli, M. (2013). On the hope for biodiversity-friendly tropical landscapes. Trends in Ecology and Evolution, 28: 462-468. https://doi.org/10.1016/j.tree.2013.01.001

Michelutti, K.B., Soares, E.R.P., Prezoto, F. & Antonialli-Junior, W.F. (2017). Opportunistic strategies for capture and storage of prey of two species of social wasps of the genus *Polybia* lepeletier (Vespidae: Polistinae: Epiponini). Sociobiology, 64: 105-110. https://doi.org/10.13102/sociobiology.v64i1.1142

Myers, N., Mittermeier, R.A., Mittermeier, C.G. et al. (2000). Biodiversity hotspots for conservation priorities. Nature, 403: 853-858. https://doi.org/10.1038/35002501

Niether, W., Jacobi, J., Blaser, W.J. et al. (2020). Cocoa agroforestry systems versus monocultures: a multi-dimensional meta-analysis. Environmental Research Letters, 15: 104085. https://doi.org/10.1088/1748-9326/abb053

Oakley, J.L. & Bicknell, J.E. (2022). The impacts of tropical agriculture on biodiversity: a meta-analysis. Journal of Applied Ecology, 59: 3072-3082. https://doi.org/10.1111/1365-2664.14303

Prezoto, F., Nascimento, F.S., Barbosa, B.C. & Somavilla, A. (2021). Neotropical Social Wasps: Basic and Applied Aspects. Cham: Springer International Publishing, 472 p. https://doi.org/10.1007/978-3-030-53510-0

Prezoto, F., Maciel, T.T., Detoni, M. et al. (2019). Pest control potential of social wasps in small farms and urban gardens. Insects, 10: 1-10. https://doi.org/10.3390/insects10070192

Rafael, J.A., Melo, G.A.R., Carvalho, C.J.B., Casari, A.S., & Constantino, R. (2024). Insetos do Brasil: Diversidade e Taxonomia. Manaus: Editora INPA, 880 p.

Richards, O.W. (1978). The social wasps of the Americas excluding the Vespinae. London: British Museum, 580 p.

Santos, L.V.B., Monteiro, D.P., Somavilla, A., Neto J.R.A. & Silva, P.R.R. (2020). Social Wasps (Hymenoptera: Vespidae: Polistinae) from Northeastern Brazil: State of the Art. Sociobiology, 67: 481-491. https://doi.org/10.13102/sociobiology.v67i4.5466

Silveira, O.T. (2002). Surveying neotropical social wasps: an evaluation of methods in the "Ferreira Penna" research station (ECFPn), in Caxiuanã-PA, Brazil (Hym., Vespidae, Polistinae). Papéis Avulsos de Zoologia, 42: 299-323. https://doi.org/10.11606/0031-1049.2002.42.p299-323

Somavilla, A., Andena, S.R. & Oliveira, M.L. (2015). Social Wasps (Hymenoptera: Vespidae: Polistinae) of the Jaú National Park, Amazonas, Brazil. EntomoBrasilis, 8: 45-50. https://doi.org/10.12741/ebrasilis.v8i1.447

Somavilla, A., Barbosa, B.C., Souza, M.M. & Prezoto, F. (2021). List of species of social wasps from Brazil. In: F. Prezoto, F.S. Nascimento, B.C. Barbosa & Somavilla, A. (Eds.), Neotropical Social Wasps: Basic and Applied Aspects (pp. 293-316). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-53510-0_16

Somavilla, A. & Carpenter, M. (2021). Key to the genera of social wasps (Polistinae) occurring in neotropics. In: F. Prezoto, F.S. Nascimento, B.C. Barbosa & Somavilla, A. (Eds.), Neotropical Social Wasps: basic and applied Aspects (pp. 327-336). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-53510-0_18

Somavilla, A., Moraes Junior, R.N.M., Oliveira, M.L. & Rafael, J.A. (2020). Biodiversity of insects in the Amazon: survey of social wasps (Vespidae: Polistinae) in Amazon rainforest areas in Amazonas state, Brazil. Sociobiology, 67: 312-321. https://doi.org/10.13102/sociobiology.v67i2.4061

Somavilla, A., Moraes Junior, R.N.M. de & Rafael, J.A. (2019). Is the social wasp fauna in the tree canopy different from the understory? Study of a particular area in the Brazilian Amazon Rainforest. Sociobiology, 66: 179-185. https://doi.org/10.13102/sociobiology.v66i1.3568

Somavilla, A., Schoeninger, K., De Castro, D.G.D., Oliveira, M., Krug, C. (2016). Diversity of wasps (Hymenoptera: Vespidae) in conventional and organic guarana (Paullinia cupana var. sorbilis) crops in the Brazilian Amazon. Sociobiology, 63: 1051-1057. https://doi.org/10.13102/sociobiology.v63i4.1178

SOS Mata Atlântica. (2021). SOS Mata Atlântica Relatório Anual 2021. https://cms.sosma.org.br/wp-content/uploads/2022/07/Relatorio_21_julho.pdf. (Accessed date: May 2024)

Southon, R.J., Fernandes, O.A., Nascimento, F.S., & Sumner, S. (2019). Social wasps are effective biocontrol agents of key lepidopteran crop pests. Proceedings of the Royal Society B: Biological Sciences, 286: 1-8. https://doi.org/10.1098/rspb.2019.1676

Souza, M.M., Perillo, L.N., Barbosa, B.C. & Prezoto, F. (2015). Use of flight interception traps of Malaise type and attractive traps for social wasps record (Vespidae: Polistinae). Sociobiology, 62: 450-456. https://doi.org/10.13102/sociobiology.v62i3.708

Souza, M.M. de, Teofilo-Guedes, G.S., Milani, L.R., de Souza, A.S.B. & Gomes, P.P. (2020). Social Wasps (Vespidae: Polistinae) from the Brazilian Atlantic Forest. Sociobiology, 67: 1-12. https://doi.org/10.13102/sociobiology.v67i1.4597

Team, R. Core. (2018). R: A language and environment for statistical computing.

Vancine, M.H., Muylaert, R.L., Niebuhr, B.B., Oshima, J.E.F., Tonetti, V., Bernardo, R., Angelo, C., Rosa, M.R., Grohmann, C.H. & Ribeiro, M.C. (2024). The Atlantic Forest of South America: spatiotemporal dynamics of the vegetation and implications for conservation. Biological Conservation, 291: 110499. https://doi.org/10.1016/j.biocon.2024.110499

Supplementary Material

Table S1. Geographical location and species of social wasps (Vespidae: Polistinae) collected in 30 shaded cocoa agroforests in the south of the state of Bahia, Brazil.

The file (Table S1.xlsx) is available for download on the article webpage.