Ecological aspects of the Phlebotominae fauna (Diptera: Psychodidae) in the Xakriabá Indigenous Reserve, Brazil

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Abstract

Background: Sand fly collections were performed to study ecological aspects of the Phlebotominae fauna of the Xakriabá Indigenous Reserve, an area with endemic cutaneous leishmaniasis, located in the state of Minas Gerais, Brazil.

Methods: The collections were performed in peridomicile areas and along trails previously selected for the study of wild and synanthropic Leishmania hosts. Differences in the distribution patterns of the sand fly species as well as in species richness and abundance between the different ecotopes were investigated during both rainy and dry seasons over the course of the study period.

Results: A total of 8,046 sand flies belonging to 11 genera and 28 species were collected. Lutzomyia longipalpis and Nyssomyia intermedia were the most abundant species in peridomicile areas, whereas Martinsmyia minasensis and Lutzomyia cavernicola were the most abundant species among the different trail ecotopes.

Conclusion: The different composition of the sand fly fauna observed in the peridomicile areas and in the trails during the study, reinforces the importance of sampled different areas in a phlebotomine fauna survey. The presence of Lutzomyia longipalpis and Ny. Intermedia most abundant in peridomicile can be important to Leishmania infantum and Leishmania braziliensis transmission in the Imbaúbas native village.

Keywords: Phlebotominae fauna, Ecological aspects, Minas Gerais State, Nyssomyia, Lutzomyia, Martinsmyia, Leishmania

Background

Sand flies have been the subject of intense study, primarily in the context of the epidemiology of several diseases, the most notable being leishmaniasis [1]. In addition to Leishmania, sand flies also serve as hosts to bacteria, fungi, certain plasmodium species, haemogregarines, trypanosomes and Endotrypanum [2-6].

Although sand flies are distributed worldwide, they are most abundant in Neotropical regions, where a large number of species can be found [7]. In particular, there are approximately 900 species of sand flies worldwide, with over 500 in Neotropical regions and about 230 in Brazil [8,9]. In the state of Minas Gerais, about 100 species of sandflies have been reported, including important vectors of American Cutaneous Leishmaniasis (ACL) and Visceral Leishmaniasis (VL), such as Bichromomyia flaviscutellata, Lutzomyia longipalpis, Migonemyia migonei, Nyssomyia intermedia and Nyssomyia whitmani [10-14].

Cases of leishmaniasis within indigenous lands in Brazil were first reported in the state of Mato Grosso [15], who reported a large number of ACL cases among the Waurá Amerindians from Alto Xingu. In addition, the epidemiological profiles for VL among the Macuxi and Yanomami in the state of Roraima were described.
More recently, the prevalence of ACL in the Xakriabá Indigenous Reserve (XIR), state of Minas Gerais were reported [19]. Furthermore, the role of sand-flies in the transmission cycle of *Leishmania* within indigenous land has been reported in the Brazilian states of Mato Grosso [20] and Mato Grosso do Sul [21]. Knowledge concerning the Phlebotominae fauna is essential to understanding the transmission of leishmaniasis. Therefore, the aim of this study was to evaluate the ecological parameters of the Phlebotominae fauna – focusing on potential *Leishmania* vectors – within the XIR, where numerous cases of cutaneous leishmaniasis have been reported.

**Methods**

**Study area**

The XIR is located in the municipality of São João das Missões (14°53′ 4.26″ S 44°5′ 53.19″ W) in the northern region of the state of Minas Gerais, Brazil (Figure 1). The indigenous reserve is located in a transition zone between the cerrado and the caatinga biomes and contains native species of both biomes. This study was conducted in the Imbaúbas native village, which had both a high prevalence of human leishmaniasis cases and a number of wild, synanthropic and domestic animal species known to carry *Leishmania* [22] and was conducted under authorization by FUNAI (National Indian Foundation – Protocol Number: 2098/08).

**Sand fly collection and environmental characteristics**

Sand flies were captured with HP light traps [23] on three consecutive nights (from 6 pm to 6 am) for six months between July 2008 and July 2009. A total of 40 traps were installed in 20 randomly selected households in each of the sampled months. (Figure 2A and B).

To collect sand flies from the different ecotopes of the native village, bimonthly systematic samplings were performed between October 2011 and August 2012 on trails previously selected for the study of *Leishmania* reservoirs [22]. Four trails (330 meters in length each) were selected, and five traps were placed along each trail, totaling 20 HP traps. The traps were set for three full days, for a total of 72 hours of sampling per trap per collection.

Trails 1 and 2 (Figure 2C and D) cut through forest environments with little anthropization characterized as transitional between seasonal deciduous forest and cerrado. Along these two trails, climatic variations throughout the year can abruptly modify soil conditions and vegetation, potentially influencing sand fly abundance and richness. Trail 3 (Figure 2E) was situated on a plateau containing rocky outcrops with numerous craters, favorable for both sand flies and rodents. Trail 3 had a small amount of vegetation with caatinga characteristics. Trail 4 (Figure 2F) was located on the edge of a rocky outcrop plateau that could be characterized as a transitional region between cerrado forest and caatinga vegetation.

**Processing of collected sand flies**

Preparation and mounting of the sand flies was performed using Canada balsam for males and Berlese’s medium for females [24]. Sand flies were identified to species level using microscopic observation of various internal and external morphological characteristics and using the keys and classification proposed by Galati [8]. The species abbreviations used in the present study follow the proposal by Marcondes [25].

**Climate data**

Bioclimatic data, including relative humidity, rainfall and average temperature, were obtained from the National
Institute of Meteorology for each month of the study period. Data were also collected at the Mocambinho Automatic Weather Station, which is located in the municipality of Itacarambi, state of Minas Gerais, approximately 30 km from the XIR [26].

Characterization of dry and rainy seasons was performed based on the rainfall of the months in which the captures were performed. During the years in which the peridomicile collections were performed, the dry season included the months of July 2008, September 2008 and July 2009, and the rainy season included November 2008, January 2009 and April 2009. For the collections performed on the trails, the dry season included the months of April 2012, June 2012 and August 2012, and the rainy season included October 2011, December 2011 and February 2012.

**Statistical analysis**

Data meeting the prerequisite for normality were subjected to analysis of variance (ANOVA) (Kolmogorov-Smirnov and Lilliefors test, $p < 0.05$). Non-parametric data were analyzed using the Kruskal-Wallis test by rank and median. Richness and abundance data were considered as dependent variables, whereas season, month, location and sand fly sex were considered as categorical variables. All analyses were performed using the Statistica 10.0 software program (Statsoft, Tulsa, USA).

![Figure 2](image-url)
Results

A total of 8,046 sand fly specimens from 11 genera and 28 species were collected in the XIR over the course of the study, 5,406 of which were female (67.2%) and 2,640 of which were male (32.8%). In the peridomicile areas, 2,126 (26.4%) sand fly specimens from 9 genera and 19 species were collected. We observed a significant difference between the number of males and females collected in peridomicile areas ($H_{1,198} = 26.62; p = 0.000$), with more females (1,385) than males (741) collected. The most commonly sampled species and their relative frequencies within peridomicile areas were Lutzomyia longipalpis (51.08%), Nyssomyia intermedia (31.79%) and Micropygomyia goiana (3.01%). Along the different trail ecotopes, 5,920 sand fly specimens (73.6% of total) from 11 genera and 27 species were collected. We also observed a significant difference between the numbers of males and females collected along the trails ($F_{1,36} = 28.239; p = 0.000$). The most commonly sampled species along the trail ecotopes were Martinsimyia minasensis (26.7%), Lutzomyia cavernicola (17.24%) and Lutzomyia renei (14.0%).

The highest sand fly abundance was observed along trail 3 (52.58%), followed by trail 4 (34.71%), whereas only 12.71% of the total sand flies were collected along trail 2, showing the greatest number of sand flies ($F_{1,36} = 8.7494; p = 0.00544$). However, there was no significant difference in the number of sampled species in terms of males or females based on season ($F_{1,36} = 2.6521; p = 0.11214$).

The results of the multivariate analysis comparing the compositions of the Phlebotominae fauna among the different studied environments (forest, rocky outcrop and transition forest) and seasons (dry and rainy) are shown in Figure 3. The vertical line passing through the X-axis origin shows the difference in the sand fly fauna compositions between the forest area (trails 1 and 2), grouped in the right side of the line, while the rocky outcrop (trail 3) and the transitional region (trail 4) grouped in the left side, show that the sand fly fauna composition in the study area was different. Furthermore, the horizontal line passing through the Y-axis origin highlights the difference in sand fly fauna composition between the rainy (above the line) and dry (below the line) seasons.

Discussion

A number of studies have described the behavior of the Phlebotominae fauna, primarily those of medical importance [27-29]. Sand flies can be commonly found in a variety of natural ecotopes, including tree trunks, animal burrows, dead leaves, and rocky crevices [30-34], as well as in rural and urban environments close to domestic animal shelters and human residences [35-39]. Considering the diversity of ecotopes in which sand flies can be found, sampling from a variety of different environments within a given study area is crucial for fauna studies. In this study, we collected sand flies from several different areas, including peridomicile areas around households as well as trails containing a variety of ecotopes, such as cerrado forests, seasonal deciduous forests, cerrado strictu sensu and transition areas between cerrado and caatinga.

A great variety of genera and species were found in the Imbaúbas native village, corresponding to about 30% of the total registered species in the state of Minas Gerais [10-14].

Despite the fact that the collections in the peridomicile areas and along the trails were performed during different periods, precluding a statistical comparison between the ecotopes, certain findings were still significant. With respect to species richness, a higher diversity of sand flies was observed in the trails when compared to peridomicile areas. This difference was likely due to the
Table 1. Sand flies collected by sex and seasons in peridomicle located in Imbaúbas village, Xakriabá Indigenous Reserve, MG, from July 2008 to July 2009.

| Species                  | Dry season | Rainy season | Total |
|--------------------------|------------|--------------|-------|
|                          | July 08    | September 08 | Nov-08 |
|                          | ♀♀♂♀♀♀♂♂♂♂♂ | ♀♀♂♂♂♂♂♂♂♂♂ LOGIN | LOGIN | LOGIN |
|                          | %          | %            | %     |
| Brumptomyia avellari     | 0          | 1            | 2     | 3    | 1    | 2    | 15   | 14   | 0     | 0     | 1     | 0     | 19 (48.7) | 20 (51.3) | 39 (1.80) |
| Evandromyia lenti        | 3          | 4            | 10    | 7    | 1    | 1    | 13   | 6    | 0     | 0     | 1     | 0     | 31 (60.7) | 20 (39.3) | 51 (2.20) |
| Evandromyia cortelezzii  | 0          | 0            | 6     | 0    | 0    | 0    | 0    | 3    | 0     | 0     | 0     | 1     | 7 (63.6) | 4 (36.4) | 11 (0.50) |
| Evandromyia cortelezzii complex | 0          | 0            | 0     | 0    | 0    | 0    | 20   | 0    | 2     | 0     | 0     | 0     | 22 (100) | 0 (0)     | 22 (1.00) |
| Evandromyia sallesi      | 1          | 0            | 1     | 0    | 0    | 0    | 0    | 2    | 0     | 0     | 0     | 0     | 2 (50)   | 2 (50)    | 4 (0.10)  |
| Evandromyia spelunca     | 0          | 0            | 0     | 1    | 0    | 1    | 0    | 4    | 0     | 0     | 0     | 0     | 5 (80)   | 1 (20)    | 6 (0.20)  |
| Evandromyia termitoriophila | 0          | 0            | 1     | 0    | 0    | 1    | 3    | 0    | 0     | 0     | 0     | 1     | 3 (50)   | 3 (50)    | 6 (0.20)  |
| Lutzomyia ischnacantha  | 0          | 0            | 6     | 2    | 0    | 0    | 10   | 2    | 0     | 0     | 2     | 3    | 18 (72)  | 7 (28)    | 25 (1.10) |
| Lutzomyia longipalpis   | 6          | 39           | 176   | 60   | 33   | 42   | 260  | 295  | 40    | 54    | 27    | 54    | 542 (49.9)| 544 (39.3)| 1086 (51) |
| Lutzomyia sp.*           | 1          | 0            | 0     | 6    | 0    | 0    | 15   | 5    | 0     | 1     | 11    | 2     | 27 (65.8)| 14 (34.2) | 41 (1.90) |
| Lutzomyia renei          | 3          | 4            | 14    | 0    | 0    | 0    | 16   | 0    | 1     | 0     | 2     | 0     | 33 (97)  | 1 (3)     | 34 (1.60) |
| Martinomyia minasensis   | 1          | 0            | 0     | 0    | 0    | 0    | 1    | 0    | 0     | 0     | 0     | 0     | 1 (100)  | 0 (0)     | 1 (0.04)  |
| Micropygomyia capixaba  | 0          | 0            | 0     | 0    | 0    | 3    | 0    | 0    | 1     | 0     | 2     | 0     | 3 (50)   | 3 (50)    | 6 (0.20)  |
| Micropygomyia goiana     | 0          | 2            | 10    | 2    | 1    | 1    | 24   | 19   | 2     | 0     | 2     | 1     | 39 (60.9)| 25 (39.1)| 64 (3)    |
| Micropygomyia peresi     | 1          | 0            | 0     | 0    | 1    | 1    | 6    | 1    | 2     | 0     | 2     | 0     | 12 (85.7)| 2 (14.3) | 14 (0.60) |
| Micropygomyia quinquefer | 0          | 0            | 0     | 0    | 0    | 0    | 0    | 0    | 2     | 0     | 0     | 0     | 2 (100)  | 0 (0)     | 2 (0.09)  |
| Migoneomyia migonei      | 1          | 5            | 1     | 7    | 2    | 1    | 3    | 5    | 1     | 1    | 0     | 0     | 8 (29.6) | 19 (70.4) | 27 (1.20) |
| Nyssomyia intermediar    | 179         | 15           | 209   | 20   | 87   | 18   | 40   | 4    | 8     | 3    | 82    | 11    | 605 (89.4)| 71 (10.6) | 676 (32.78)|
| Nyssomyia whitmani      | 0          | 0            | 2     | 1    | 0    | 0    | 0    | 0    | 0     | 1     | 1     | 0     | 3 (60)   | 2 (40)    | 5 (0.20)  |
| Pintomyia serrana       | 0          | 0            | 1     | 0    | 0    | 0    | 2    | 0    | 0     | 0     | 0     | 1     | 3 (75)   | 1 (25)    | 4 (0.10)  |
| Sciopemyia sordelli     | 0          | 0            | 0     | 0    | 0    | 0    | 0    | 0    | 0     | 2     | 0     | 0     | 0 (0)    | 2 (100)   | 2 (0.09)  |

Total (%) 192 (74.1) 67 (25.9) 439 (80.1) 109 (19.9) 128 (64) 72 (36) 429 (54.6) 356 (45.4) 59 (48.7) 62 (51.3) 138 (64.7) 75 (35.3) 1385 (65.1) 741 (34.9) 2126 (100)

259 (12.18) 548 (25.77) 200 (9.43) 785 (36.92) 121 (5.69) 213 (10.01) 2126

*The specimens have damaged essential morphological structures.
| Species                  | Oct-11 | Dec-11 | Feb-12 | Apr-12 | Jun-12 | Aug-12 | Total (%) |
|--------------------------|--------|--------|--------|--------|--------|--------|-----------|
| Brumptomyia avellari    | 1      | 1      | 0      | 0      | 0      | 0      | 5 (71.4)  |
| Brumptomyia brumpti     | 0      | 0      | 0      | 0      | 0      | 0      | 2 (28.6)  |
| Evandromyia cortezeii   | 0      | 0      | 4      | 0      | 0      | 0      | 3 (4.2)   |
| Evandromyia evandroi    | 0      | 0      | 0      | 0      | 0      | 0      | 3 (4.2)   |
| Evandromyia lenti       | 6      | 10     | 0      | 7      | 6      | 5      | 18 (23)   |
| Evandromyia sallesi     | 1      | 0      | 1      | 0      | 2      | 0      | 4 (5.2)   |
| Evandromyia sp.*        | 0      | 4      | 0      | 0      | 0      | 0      | 4 (5.2)   |
| Evandromyia spelunca    | 0      | 50     | 28     | 43     | 8      | 84     | 79 (19.7) |
| Evandromyia termotopila | 4      | 10     | 0      | 1      | 0      | 0      | 7 (9.2)   |
| Lutzomyia cavernicola  | 0      | 0      | 2      | 263    | 5      | 49     | 12 (1.1)  |
| Lutzomyia ischnacantha | 0      | 6      | 28     | 64     | 11     | 40     | 16 (2.1)  |
| Lutzomyia longipalpis  | 7      | 4      | 0      | 1      | 0      | 2      | 4 (5.2)   |
| Lutzomyia renei         | 13     | 5      | 108    | 25     | 59     | 0      | 665 (79.9)|
| Lutzomyia sp.*         | 0      | 39     | 0      | 0      | 0      | 0      | 39 (4.8)  |
| Martinomyia minasensis | 58     | 559    | 150    | 234    | 98     | 341    | 332 (41.7)|
| Micropygomyia capixaba | 0      | 0      | 12     | 114    | 0      | 45     | 14 (6.3)  |
| Micropygomyia gaiana   | 1      | 96     | 5      | 29     | 8      | 9      | 66 (19.7) |
| Micropygomyia longipennis | 0     | 8      | 0      | 12     | 0      | 0      | 22 (2.8)  |
| Micropygomyia peresi    | 27     | 37     | 152    | 34     | 7      | 33     | 314 (41.7)|
| Micropygomyia quinquefer | 0   | 0      | 0      | 0      | 0      | 0      | 210 (26.6)|
| Micropygomyia schreiberi | 0  | 0      | 21     | 0      | 3      | 0      | 34 (4.2)  |
| Micropygomyia sp.*     | 0      | 12     | 0      | 0      | 0      | 0      | 13 (1.6)  |
| Mygomyia migonei       | 0      | 2      | 0      | 0      | 1      | 0      | 1 (0.1)   |
| Nyssomyia intermedia   | 1      | 9      | 5      | 6      | 9      | 42     | 46 (5.8)  |
| Nyssomyia neivai       | 0      | 0      | 0      | 0      | 0      | 0      | 0 (0)     |
| Pintomyia misionensis  | 0      | 0      | 0      | 0      | 0      | 0      | 0 (0)     |
| Pintomyia serrana      | 0      | 0      | 0      | 0      | 0      | 0      | 0 (0)     |
| Pathomyia (Foratiniella) sp.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 (0)       |
| Sandfly Species       | Sex Male | Sex Female | Sex Total | Sampling Months | Sex Male | Sex Female | Sex Total | Sex Male | Sex Female | Sex Total | Sex Male | Sex Female | Sex Total | Sex Male | Sex Female | Sex Total |
|----------------------|----------|------------|-----------|----------------|----------|------------|-----------|----------|------------|-----------|----------|------------|-----------|----------|------------|-----------|
| Psychodopygys ayrozai| 0        | 0          | 1         | 0              | 0        | 0          | 0         | 0        | 0          | 1         | (100)    | 0          | (0)       | 1 (0.02) | 0 (0)      | 1 (0.02)  |
| Scyopemyia sordellii | 0        | 0          | 0         | 1              | 0        | 0          | 1         | 0        | 1          | 0         | 1 (33.4) | 2 (66.6)   | 3 (0.06)  |          |            |           |
| Total (%)            | 119 (12.3)| 852 (87.7) | 516 (61.9) | 217 (24.9)     | 652 (75.1)| 279 (30.3) | 671 (70.7)| 539 (42.1)| 740 (57.9) | 219 (56.2)| 280 (56.2)| 1889 (31.9)| 4031 (68.1)| 5920 (100)|          |
|                      | 971 (16.4)| 1352 (22.9)| 869 (14.7) | 950 (16.0)     | 1279 (21.6)| 499 (8.4) | 5920      |          |            |           |           |            |           |          |           |           |

*The specimens have damaged essential morphological structures.*
The diversity of ecotopes found along the trails as well as the preferences of the sand flies for the specific wild animals, domestic animals or humans found in these areas. By definition, peridomicile areas are significantly impacted by human intervention, which likely hinders the adaptation of certain sand fly species to these areas. It is important to note that the peridomicile areas surrounding houses within the XIR possess numerous rural characteristics, such as domestic animals, fruit trees and grain plantations, that provide shelter and food sources for adult sand flies as well as organic matter for the development of immature stages. Therefore, these characteristics may explain the significant number of species (19) found in this ecotope.

In the peridomicile areas, *Lu. longipalpis* and *Ny. intermedia* were the predominant species, which was significantly different from what was observed along the trails, where these species were relatively rare. Importantly, these species are involved in transmission of the VL and ACL etiological agents in several endemic areas of Brazil [1,40].

Since the VL transmission cycle began to be elucidated in Brazil in the 1930s, several research groups have demonstrated the ability of *Lu. longipalpis* to adapt to human-modified environments as well as its crucial role in the transmission of *Leishmania infantum* [1]. Therefore, the near constant presence of *Lu. longipalpis* in peridomicile, where it can feed on domestic and synanthropic hosts of *Leishmania*, associated with their anthropophily contribute to its vectorial capacity [41,42]. As a consequence, *Lu. longipalpis* plays an important role in the transmission of VL in peridomicile areas of both rural and urban regions [41,43,44].

Our results agree with previous entomological studies performed in the north of Minas Gerais state. In these studies, *Lu. longipalpis* was identified as the predominant species found in peridomicile areas [45,46]. Correlations between *Lu. longipalpis* density and specific conditions in this environment have been noted, and this species is commonly associated with the presence of domestic animals [47-50]. This behavioral trait was also observed in the present study, as we found domestic animals, including chickens, pigs and dogs in the peridomicile areas.

With respect to *Ny. intermedia*, most of the specimens were collected in peridomicile areas and few specimens were collected in forest fragments near residences. These results are consistent with the reports of Forattini in the Paulista plateau, state of São Paulo [47,51] and Rangel et al., in the municipality of Mesquitia, state of Rio de Janeiro [52]. These authors showed that *Ny. intermedia sensu lato* lives in close association with humans as well as domestic and synanthropic animals in a variety of habitats, including peridomicile and forested areas. Epidemiological evidence accumulated over the years suggests that *Ny. intermedia sensu lato* is the primary vector of the ACL etiological agent in endemic areas of southeastern Brazil [53-57], and the distribution of this species consistently coincides with the distribution of ACL in humans [51,58-61]. Therefore, based on the proven epidemiological importance of *Ny. intermedia sensu lato* and...
its high population density within peridomicile areas, this species likely plays an important role in the Leishmania transmission cycle in the XIR.

Despite being found in low numbers in the present study, the presence of the species Ev. cortellezii, Ev. sallesi, Ev. termitiphila, Migonemys migonei, Ny. neivai and Ny. whitmani should also be addressed. These species have been found to be naturally infected by Leishmania in Brazil, thus implicating them as potential etiological vectors, and some may be sporadically involved in Leishmania transmission [40,56,62,63].

It is necessary to highlight the presence of Ev. lenti in both the peridomicile and trail areas, despite the small number of collected specimens. In a study performed in Ceará state – Brazil [64], although only a small number of Ev. lenti individuals were found in peridomicile areas, a large number were found inside the associated households. In the municipality of Jacobina, state of Bahia - Brazil, Ev. lenti specimens that were naturally infected with promastigotes were found biting humans, horses and dogs [65]. In contrast with these reports, in a study of Ev. lenti biology involving a population from the state of Minas Gerais, demonstrated that this species does not have anthropophilic habits and is refractory to Leishmania species [66]. However, recently, cases of natural infection with Le. braziliensis by Ev. lenti were reported and verified using molecular biology techniques [67,68]. Therefore, the epidemiological role of Ev. lenti must be clarified, which is highlighted by the fact that this species was collected in both peridomicile and forested areas near humans in this study.

Regarding the Phlebotominae fauna collected along the trails, it was observed that trail 3 showed the highest sandfly abundance. During the study period, about 40% of the collected specimens were captured in this eco- tope. Furthermore, a high species richness was observed. This phenomenon was primarily due to the environmental composition of trail 3, which consisted of vertical rocky outcrops that formed craters in the soil where temperature and relative humidity remained relatively stable throughout the day, making it a suitable habitat for the breeding and establishment of a variety of vertebrate species, including small- and medium-sized rodents and bats that can serve as food sources for sand flies.

The presence of Mt. minasensis was largely confined to trails 3 and 4 and little is known concerning the feeding behaviors and habits of this species. Species of the genera Martinsmyia can be attracted by rodents, as suggested to Mt. gasparviannai in the state of Espírito Santo [69] and Mt. oliveirai in the state of Mato Grosso do Sul [34]. In addition to the high prevalence of Mt. minasensis along the trails, the regular presence of Mi. peresi, Mi. goiana, Lu. renei, Lu. cavernicola and Ev. spe- lanca throughout the year suggests that these species use these wild environments as breeding sites, as specimens of both sexes were routinely collected. For the remaining species that were only sporadically collected, our findings suggest that these trails serve only as temporary shelters [70].

The impact of climatic factors on sand fly populations has been addressed by several authors. According to the literature, temperature, humidity and rainfall can influence sand fly populations in varying ways, depending on the region studied. Rutledge & Ellenwood [71] suggest that sand fly seasonality is related to rainfall distribution patterns, which affect breeding conditions on the ground. In our study, we observed significant correlations between sand fly abundance and the rainy season along the trails, as well as for species richness and the rainy season in the peridomicile areas. Indeed, significant correlations between season and fluctuations in Phlebotominae populations have been observed in several Brazilian states, including Minas Gerais [46,72], Rio Grande do Norte [73], Mato Grosso [74], Mato Grosso do Sul [75,76], Ceará [41] and Bahia [48].

Even slight variations in certain climatic factors can affect sand fly micro-habitat enough to alter population dynamics, as these insects are very sensitive to desiccation [45]. Therefore, this phenomenon may explain the higher number of sand flies collected along trail 3, which consisted of rocky outcrops that could serve as micro-habitat with relatively stable temperature and humidity throughout the year. However, in the forest, transition and peridomicile areas, climatic changes occur more frequently, leading to environmental changes throughout the year. For example, during the driest months, reduced rainfall levels result in drastically reduced vegetation cover (characteristic of seasonal deciduous forests), which may directly affect the sand flies breeding sites.

**Conclusion**

In recent decades, significant changes have been occurring in many natural environments, mostly due to human activity. As a result, many insects that transmit disease and various components of parasitic life cycles are beginning to show population dynamics and interactions different from their original descriptions. Therefore, studies involving fauna surveys that also address biological aspects of specific vectors contribute to a better understanding of the dynamic interactive processes between hosts and parasites. This study addressed the sand fly fauna in a significant leishmaniasis endemic area, and these results will enhance our knowledge concerning the number of sand fly species found in this region as well as the distribution of these species across different ecotopes. This knowledge may prove useful for establishing more effective prophylactic measures.
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Competing interests
The authors declare that they have no competing interests.

Authors’ contributions
FDR: designed the study, field work, processed and identified the collected sand flies and reviewed the manuscript; PMQ: designed the study, field work and processed the collected sand flies; RAB: processed the collected sand flies, conceived and designed the experiments; KMSS: field work and processed the collected sand flies and reviewed the manuscript; all authors approved the final version of the manuscript.

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