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Scientific Note

Influence of urbanization characteristics on ant (Hymenoptera: Formicidae) and spider (Arachnida: Araneae) diversity

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Abstract: Demographic characteristics and length of land use occupation time are important factors in the evaluation of the influence of urbanization on biodiversity. Thus, the aim of this study was to evaluate how population density and human occupation history influence taxonomic and guild spider (Arachnida: Araneae) and ant (Hymenoptera: Formicidae) diversities in four distinct Administrative Regions (ARs) of the municipality of Salvador (Bahia, Brazil). The ants and spiders in the ARs were collected in different types of green areas: forest fragments, vacant lots, and gardens/backyards, using three capture techniques (Winkler trap, entomological umbrella, and manual collection). We tested for eventual differences in myrmecofauna and araneofauna richness and composition, in addition to guilds (FGs) according to population density level (high vs. low) and urbanization time (old vs. recent). A total of 148 ant species were collected and classified into 15 guilds. Whereas a total of 97 spider species were captured and classified into 10 guilds. Spider richness varied significantly between the ARs, instead of to ant richness. There were also significant differences between ARs for the taxonomic composition of spiders, but not for ants. Those of the guild compositions of ants and spiders were not significant. Finally, our results indicate the importance of how historical processes of neighborhood occupation influence the distribution of spiders, demonstrating increased richness in areas with lower population densities, while other factors related to urban landscapes may be related to the distribution of ant and spider species.

Keywords: Urbanization, Green areas, Population density, Guilds.

The way in which cities are managed, particularly from an urban zoning perspective, influences the environmental sustainability of large urban centers (Melo et al. 2020). Within urban estimators, demographic factors are essential city characteristics that should be quantified (Toit & Cilliers 2011). Thus, qualitative aspects related to occupation history (such as time), cannot be disassociated with urban management (Brazil et al. 2005; Melo & Delabie 2017). In cities such as Salvador (state of Bahia, Brazil), where there has been a long history of urban growth and development since its founding in the year 1549, it is possible to observe completely different areas in terms of urbanization time and the way in which neighborhoods are constructed (Brazil et al. 2005). Regarding the changes in biodiversity caused by urbanization, a reduced number of species are observed in more densely populated areas, while areas with longer urbanization times have increased richness (Sattler et al. 2010). In cities, the composition of species also changes according to the degree of urbanization, since factors related to urban habitat landscape and management influence species distribution (Melliger et al. 2018; Melo et al. 2021). Due to the complexity of variables that allow urbanization characterization and the extreme variation of organism responses (McDonnell & Hahs 2008), it is important to use more than one taxonomic group in urban ecology studies (MacGregor-Fors et al. 2014). As such, spiders and ants are ideal ecological models since, in addition to being highly susceptible to environmental impacts, they present distinct biological characteristics (one group has solitary organisms, the other is social) and ecological functions (MacGregor-Fors et al. 2014; Melliger et al. 2018; Melo et al. 2021). In a previous landscape-scale study, spiders were found to be more sensitive to the influence of urbanization compared to ants, with a decrease in species richness as a function of forest habitat loss (Melo et al. 2021). However, in terms of composition, both groups have been observed to respond in a similar way, presenting generalist and synanthropic ants and spiders in more urbanized environments (Melliger et al. 2018; Melo et al. 2021).

This study aimed to evaluate the distribution of spiders (Arachnida: Araneae) and ants (Hymenoptera: Formicidae) in distinct areas of an urban municipality zone, known here as Administrative Regions (ARs). More specifically, we evaluated the hypotheses that: (i) ARs with greater human population densities have lower ant and spider species richness; and (ii) areas with longer urbanization histories shelter a larger number of species; (iii) since predatory animals such as spiders are more influenced by urbanization (Corcos et al. 2019), we expect that this group of organisms will be more sensitive compared to ants.

The city of Salvador (12°58'16'' S, 38°30'39'' W), is one of the oldest and largest cities in Brazil and is inserted into the Atlantic Forest domain (Fig. 1) (IBGE 2021). The city's territory is subdivided into 18 macroregions known as Administrative Regions (ARs), for administrative and planning management purposes (SIM 2010). In this study, four ARs were selected (Tab. S1, Supplementary online material) based on populational densities and urbanization time (Brazil et al. 2005; McDonnell & Hahs 2008; Toit & Cilliers 2011): Barra, Boca do Rio/Patamares, Pituba/Costa Azul and Subúrbio Ferroviário. Since there is no technical or legal standardization for the classification of population density classification or urban zoning (Melo et al. 2020), we considered ARs in Salvador that presented more than 10,000 inhabitants per km^2 as having high population densities compared to the others. In relation to urbanization time, the ARs that were established before the XX

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Century were classified as old, based on Brazil et al. (2005).

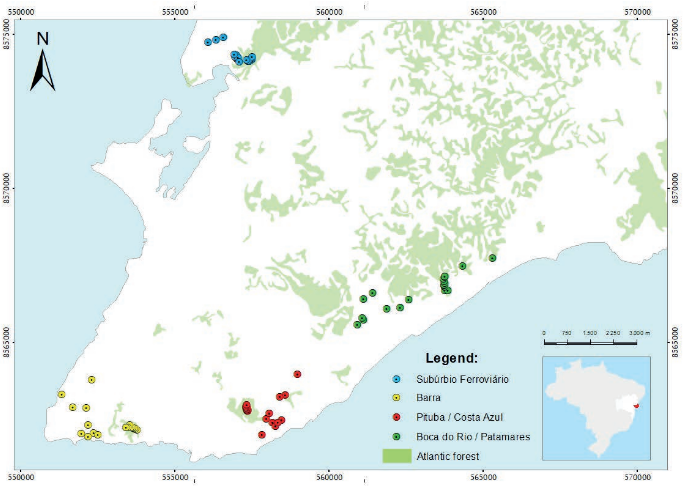

Figure 1. Distribution of the sample points by land uses in four administrative regions in Salvador, Bahia state, Brazil.

During the month of October 2012, 20 Sample Points (SPs) were collected in each of the four ARs, distributed across different types of green areas: five gardens/backyards (=five SPs), five vacant lots (=five SPs) and one forest fragment (= ten SPs) (Tab. S1, Supplementary online material). The gardens/backyards were green areas belonging to private residences and composed of ornamental plants and/or fruit trees. The vacant lots were public and/or private land composed, primarily, of native plant species and presenting canopy formation and understory vegetation. In each of the habitat categories, the SPs were located at intervals of greater than 30 meters. At the end of the experiment, 20 gardens/backyards, 20 vacant lots and four forest fragments were sampled, totaling 80 SPs. In each SP, the surface soil and vegetation were sampled to guarantee the detection of spider and ant diversity in different habitats (Tab. S1, Supplementary online material). On the ground, the leaflitter fauna were sampled with the aid of a sieve in units of 50 x 50 cm and the collected material was placed in a Winkler extractor in the laboratory for 24 h to extract the fauna. The arboreal fauna was sampled with the aid of an entomological umbrella (1 m^2), where each sample was composed of the material obtained from every third bush (between 1 and 3m in height) which was shaken continually for 10 seconds above each trap. To complement these sampling methods, a manual collection lasting 15 minutes was performed during the day at all SPs. These are the most commonly used methodologies for arthropod sampling, especially for ants and spiders (Delabie et al. 2021; Tourinho & Lo-Man-Hung 2021). Sample collection was authorized under the license n° 33828-1 by MMA/SISBIO and n° 15-2012 by INEMA/DIRUC. The collected invertebrates were sorted and morphotyped after being fixed in alcohol (spiders) or dry mounted (ants). The spider specimens were taken to the Instituto Butantan in São Paulo where they were deposited in the Arachnological Collection, acronym IBSP (curator: A.D. Brescovit, vouchers n° #164953). After identification, the ants were deposited in the Myrmecology Laboratory (acronym CPDC Delabie et al. 2020), Itabuna, BA (curator: J.H.C. Delabie, vouchers n° #5703), Comissão Executiva do Plano da Lavoura Cacaueira (CEPLAC; *Executive Commission of the Cacao Crop Plan*). The ant and spider species were sorted by guild. Ant nomenclature followed Bolton (2021) and guild classification followed Brandão et al. (2012), using morphological features and trophic position, nest and foraging location, type of foraging, worker recruitment mode, colony size and workers, behavior during interspecific interactions and the agility of workers to classify species. For spiders, nomenclature followed the World Spider Catalog (2021) and guild classifications followed Dias et al. (2010), using factors such as the time of capture, foraging site, foraging mode, web use and type to characterize species.

The analyzes were performed considering all methods together. A matrix of ant and spider species and guilds was constructed based on the presence (1) or absence (0) of species in each SP. To evaluate sample effort, the Jackknife 2 estimator was used. This estimator is indicated for presence-absence type data in assemblages with an elevated number of rare species (Gotelli & Colwell 2011). The data were randomized 100 times to remove the effect of ordered sample sequencing during the procedure using the program EstimateS 8.2.0 (Colwell 2009). Species accumulation curves were produced to compare the efficacy of sample effort between environments using the software PAST 4.02 (Hammer et al. 2001). We used two-way analyses of variance to test for eventual differences between ant and spider richness, as well the number of ant guilds (FGs) and spider guilds, according to population density level (high vs. low) and urbanization time (old vs. recent). Before performing these analyses, data were square-root transformed $\sqrt{(y+0.5)}$. We performed a Permutational Analysis of Variance (Permanova) using Jaccard's similarity index as an associate measure, in order to determine whether the composition of ant and spider species and guilds differed between ARs. All statistical analyses were performed in R version 3.6.1 (R Development Core Team 2019).

A total of 148 ant species were collected, distributed across 39 genera and seven subfamilies (Tab. S2, Supplementary online material). The subfamily with the greatest number of species was Myrmicinae (86 species), representing 58.1% of collected species. Ant species were classified into 15 different guilds, where "Myrmicinae Generalists" was the most commonly registered group (30 species), representing 20.2% of the total number of species. The richness observed in the ARs varied between 78 and 90, whereas the estimated number of species varied from 123.4 to 137.7 between ARs. The species accumulation curves were ascending for all areas, despite the sample effort (Fig. S1A, Supplementary online material). According to the Jackknife 2 estimator, the sampling sufficiency was 63% on average.

A total of 97 spider species were registered, distributed across 60 genera and 22 families (Tab. S3, Supplementary online material). The family with the greatest number of species was Salticidae (25 species) representing 25.7% of the species collected. The spider species were classified into 10 guilds, where "Orbicular weaver" was the most represented group (27 species, 27.8% of the total). The richness observed in the ARs varied between 34 and 48, while the estimated number of species varied between 66.8% and 96.8% between ARs. The species accumulation curves were ascending for all areas, despite the sample effort (Fig. S1B, Supplementary online material). According to the Jackknife 2 estimator, the sampling efficiency was 50% on average.

The number of ant species did not vary according to urbanization history ($F_{1.79}$ = 0.067, p = 0.796) and population density ($F_{1.79}$ = 0.796, p = 0.375) (Fig. 2A). This was also observed for the number of ant guilds (history of urbanization: $F_{1.79}$ = 0.083, p = 0.773; population density: $F_{1.79}$ = 1.471, p = 0.229) (Fig. 2B). We did not observe differences in ant species composition (history of urbanization: $F_{1.79}$ = 1.357, p = 0.067; population density: $F_{1.79}$ = 1.233, p = 0.131) or ant guild composition ($F_{1.79}$ = 1.899, p = 0.067; population density: $F_{1.79}$ = 2.013, p = 0.055) according to the variables studied (Fig. S2, Supplementary online material).

The number of spider species varied according to population density ($F_{1.79}$ = 6.073, p = 0.016), but not according to urbanization history ($F_{1.79}$ = 0.039, p = 0.844) (Fig. 3A). We did not observe variation in the number of spider guilds according to urbanization history ($F_{1.79}$ = 0.205, p = 0.652) and population density ($F_{1.79}$ = 3.610, p = 0.061) (Fig. 3B). Spider species composition varied according to urbanization history ($F_{1.79}$ =1.462, p = 0.036) and population density ($F_{1.79}$ = 2.274, $p < 0.001$) (Fig. S3, Supplementary online material). However, the composition of spider guilds did not differ according to the variables evaluated (urbanization history: $F_{1,79}$ = 0.684, p = 0.64; population density: $F_{1.79}$ = 0.815, p = 0.539) (Fig. S3, Supplementary online material).

Our results indicate that ant and spider diversities respond differently to the occupation histories of different areas in the city of Salvador. Although the number of ant species did not vary in terms of urbanization and population density, spider richness varied significantly, presenting a greater number of species in the ARs with lower human population densities. These areas also presented a greater proportion of green areas compared to Ba and PCA (SIM 2010), which is certainly correlated with the distinct responses of both groups. On a broader spatial scale, spiders responded better, as their diversity was correlated with the proportion of green areas (Melo et al. 2021). Within the urban matrix, ants presented a large difference in richness when comparing more conserved habitats (i.e., green areas) and altered areas (i.e., built-up environments) (Melo & Delabie 2017). It is likely that we could not detect the influence of urbanization on ant richness as they were only sampled in "green areas", with no sample collections performed in built-up areas (i.e., buildings, roads, and pavements). This absence of richness variation has also observed for a city located in the Amazon, with low variation in ant richness between backyards and forest (Santos-Silva et al. 2016).

Figure 2. (A) Average number of ant species and (B) average number of ant guilds according to the urbanization history and population density of the studied areas.

This lack of collection at sample points with contrasting characteristics (green vs. built-up areas), may also explain the results found for the guild richness of both taxonomic groups. In relation to guilds richness, neither ants nor spiders presented significant variations in terms of urbanization rate in the ARs. As foraging method and location determine the occurrence of spider and ant guilds (Dias et al. 2010; Brandão et al. 2012), and since the samples were collected in different habitat strata, our data collection naturally allowed for the consecutive collection of a large number of guilds in green areas in the neighborhoods of Salvador, presenting no differences between areas.

In relation to the qualitative aspects investigated here, differences were only observed for araneofauna between ARs, however, ants and spiders did not present any variation in terms of guild composition. Differences in the taxonomic composition of both groups have been related to the influence of composition and urban matrix configuration on the process of ant and spider dispersion, while factors associated with habitat characteristics have been found to influence guild composition (Sattler et al. 2010; Melliger et al. 2018; Melo et al. 2021). However, we expected that the taxonomic composition of myrmecofauna, in addition to ant and spider guilds, would also vary in terms of occupation history and AR development. This lack of variation in ant and partly spider composition, may be related to the influence of the urban matrix, which selects species and guilds that are more tolerant to cities (Sattler et al. 2010; Melliger et al. 2018; Melo et al. 2021). Especially for urbanization-tolerant ants, behaviors related to the discovery and defense of resources allow the coexistence of several species (Dáttilo & MacGregor-Fors 2021). This is because usually the first to discover the food monopolizes the source (Dáttilo & MacGregor-Fors 2021), a strategy that allows the occurrence of different ants in the different types of green areas distributed throughout the city. As such, at an AR scale, the lack of difference in guild composition may be due to the biotic homogenization of ant and spider assemblages in the urban matrix of Salvador.

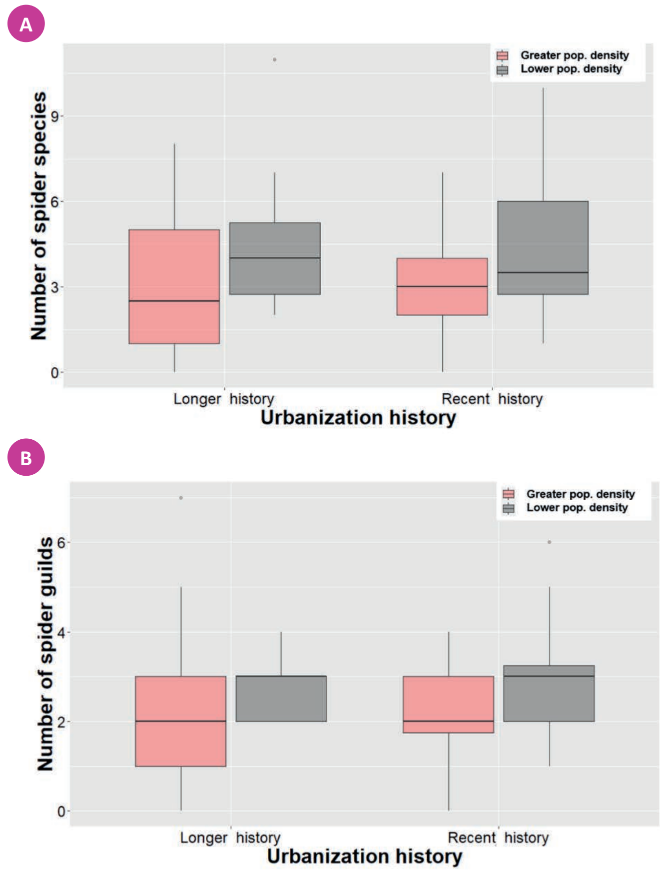

Figure 3. (A) Average number of spider species and (B) average number of spider guilds according to the urbanization history and population density of the studied areas.

Given the importance of understanding how different historical processes of neighborhood formation can influence the distribution of organisms in a city, our results demonstrate how distinct arthropod groups (one social, the other not) respond to urbanization. Within community metrics, only spider taxonomic richness varied in terms of population density and rate of green areas in ARs, indicating that spiders are more sensitive to urbanization, which is an important predictive factor that should be considered in urban planning. In general, the composition of myrmecofauna and araneofauna did not present variation, which may indicate biotic homogenization between the study ARs, or that other urban landscape characteristics influence species distribution. Factors such as heterogeneity and habitat configuration in cities, have been found to influence ants and spiders (Sattler et al. 2010; Melliger et al. 2018; Melo et al. 2021). Furthermore, how the quantity and type of green areas are distributed in cities may be important factors for the evaluation and conservation of spider and ant diversity.

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Authors' Contributions

TSM, MCLP and JHCD contributed to the study conception and design. Material preparation, identification and data organization were performed by TSM, JHCD and ADB. Statistical analysis was performed by TSM and EBAK. The first draft of the manuscript was written by TSM, ARSA, EBAK and METS. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflict of Interest Statement

The authors declare no conflict of interest.

Supplementary Material

Supplemental data for this article can be accessed at doi: 10.6084/m9.figshare.19372295.v7

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