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Ecology

Harvestmen (Arachnida: Opiliones) from the Atlantic Forest-Cerrado transition zone of Luminárias, southern Minas Gerais state, Brazil

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Abstract. The Cerrado and Atlantic Forest biomes are global biodiversity hotspots. However, these environments still face large knowledge gaps concerning fauna inventory studies, such as those on harvestmen. Our study aimed to sample harvestmen species in a transition area between the Atlantic Forest and Cerrado, contributing to future biodiversity assessments and conservation efforts in Brazil. The surveys were conducted in the municipality of Luminárias, southern Minas Gerais state, between May 2023 and March 2024. We collected 185 individuals from six species and three morphospecies with a wide geographical distribution, but whose conservation status has not been assessed, which may affect their protection. Additionally, loss of native vegetation may lead to reductions in their populations. Our study supports current literature, which suggests the need for more inventories and the creation of a Conservation Unit in the Luminárias region.

Keywords: Biodiversity; Conservation unit; Ecotone; Inventory.

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In Brazil, the Atlantic Forest and Cerrado biomes harbor high biodiversity, high rates of endemism, as well as many species (both animals and plants) at some degree of extinction risk (Mittermeier *et al*. 2005; Rech-Filho *et al*. 2009; Jordão *et al*. 2017; ICMBio 2018; Souza *et al*. 2020). All these factors, combined with their ongoing reduction and transformation, explain why these biomes are currently considered global hotspots for biodiversity conservation (Myers *et al*. 2000; Lima *et al*. 2020). Currently, only about 12.4% of the original vegetation cover of the Atlantic Forest and 45% of the Cerrado remain. This is an effect caused by deforestation, the expansion of urban areas, wildfires, the increased pressure of agricultural and livestock activities, and mining activities (Klink & Machado 2005; Oliveira *et al*. 2023).

In this way, it is essential to carry out inventories of biological diversity in these areas to build up knowledge about the richness and distribution of species, so that biodiversity management and protection programs can be designed (Stephenson & Stengel 2020). Inventories also assist in assessing the species' conservation status by the International Union for Conservation of Nature (IUCN) and the Brazilian Chico Mendes Institute for Biodiversity Conservation (ICMBio). These assessments help in implementing public policies to create, for example, Conservation Units (CUs), which are the main tools for protecting biodiversity and natural resources (Fonseca *et al*. 2010; Salvio 2017; Souza *et al*. 2018). However, many species do not have conservation status assessments, or, in some cases, the data is insufficient for a proper assessment, making it difficult to identify priority areas for their protection.

This is the case with harvestmen (Arachnida: Opiliones), popularly known in Brazil as "vira-mundo", "bodum", "João-fedido", "aranha-alho", among others (Gnaspini & Hara 2007; Machado *et al.* 2007). These invertebrates provide numerous environmental services to the ecosystem, such as carbon cycling and direct role in several food chains (Acosta & Machado 2007; Papura *et al*. 2020; Rubim *et al*. 2021, 2022). In Brazil, the Atlantic Forest is the best-researched biome in terms of opiliofauna and is home to the greatest richness of these arachnids in the country (Pinto-Da-Rocha *et al.* 2005; Rubim *et al*. 2023a), followed by the Amazon Rainforest (Tourinho *et al.* 2014; Kury & Pinto-da-Rocha 2022). On the other hand, biomes with lower annual humidity, such as the Cerrado and Caatinga, are still poorly investigated and have under-sampled harvestmen faunas (Souza *et al.* 2014; Pérez-González *et al*. 2017; Rubim *et al*. 2023b, 2024).

In Minas Gerais state, southeastern Brazil, studies with harvestmen fauna are also centered in the Atlantic Forest, where the richness can reach up to 24 species per locality (Soares 1970; Costa *et al*. 2020; Ferreira *et al*. 2019, 2020; Pádua *et al.* 2022, 2023). There are also studies in the Cerrado of Minas Gerais, with a diversity of up to 13 species per site (Rubim

et al. 2024). In the Caatinga, currently reported diversity is up to three species per locality (Rubim *et al*. 2023b). In the transition regions between the Atlantic Forest and Cerrado, up to nine species have been recorded (Lima *et al*. 2022). It is clear, therefore, that there are biomes and many regions with low sampling and no information on the local opiliofauna (Figure 1).

Intensifying the development of inventories in ecotone areas is essential for understanding the diversity, distribution, and adaptation of different taxa in distinct phytophysiognomies. This effort contributes to the conservation of these environments, which often exhibit high species richness (Kark & Rensburg 2006; Pinheiro & Dornas 2006; Faria & Kaizer 2020).

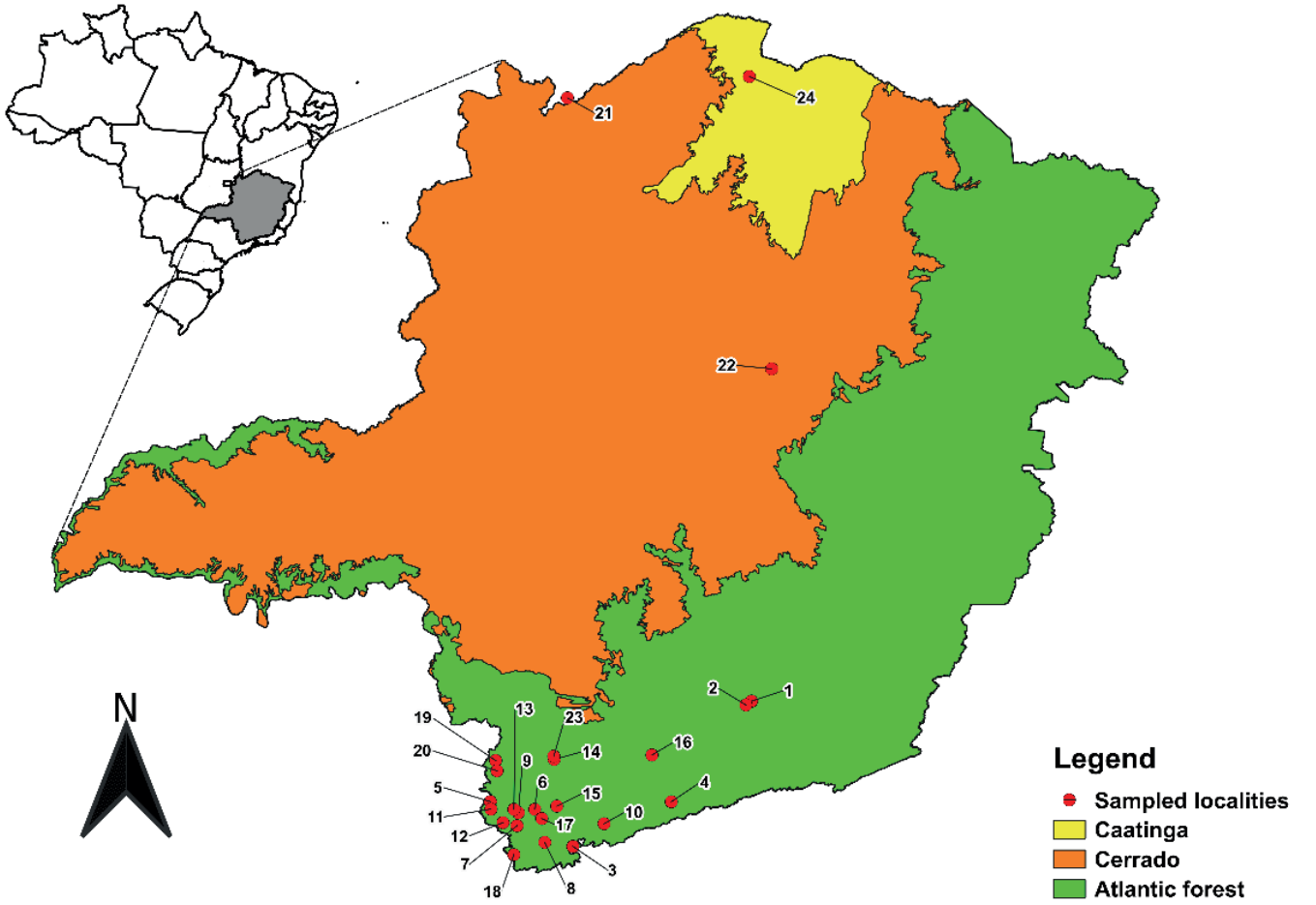

Figure 1. Localities in Minas Gerais state, southeastern Brazil (municipalities or Conservation Units) with opiliofauna sampling: municipalities of Barroso and Prados (1 and 2: Lima *et al*. 2022); Fernão Dias Permanent Protection Area, Gonçalves (3: Pádua *et al*. 2023); Serra do Papagaio State Park (4: Ferreira *et al.* 2019); municipalities of Albertina, Borda da Mata, Bueno Brandão, Cambuí, Inconfidentes, Itajubá, Monte Sião, Jacutinga, Ouro Fino, Poço Fundo, Pouso Alegre, São Tomé das Letras, Tocos do Mogi and Toledo (5 to 18: Costa *et al.* 2020); municipality of Poços de Caldas (19 and 20: Soares 1970; Pádua *et al*. 2022); Grande Sertão Veredas National Park (21: Rubim *et al*. 2024); Sempre Vivas National Park and Rio Machado Environmental Protection Area (22 and 23; Ferreira *et al.* 2020); Mata Seca State Park (24: Rubim *et al.* 2023b).

Thus, the aim of this study was to sample harvestmen species present in a transition area between the Cerrado and the Atlantic Forest in the municipality of Luminárias, southern Minas Gerais state. With this data, we intend to provide information on their distribution in these biomes for possible management and preservation initiatives.

MATERIAL AND METHODS

The municipality of Luminárias (-22.30908, -49.32947) has an average annual temperature of 17.8°C, rainfall of 1,594 mm (Alvares *et al*. 2013), a minimum altitude of 845 m and a maximum of 1,496 m, and a subtropical climate with dry winters and rainy summers (Cwa, *sensu* Köppen).

Luminárias is inserted in an ecotone area of Atlantic Forest and Cerrado, with the presence of Rupestrian Field. This region is assessed as vulnerable to the loss of fauna and flora and to erosion, which can be intensified by anthropogenic exploitation activities in the region, characterized by agriculture and quartz mining (Carvalho *et al*. 2007; Lima *et al*. 2011; Silva *et al*. 2011).

Sampling took place in May 2023, from September to December 2023 and February and March 2024. Seven campaigns were carried out lasting two to three consecutive days, except for the October 2023 campaign, which lasted five days for logistical reasons. We exclusively used active search for collection of specimens through visual search and manual gathering, as this method is regarded as the most effective for harvestmen (Pinto-da-Rocha & Bonaldo 2006). The collections were carried out by five researchers who inspected ravines, leaf litter, cracks in rocks, cave entrances, the surface of trunks and decomposing soil. The sampling period took place between 6 pm and 9 pm, when harvestmen are most active (Resende *et al*. 2012), with 69 h of sampling effort per researcher (a total of 345 h).

The specimens were collected in six locations, three of which were characterized by the presence of gallery forest, a Cerrado phytophysiognomy: Cachoeira do Mamono, Complexo do Mandembe and Pedra Furada. The other localities are characterized by montane semi-deciduous forest (or altitude fields), Atlantic Forest phytophysiognomies (*sensu* Oliveira-Filho 2006): Rio Ingaí (Serra de São José), Serrinha and Caverna da Serra Grande (Figure 2).

Figura 2. Sampling locations for harvestmen (Arachnida: Opiliones) in Luminárias municipality: Serra de São José (A), Cachoeira da Pedra Furada (B), complexo do Mandembe (C), Caverna da Serra Grande (D).

The hand collected specimens were stored in 70% alcohol and then sent for identification by Dr. Adriano Brilhante Kury (Federal University of Rio de Janeiro, National Museum, Department of Invertebrates), where the material was deposited.

To assess the species' threatened status, the websites of the Chico Mendes Institute for Biodiversity Conservation (ICMBio, salve.icmbio.gov.br) and the International Union for Conservation of Nature (IUCN, iucnredlist.org) were consulted.

To discuss the inventory studies carried out in Minas Gerais, we considered only species lists focusing on the Atlantic Forest and/or Cerrado. Therefore, descriptions of new species (Pinto-da-Rocha 1996; Hara & Pinto-da-Rocha 2008; Kury 2008) or literature reviews (Ázara *et al*. 2016, Ázara & Ferreira 2018) were not included. A cluster analysis of the diversity between the areas was carried out using Jaccard's similarity index, using the Past software (Hammer *et al*. 2005).

To assess the sampling effort, we created an accumulation curve based on the observed richness with a 95% confidence interval, applying the Bootstrap 1 estimator, using the EstimateS 9.1.0 software (Cowell & Elsensonh 2014). Collections were carried out under the license SISBio: 91709-1.

RESULTS AND DISCUSSION

We collected 185 individuals belonging to six species and three morphospecies (Table 1, Figure 3), from three families: Cryptogebiidae, Sclerosomatidae and Gonyleptidae. The most abundant species was *Acutisoma longipes* (Roewer, 1913) (Opiliones: Gonyleptidae) with 54 specimens (Figures 3C-D).

The richness observed in our study is similar to other studies carried out in semi-deciduous forests or gallery forests in Minas Gerais state, which reported seven to 11 spp. (Soares 1970; Ferreira *et al*. 2020; Lima *et al*. 2022). However, the richness found in our study was lower compared to studies carried out in mixed forests at altitudes above 1,400 m, which are home to 17 to 24 spp. (Ferreira *et al.* 2019; Pádua *et al*. 2023). Our species richness was also lower compared to studies carried out on the coastal areas of southern and southeastern Brazil, which can reach 52 spp. per locality (Bragagnolo & Pinto-da-Rocha 2003; Resende *et al.* 2012). This is probably because mixed forests and coastal ombrophilous forests are located at higher altitudes, offer more humidity and therefore are preferred by most harvestmen, which are susceptible to desiccation (Curtis & Machado 2007; Santos 2007; DaSilva *et al*. 2011). However, it is important to emphasize that differences in methodologies, sampling periods and geographic extent of areas covered in different studies may influence these results.

The high abundance of *A. longipes* can therefore be explained by its generalist habits, with a wide geographical distribution (Peres *et al*. 2018). This species has already been recorded in the states of São Paulo and Rio de Janeiro (DaSilva & Gnaspini 2010) and in several localities in the Atlantic Forests of Minas Gerais state (Ferreira *et al.* 2019, 2020; Costa *et al*. 2020; Lima *et al*. 2022; Pádua *et al*. 2022, 2023), and also associated with cave environments (Ázara & Ferreira 2018). This species also occurs in Cerrado phytophysiognomies (Ferreira *et al*. 2020; Lima *et al*. 2022), probably due to its broad ecological relevance and the ability to explore drier ecosystems, as suggested by DaSilva & Gnaspini (2010). However, *A. longipes* was not found in a recent expedition in the dry Caatinga of Minas Gerais state (Rubim *et al*. 2023b). Additionally, the review of scientific collections by Ázara & Ferreira (2018) also lists the presence of *A. longipes* in caves located in different biomes, including in the municipality of Luminárias.

The species accumulation curve has completely reached an asymptote (Figure 4), and even though the BootStrap1 estimator shows that the richness could reach 9.17, the

Table 1. Families, species, abundance, and richness of harvestmen collected in the transition area between Cerrado and Atlantic Forest, Luminárias municipality, southern Minas Gerais state, Brazil.

Family	Species / morphospecies	Abundance
Gonyleptidae	*Acutisoma longipes* Roewer, 1913	54
	Currala spinifrons Roewer, 1927	4
	Discocyrtus flavigranulatus Soares, 1944	11
	Krateromaspis dilatata (Sørensen, 1884)	29
	Longiperna trembao Pinto-da-Rocha & Bragagnolo, 2010	39
	Mischonyx squalidus Bertkau, 1880	1
Cryptogebiidae	*Camarana* sp.	5
Sclerosomatidae	Gagrellinae gen. sp 1.	30
	Gagrellinae gen. sp 2.	6

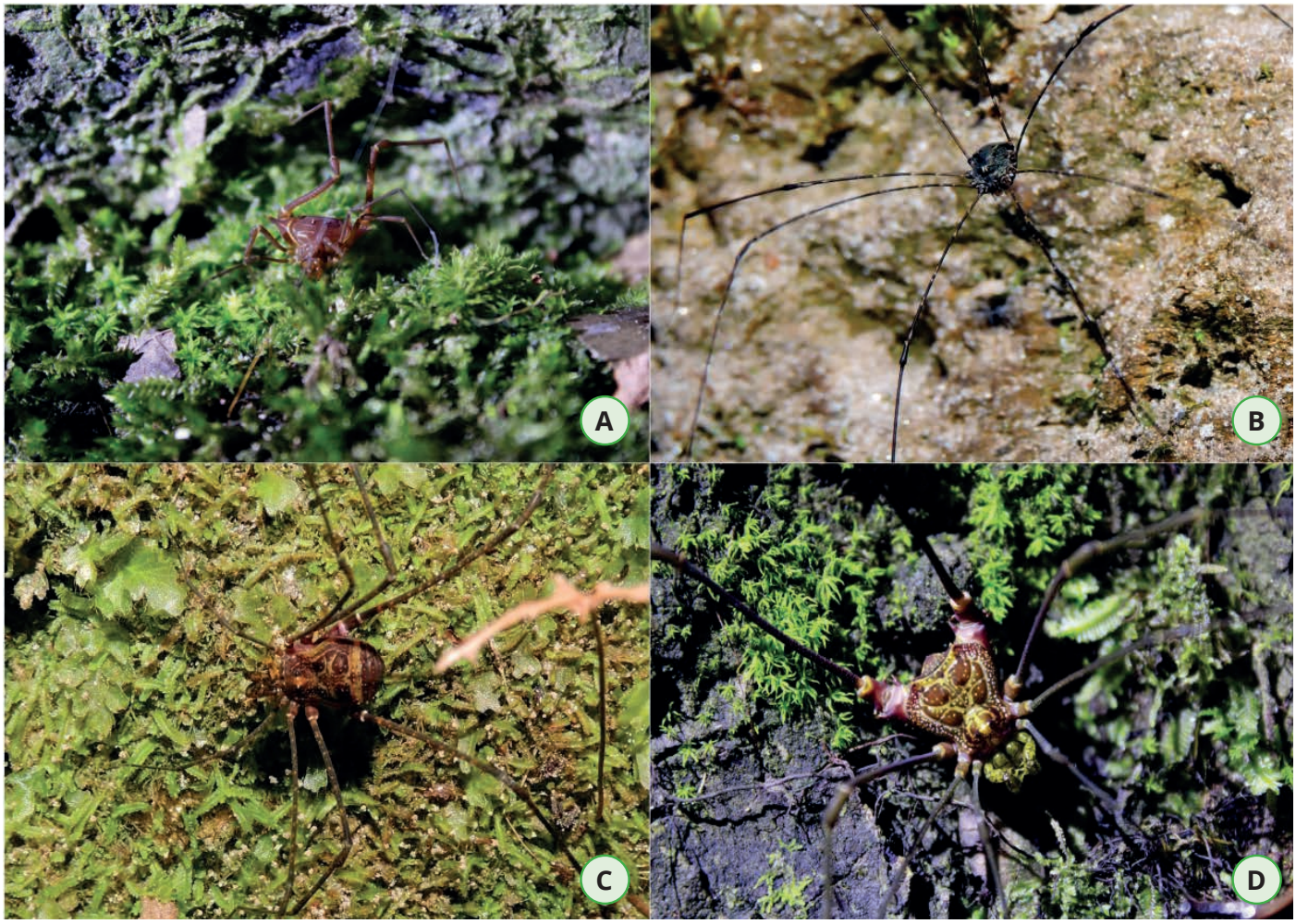

Figure 3. Species of harvestmen (Arachnida, Opiliones) in the transition area between Cerrado and Atlantic Forest, Luminárias municipality, southern Minas Gerais state, Brazil: *Krateromaspis dilatate* (Sørensen, 1884) (Opiliones: Gonyleptidae) (A) Gagrellinae gen. sp. 1 (B) and *Acutisoma longipes* (Roewer, 1913) (Opiliones: Gonyleptidae) female (C) and male (D).

sampling effort was clearly sufficient. This means that sampling over an entire year produced results that can be considered a good estimate of the real biological diversity in the study area. Although active collection is the most efficient method, the use of complementary methodologies can capture different species (Bragagnolo & Pinto-da-Rocha, 2003), potentially revealing even greater diversity.

The similarity analysis between inventory studies conducted in the Cerrado and the Atlantic Forest showed very low similarity with our study (< 30%) (Figure 5), except for the study carried out by Pádua et al. (2022) (60%).

This low degree of similarity between communities may reflect the local abiotic and biotic factors, which can limit the presence of harvestmen to specific environments. This can lead to a certain degree of isolation, which consequently increases the rate of endemism and abundance of certain species in different areas (DaSilva *et al*. 2011). These factors also include the low mobility of harvestmen in their habitats (Zampaulo 2007). For instance, temperature and rainfall influence harvestmen richness, which tends to increase in places with moderate to high temperature and precipitation (Curtis & Machado 2007), due to a high susceptibility to desiccation (Santos 2007). Another abiotic factor is the humidity associated with the degree of conservation of the area (Bragagnolo *et al*. 2007; Resende *et al.* 2012; Andrade *et al.* 2022). However, it is common for some specimens (such as those of the Gagrellinae subfamily, which has a complex taxonomy) not to be identified to species level in inventories (Costa *et al*. 2020; Ferreira *et al*. 2020; Pádua *et al.* 2022; Rubim *et al*. 2024). This is also a factor that hampers comparison of similarities between areas (Tourinho-Davis 2004).

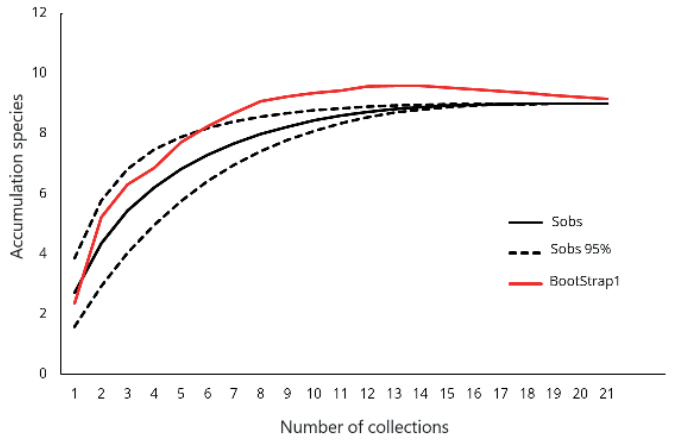

Figure 4. Species accumulation curve of harvestmen collected in Luminárias municipality, using observed species richness (Sobs, black line) within a 95% confidence interval (dotted line) and estimated species richness (BootStrap 1, red line).

The municipality of Poços de Caldas, southern Minas Gerais state, has a similar harvestmen community to that of Luminárias, as revealed by the study by Pádua *et al.* (2022). Nevertheless, the biggest difference between the communities was also with the same locality, but 50 years ago (Soares 1970). The change in the Poços de Caldas communities over half a century may be a reflection of anthropogenic actions in the environments, where the Campos de Altitude and the Capões de mata have been partly replaced by eucalyptus plantations, as also shown in the study by Vilela *et al.* (2023), sampling dragonflies in that municipality 50 years after the first dragonfly inventory. In addition, studies carried out with the dragonfly community in Gonçalves (south-central Minas Gerais) revealed changes in the Odonata community over the course of a decade, mainly due to the replacement of native habitat with pasture and eucalyptus (Souza *et al.* 2013; Gouveia *et al.* 2023). In this scenario, it is highly likely that the harvestmen fauna of the municipality of Luminárias is also being modified by the reduction or alteration of natural environments by local anthropogenic activities (Carvalho *et al.* 2007; Lima *et al.* 2011), and may be reflected in the species diversity observed in this work and that recorded in Poços de Caldas (Pádua *et al.* 2022).

The study by Pádua *et al.* (2022) was carried out in areas modified by anthropogenic pressures and has three species in common with the present study: *A. longipes*, *Mischonyx squalidus* Bertkau, 1880 (Opiliones: Gonyleptidae) and *Discocyrtus flavigranulatus* Soares, 1944 (Opiliones: Gonyleptidae). *A. longipes* has great adaptive capacity (Peres *et al.* 2018), and occurs in both protected and anthropized areas (Ferreira *et al.* 2019, 2020; Costa *et al.* 2020; Lima *et al.* 2022; Pádua *et al.* 2022, 2023). *M. squalidus* has synanthropic behavior, which allows it to tolerate more disturbed environments (Mestre & Pinto-da-Rocha 2004; Nogueira *et al.* 2019). In contrast, *D. flavigranulatus*, which occurs in more protected areas of mixed forest in the municipality of Gonçalves, southern Minas Gerais (Rubim *et al.* 2023a), may suffer a reduction in its populations if the forest remnants in Luminárias further deteriorate from anthropomorphic pressures.

No harvestmen species collected in Luminárias appear on the list of assessed species by ICMBio (2018) and the IUCN (2024), largely due to the low number of inventory studies in Brazil. In some of the largest Brazilian states, such as Bahia, Goiás, Maranhão and Mato Grosso, with vast and heterogeneous Cerrado phytophysiognomies, inventory studies are still scarce or nonexistent (Rubim *et al.* 2024). Even with the growing number of studies on harvestmen in Minas Gerais state, they are mostly confined to the south-central portion, in areas of Atlantic Forest (Figure 1), and as a result, only 11 of the 1,008 harvestmen species known to occur in Brazil (Kury 2024) have their conservation status assessed by ICMBio (2018) and none by IUCN (2024). Carrying out more inventory studies in the Cerrado of Minas Gerais and Brazil are essential to provide accurate information for conservation status assessment.

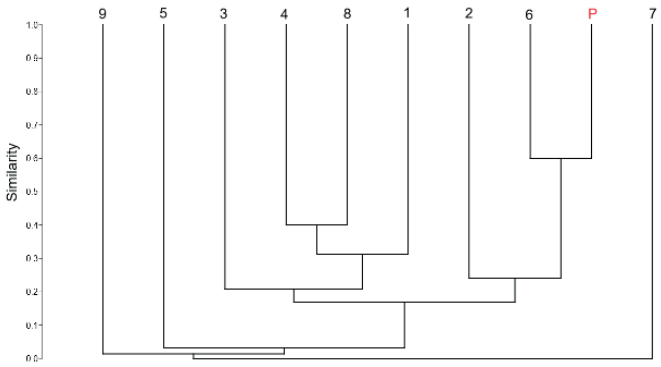

Figure 5. Cluster analysis of harvestmen fauna from different inventory studies in the Cerrado and Atlantic Forest of Minas Gerais state, Brazil: municipalities of Barroso and Prados (1: Lima *et al.* 2022); municipality of Gonçalves (2: Pádua *et al.* 2023); Serra do Papagaio State Park (3: Ferreira *et al.* 2019); municipalities of Albertina, Borda da Mata, Bueno Brandão, Cambuí, Inconfidentes, Itajubá, Monte São, Jacutinga, Ouro Fino, Poço Fundo, Pouso Alegre, São Tomé das Letras, Tocos do Mogi and Toledo (4: Costa *et al.* 2020); municipality of Poços de Caldas (5: Soares 1970); municipality of Poços de Caldas (6: Pádua *et al.* 2022); Grande Sertão Veredas National Park (7: Rubim *et al.* 2024); Rio Machado Environmental Protection Area (8: Ferreira *et al.* 2020); Sempre-Vivas National Park (9: Ferreira *et al.* 2020); P – Present study.

The opiliofauna of the municipality of Luminárias is composed of species with a wide geographical distribution, however, the reduction in the remnants of native vegetation can lead to a reduction in their populations. Therefore, our study contributes to understanding the diversity of the region's fauna, which, along with future studies on other taxa, provides essential information for assessing the potential establishment of a Conservation Unit.

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AUTHORS CONTRIBUTIONS

MLSS: Investigation, Writing-Original Draft. MJCA: Investigation, Writing-Original Draft. LGTR: Writing-Review & Editing. THRP: Writing-Review & Editing. DSV: Visualization; Pictures. GCJ: Conceptualization, Resources, Writing-Review & Editing. MMS: Conceptualization; Resources, Writing-Review & Editing.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

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