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Diversity of Ants (Hymenoptera: Formicidae) in a Sub-Montane and Sub-Tropical Cityscape of Northeastern Mexico

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Abstract

The role of urban ecosystems in maintaining biodiversity and ecosystem services is highly variable because of the heterogeneity of habitats in human-used landscapes. We analyzed ant diversity in a sub-montane and sub-tropical urban area of northeastern Mexico to determine the conservation value of this cityscape. Ants were collected in 16 sites (each located at a 1 Km^2 quadrat) across the cityscape, including spaces at the periphery and urban center, during the rainy season (August to October) of 2015. To capture ants, in each site eight pitfall traps, with for different baiting treatments were installed along a 100-m transect, and hand collections were performed. In total, 7,415 ant workers belonging to 32 species, 23 genera, 11 tribes, and 5 sub-families were collected. The richness and structure of the assemblages varied among the sampling sites. The compositional similarity also varied significantly among sampling sites, and unique species were found in four sites. Each site showed an important and particular ant assemblage that differed from that of the other sites and the surrounding habitats in the cityscape. The results suggest that some sampling sites in the studied cityscape may contribute to the conservation of certain ant groups and invertebrate communities threatened by urban intensification. Ultimately, our findings support the importance of conserved areas and green spaces for the conservation of native species in and near urban areas.

Introduction

Many urban areas around the world have rapidly grown and expanded into outlying rural areas, negatively transforming the regional environment and conditions for a variety of productive activities dependent on the availability and quality of natural resources, such as livestock grazing and crop production (Gaviría-Gutíerrez, 2014). Urban ecosystems feature physical barriers, high temperatures, and warm wind streams as well as pollution and therefore represent artificial environments (Simonetti et al., 2010). The human-induced processes associated with urbanization may threaten biodiversity and affect ecosystem productivity, leading to the loss of habitats, biomass, and the carbon storage capacity of ecosystems (Seto et al., 2012). Several studies have suggested that the fauna inhabiting cityscapes may, in some cases, positively respond to human-induced changes, including the increased availability of certain resources or other beneficial environmental conditions. In fact, the settlement and dispersal of some fauna, such as invasive species, may be favored (Uno et al., 2010).

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Currently, the spread of human settlements and infrastructure is accelerating across the globe, and some projections estimate that the worldwide urban population will reach almost 5 billion in 2030 (Seto et al., 2012). The domination of the planet by urban ecosystems reveals the immediate need of evaluating the value of cityscapes and their associated fauna. Such assessments are important for the management of urban fauna and for the generation of different management alternatives for urban microhabitats to avoid the disappearance of native species.

Urban ecosystems have been extensively studied in the field of ecology, and their importance for the conservation of flora and fauna is increasingly being recognized. The majority of studies have focused on the conservation value of cityscapes (Alvey, 2006; Shochat, 2010). Several research studies on gray and green urban areas have highlighted the relative importance of urban or peri-urban habitats as biodiversity reservoirs based on the study of several common bioindicator groups, including ants, butterflies, beetles, and spiders (Aronson, 2014; Ramírez-Restrepo, 2015; Rocha & Castaño, 2015). In general, as urban intensification increases, a significant and negative decrease in the diversity of native species is found along with an increase in the abundance of some generalist species (Buczkowski & Richmond, 2012). However, high levels of biodiversity have also been reported in green cities (Aronson et al., 2014; Fortel et al., 2014) with favorable temperatures and high resource availability due to the maintenance of natural and native vegetation (Rocha & Castaño-Meneses, 2015).

Ideal organisms for biodiversity analysis in urban environments should perform various functions in the community, have a relatively short generation time (in order to assess sensitivity to environmental changes), and be abundant and relatively easy to collect (Monteiro-Júnior et al., 2015). Based on these criteria, insects are good indicators of the impact of urbanization on biodiversity (Jaganmohan et al., 2013). Among the vast insect groups, ants (Hymenoptera: Formicidae) represent a suitable group for studying the effects of urbanization because of their important ecological role in ecosystems. In particular, ants form a highly diverse and abundant insect group with distinct habitat and nutrient preferences and have important effects on soil physical and chemical properties (Calcaterra et al., 2010). Usually, ants are abundant in urban zones, although some studies have indicated that urbanization has resulted in the permanent loss of up to 85% of ant species (Buczkowski & Krushelnycky, 2012; Buczkowski & Richmond, 2012).

In several urban cityscapes, certain dominant and abundant ant species were found to damage the structures of buildings, contaminate stored food, cause direct harm to humans, nest in gardens, and be vectors of pathogens (Olaya-Masmela, 2005). In recent decades, research has also been carried out on diverse topics surrounding the use of formicides in urban environments or inside or outside household, listing the effects on different species (Cupul-Magaña, 2009; Taheri & Reyes-López, 2018). Other studies have evaluated variation in the diversity patterns of ant communities along of a gradient of urban disturbance (Rocha & Castaño-Meneses, 2015), ant responses to urban environments (Angilleta Jr., 2007), ants as nosocomial vectors (Rodovahlo et al., 2007), ant responses to insecticides, and ant management with repellents (Mothapo & Wossler, 2016).

Until now, little research has been carried out on the urban myrmeco fauna of Mexico. One study detailed a rapid descriptive ecological assessment for testing the effect of urbanization on ant morphospecies (MacGregor-Fors et al., 2015), and several additional studies have reported on the importance of urban green spaces as reservoirs of ant diversity (Rocha & Castaño-Meneses, 2015), the bait preferences of ants (Rosas-Mejía et al., 2015), and new species records (Rosas-Mejía et al., 2013; Landero-Torres et al., 2014). However, it is crucial to contribute toward current knowledge of the real influence of urbanization on ant species diversity at a local and landscape level. The present study was designed to analyze the ant diversity associated with 16 sampling sites in a cityscape of northeastern Mexico surrounded by a sub-montane and sub-tropical thorn scrub area. In particular, we analyzed the changes in alpha, beta, and gamma diversity among ant assemblages to determine the conservation value of each sampling site within the cityscape. Greater knowledge of ants and other groups of arthropods in cityscapes can improve our understanding on how the urbanization process affects these insects and will contribute to the formation of baseline management and planning strategies for the conservation of native species.

Materials and Methods

Study area

The study was conducted in the sub-montane and sub-tropical city of Ciudad Victoria, located in central Tamaulipas between the parallels 23°47’21”and 23°41’47” N and the meridians 99°11’40” and 99°04’30” W at an elevation range of 295 to 495 m a.s.l. The city has a population of 305,155 inhabitants. The climate is sub-humid semi-warm throughout the year with a summer rainfall pattern. The average annual rainfall is 926 mm, and the average annual temperature is 24°C. The soil is mainly characterized as medium lithosol with a small proportion of medium-fine rendzina (INEGI, 2012). The vegetation near the downtown area of the cityscape is dominated by ornamental and fruit trees. Meanwhile, in the peripheral areas, native vegetation is present in different stages of degradation. The vegetation type is known as sub-montane and sub-tropical Tamaulipan thorn scrub and it is mainly composed of large and medium-sized bushes ranging from 3 to 5 m in height (Salazar-Olivo & Solis-Rojas, 2015).

Site selection

To establish sampling sites across the studied cityscape, we established the boundaries of Ciudad Victoria by digitizing the boundaries between urban and non-urban area on a previously generated land use/cover map of the study region belonging to an ongoing project (Rosas *in prep*.). Then, we randomly set a 1 × 1 km grid on the urban polygon of the city and established all quadrat centroids as the sampling sites. Later, through ground truthing, we adjusted the position of each sampling site to the nearest public land where sampling was feasible (given that several points were originally set at inaccessible areas). The resulting number of sampling sites was 20, but for security reasons, several sites in the peri-urban areas of the city were discarded, reducing the number of sampling sites to 16 (Fig 1).

Ant sampling

Ant sampling was carried out from August to October 2015 during the rainy season along a 100-m long transect in each sampling site. To capture ants, eight pitfall traps (300 ml plastic containers) were set along each transect, and two people also performed a direct visual search and hand collection. Two pitfall traps had no bait. Another two were baited with tuna, two with fruit, and two with honey. These traps were alternately set every 10 m along the length of each transect and were recovered after 48 h of exposure in the field. Direct collections were performed for 60 min along each transect between 09:00 and 16:00 h.

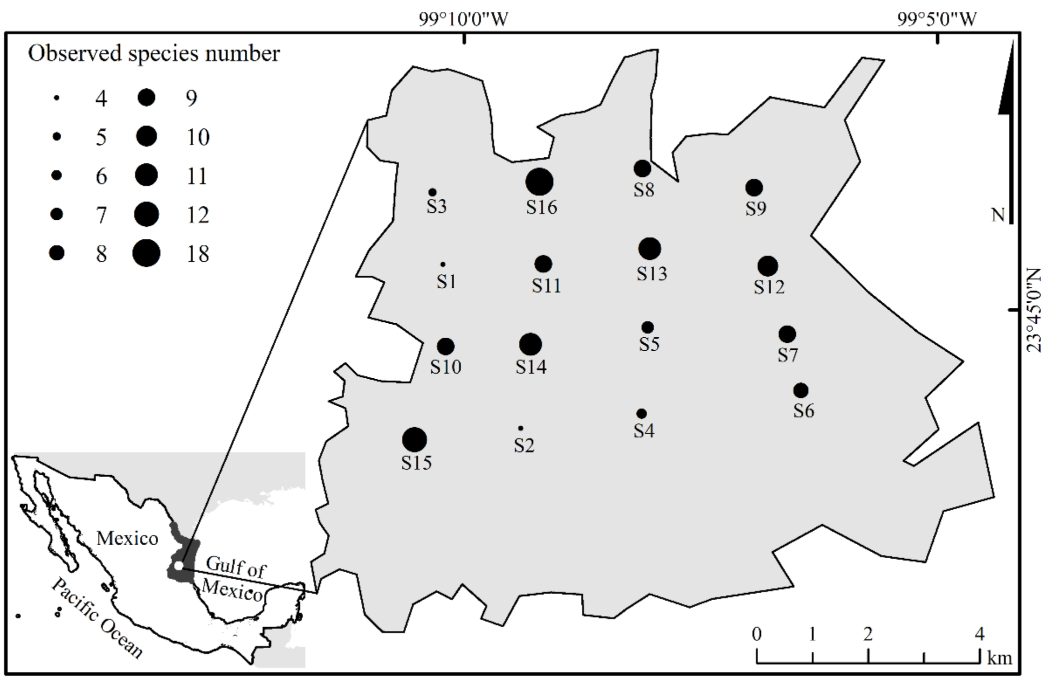

Fig 1. Location of the studied cityscape in Ciudad Victoria, Tamaulipas, Mexico. The location of the cityscape (white circle) within the state of Tamaulipas (black polygon) is shown. The black circles indicate the sampling sites (larger size indicates greater species richness).

All collected ants were preserved in 100% ethanol, and one to three of the collected specimens per sample that differed morphologically were dry mounted. The key of Mackay and Vinson (1989) was used to identify ant genera along with several additional keys for species identification depending on the genus involved. Voucher specimens were deposited in the Ant Collection of the Laboratorio de Zoología of the Instituto de Ecología Aplicada of the Universidad Autónoma de Tamaulipas in Ciudad Victoria, Tamaulipas, Mexico.

Data analysis

The number of species occurrences at each site during the three months of sampling was used as a measure of abundance (maximum abundance = 30). The inventory completeness for each site was calculated using the sample coverage estimator ($\hat{C}n$), which is a less biased estimator of inventory completeness than non-parametric methods. This estimator indicates the proportion of the "total community" represented by the trapped species; when $\hat{C}n \approx 100\%$, sampling is complete given the effort and utilized capture technique (Chao & Jost, 2012). Values of $\hat{C}n$ were calculated using the iNEXT package for R (Hsieh *et al*. 2016).

The comparison of species richness among sites is only ecologically appropriate for sites with a similar level of inventory completeness. Therefore, the comparison of our estimates of species richness per site could be biased because of differences in inventory completeness. Additionally, species richness is sensitive to variations in the number of singletons and doubletons (Chao & Jost, 2012). Thus, we estimated the species richness for each site using coverage-based inter- and extrapolations in the iNEXT package for R (Hsieh et al., 2016). We considered 99.99% completeness as a reliable estimator of richness for all sites (Chao & Jost, 2012). To compare species richness among sites, we used 95% confidence intervals in which significant differences were indicated by non-overlapping confidence intervals (Cumming et al., 2007).

To evaluate differences in species dominance and rarity and in community evenness among sites, ant abundance was represented by rank-abundance species curves or Whittaker plots (Magurran, 2004). We plotted the proportional abundance of each species, ordered from the most to the least abundant, to show differences in species dominance and rarity and in assemblage evenness among sites.

To analyze beta diversity, we determined the compositional similarity among sites using the Jaccard index. This index has values ranging from 0 (minimum similarity) to 100 (maximum similarity) (Magurran, 2004). It only takes into account shared species and the presence/absence of species between sites (Jost, 2006). The compositional similarity among sites was represented by a cluster analysis using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) linkage technique. For the *pos thoc* analysis, a similarity profile test (SIMPROF) was used as a statistical test to compare similarity among assemblages in the PRIMER software version 6.1.16 (Clarke & Gorley, 2006). The SIMPROF test assumes that a real clustering of assemblages will be evidenced by an excess of smaller and/or larger similarities than expected under the null hypothesis that all assemblages are drawn from the same species assemblage (Clarke et al., 2008).

To quantify the contribution of each site to total diversity (i.e., gamma diversity), we calculated the average number of species absent from each site (beta diversity), which is defined as $\beta=\gamma-\alpha$, where γ corresponds with the number of species historically recorded in the study area (gamma diversity) and α with the average number of species present in a given site (alpha diversity) (Lande, 1996). This approach allows for a direct comparison between alpha and beta diversities in terms of numbers (or percentages) of species (Crist et al., 2003).

Results

In total, 7,415 ant workers belonging to 32 species, 23 genera, 11 tribes, and 5 sub-families were collected. The sub-family Myrmicinae had the highest number of tribes, genera, and species. The genera *Crematogaster*, *Pheidole*, and *Solenopsis* had the highest number of species (3 spp. each), followed by *Forelius*, *Mycocepurus*, and *Pseudomyrmex* (2 spp.). The 17 remaining genera were represented by only one species. The average inventory completeness was 99.57% (range: 97.83–100%). Considering all 16 sampling sites, the overall inventory completeness was 99.9%.

With respect to species abundance, a total of 1,057 species occurrences were recorded in the entire sampling, ranging from 36 (S7) to 136 (S16). We observed that the assemblage structure changed across the sites (Fig 2). Considering proportional abundance, the general pattern indicated an increase in species dominance in sites S1, S2, S4, and S6 (Fig 2). The dominant species in the studied cityscape were *Atta texana* (Buckley), *Forelius mccooki* (McCook), *Paratrechina longicornis* (Latreille), *Pheidole bilimeki* (Mayr), *P. dentata* (Mayr), *Solenopsis geminata* (Fabricius), and *S. xyloni* (McCook), with a relative abundance greater than 20%. With respect to observed species richness (Fig 3), a minimum of four species were recorded in sites S1 and S2 and a maximum of 18 in site S16. The estimated species richness increased significantly from site S1 to site S16.

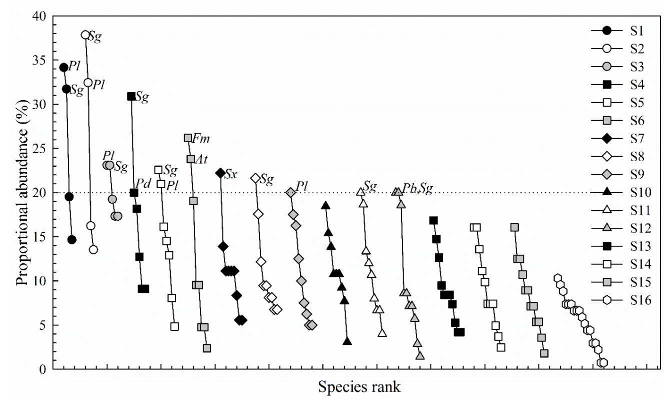

Fig 2. Rank-abundance curves of the ant assemblages recorded in the sub-montane and sub-tropical cityscape of Ciudad Victoria, Tamaulipas, Mexico. Only species with a relative abundance higher than 20% (above dashed line) in a given sampling period are shown. Pl: *Paratrechina longicornis* (Latreille), Sg: *Solenopsis geminata* (Fabricius), Pd: *Pheidole dentata* Mayr, Fm: *Forelius mccooki* (McCook), At: *Atta texana* (Buckley), Sx: *Solenopsis xyloni* McCook, Pb: *Pheidole bilimeki* Mayr.

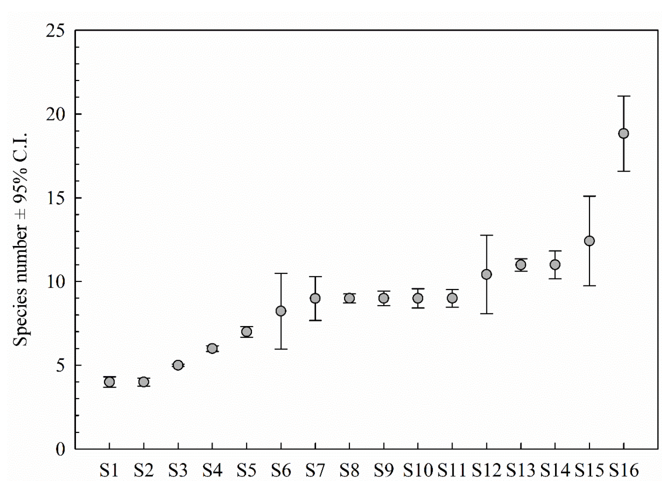

Fig 3. Comparison of ant species richness estimates for a rarefied and extrapolated sample with a size up to double the reference sample. Differences are considered to be statistically significant when the 95% confidence intervals (C.I.) do not overlap; for overlapping intervals, no differences are assumed (α=0.05).

The evaluation of compositional similarity using a cluster analysis and SIMPROF test based on the Jaccard index showed the significant separation of three assemblage clusters at a similarity of 7.34% (π=3.18, p=0.002) and 10.27% (π=2.62, p=0.003) (Fig 4). The ant assemblage collected in site S6 was significantly separated from the assemblages collected in sites S15 and S7 and the remaining assemblages.

Regarding species turnover among sampling sites, 12.50% of total species were unique to a single site, and no single species was shared by all sites (Fig 5). In addition, no single species was shared by 5, 10, 11, 12, 14 or 15 sites, although 3.12% of total collected species were shared by 13 sites. The species *Lasius niger* (Linnaeus), *Carebara urichi* (Wheeler), *Cyphomyrmex rimosus* (Spinola), and *Mycocepurus smithii* (Forel) were unique to sites S3, S6, S7, and S15, respectively. In the remaining sites, no unique species were found.

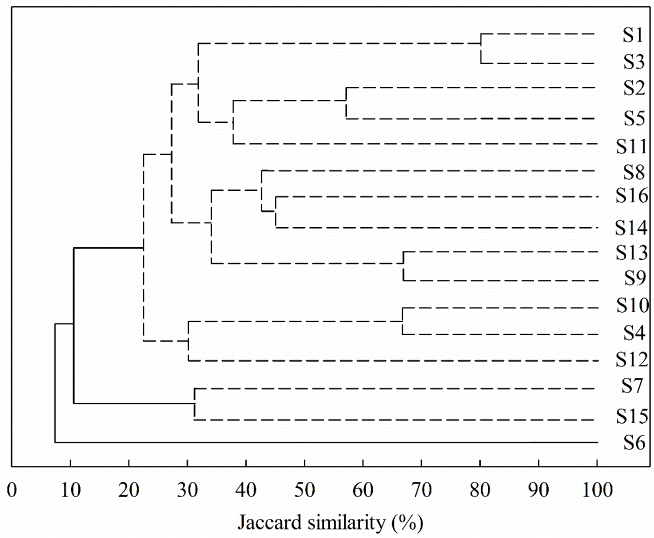

Fig 4. Dendrograms of the hierarchical clustering of urban ant assemblages recorded in the sub-montane and sub-tropical cityscape of Ciudad Victoria, Tamaulipas, Mexico. The dendrograms display as continuous lines the divisions for which the SIMPROF test rejects the null hypothesis (assemblages in these groups have no further structure to explore); the groups of assemblages indicated by dashed lines were not separated by the SIMPROF test (at p<0.05).

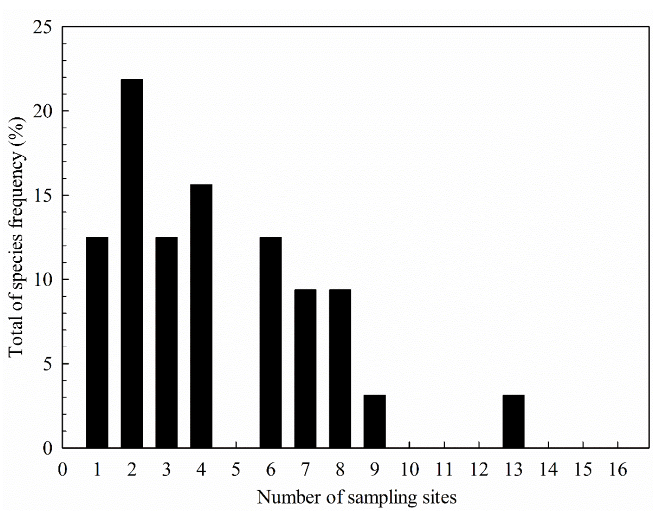

Fig 5. Percentage of total species (n=32) that occur in the sub-montane and sub-tropical cityscape of Ciudad Victoria, Tamaulipas, Mexico.

Discussion

The present study evidences the high variability of urban entomo fauna as a result of constant anthropogenic pressures (Slipinski et al., 2012). In our study, we empirically

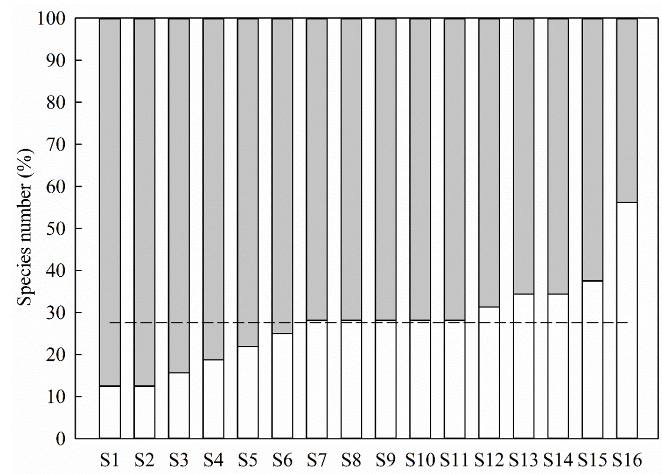

Fig 6. Contribution of alpha and beta diversity to the gamma diversity of urban ant assemblages of the sub-montane and sub-tropical cityscape of Ciudad Victoria, Tamaulipas, Mexico. The gray bars represent alpha diversity per sampling site, the white bars beta diversity, and the dotted line mean alpha diversity. All diversities are expressed as a percentage of total recorded species (n=32).

demonstrated that the cityscape of Ciudad Victoria in northeastern may provide several and unique habitats for ants. Overall, the alpha, beta, and gamma diversities of the studied assemblages seem to be high in comparison to those of other urban myrmecofaunas for the Fig 6 (Slipinski et al., 2012; Ossola et al., 2015; Rocha & Castaño-Meneses, 2015). A high proportion of native species and a relatively low proportion of exotic species (1.32%) were found in addition to high compositional dissimilarity among the different sampling sites. The conservation value of the studied cityscape likely rests on the fact that it is formed by diverse habitats that support a particular array of myrmeco fauna. Therefore, cityscapes should be included in conservation strategies for terrestrial biodiversity based on their conservation value.

Notably, compared to previous studies on urban myrmeco fauna, we recorded a higher number of species (Clarke et al., 2008; Cupul-Magaña, 2009; Slipinski et al., 2012; Ossola et al., 2015). We also recorded a higher proportion of native ants with respect to exotic ants, yet it is important to emphasize that the encountered exotic species of *P. longicornis, L. niger, M. floricola* (Jerdon), and *Tapinoma melanocephalum* (Fabricius, 1793) are considered highly problematic at the worldwide level (Pagad et al., 2015; Bertelsmeier et al., 2017). Further studies on urban ant assemblages should be performed to elucidate the relative influence (positive or negative) of different habitats and the landscape drivers of ant diversity in novel urban-influenced ecosystems.

The sites of the studied cityscape varied significantly in their conservation value and associated ant diversity because of the presence of lowly (e.g., structurally complex parks and gardens) and highly urbanized areas (e.g., areas with high built cover). Overall, we observed that species richness is highly variable among the sampled sites. Particularly, sites S15 and S16, which are close to vast areas of sub-montane and sub-tropical thorn scrub, showed a significantly higher species richness. In contrast, sites with high urban intensity or built cover, such as S5, had lower species richness.

In human-dominated landscapes, it appears that the structure, of ant communities, changes as a result of interspecific competition and the exclusion of native species by introduced dominant species. The dominant species *A. texana, F. mccooki, P. longicornis, P. bilimeki, P. dentata, S. geminata*, and *S. xyloni* were particularly well represented in peri-urban sites (S1, S2, S3, S4) of the urbanized area near areas with native vegetation. These dominant species mainly exhibit generalist nesting and feeding habits, which provide greater plasticity, and are highly adaptable to areas with a high degree of anthropogenic disturbance. Such generalist species may have some advantages over other specialist or native species in anthropized environments. Their abundance patterns may be the result of construction activities during the ant sampling. Thus, the dominant species mainly exhibited generalist nesting and feeding habits, which provide greater plasticity and enable adaption to areas with a high degree of anthropogenic disturbance (Pećarevićet al., 2010).

The presence of aggressive and dominant species in urban sites or in sites near conserved areas could interfere with the dispersal of arthropods living in the soil and adversely affect the composition of the arthropod community (Lessard & Buddle, 2005). However, in one of the sites, we found that the presence of *L. niger*, an introduced species that is highly common around the world, did not seem to cause an imbalance in the native myrmeco fauna, even though our analysis is not necessarily focused on the positive or negative effects of introduced species. It appears that most introduced ants remain confined to habitats modified by humans without altering the community of native ants (Lester, 2005).

One previous study suggested that urban areas connected and containing native vegetation have higher ant species richness and lower dominance compared to other urban sites in the city center (Rocha & Castaño-Meneses, 2015). This was confirmed by our finding that three of the four species unique to particular sites had specialized feeding habits and were found in sites near native vegetation fragments. In contrast, urbanization, which results in changes in vegetation cover, habitat fragmentation, and environmental pollution, may negatively affect species richness (Yasuda & Koike, 2009). Accordingly, a smaller number of species are expected in areas of greater urban influence. In the present case, a smaller number of species was indeed obtained in urban areas (S13 and S14), although the number of species (11 and 12, respectively), was still notable. The myrmecofauna found at these latter sites is common in anthropized environments and is composed a mixture of native and exotic species that show a high tolerance to human disturbances.

In the analyses of compositional similarity, we observed a significant separation into three assemblage groups. Site S6, which is located in a landscape composed of human settlements and infrastructure, differed significantly from site S16, which is located near a remnant of native vegetation (Fig 1). This finding is concordant with the studies of Kamura et al. (2007) and Cupul-Magaña (2009), where in changes were reported in the compositional similarity and structure of ant assemblages between sites located near mountain forest fragments and sites located near urban centers. One of the explanations for this phenomenon is the differential availability of the resources used by ants in urban areas and native forests (Kim, 1992).

In conclusion, this study provides one of the first standardized inventories of the myrmecofauna associated with a cityscape in Mexico. The gamma diversity of ants in the studied cityscape is mainly determined by the beta diversity or high species turnover of ants among the sampling sites to the Fig 6. Each studied site holds an important and particular myrmeco fauna that differs from that of the other sites and surrounding habitats of the cityscape. The relatively high alpha and beta diversities may be shaped by the high habitat heterogeneity of the cityscape, even though urban intensification can also negatively affect the alpha diversity of ants and probably of another arthropods. Therefore, some green areas in the cityscape may positively contribute toward the conservation of ant assemblages and probably other invertebrate communities that are threatened by urban intensification. These data support the importance of conserving green areas and of considering such areas in urban planning measures to conserve native species. We suggest that future research studies analyze the relative effects of the resources and environmental conditions associated with the different habitats present in the cityscapes of the Sierra Madre of Tamaulipas, including those of transitional zones and well-conserved regions, to further determine the conservation value of novel urban-influenced ecosystems.

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Authors' Contribution

MA García-Martínez and M Rosas-Mejía: Designed the experiment, performed experiments, and analysis, wrote the paper. OR Leyva-Ovalle and P Zetina-Córdoba helped in performing experiments and the preparation of the paper. V Vanoye-Eligio and MJ Aguilar-Méndez: Performed the analysis, wrote the paper.

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