



Effects of vegetation structure and edge proximity on insect distribution in an arboreal Caatinga area in Brazil

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ABSTRACT

Caatinga is a very important and neglected dry tropical forest biome of Brazil. Recent evidence indicates that anthropogenic threats to Caatinga have grown in recent years, and there are still gaps in the knowledge of how these effects alter biodiversity. In the present study, we evaluated the effects of vegetation structure and edge proximity on the distribution of bioindicator insects (galling insects and ants) in an arboreal Caatinga area under the influence of a monoculture in Brazil. We recorded a total of 10 species and 2,131 specimens of ants and 11 species and 29 individuals of galling insects. Species richness, abundance, and composition of galling insects and ants did not differ between edge and interior plots of the forest. Ant diversity was also not affected by the structural parameters of vegetation (plant abundance, vegetation cover, and vegetation height). On the other hand, the plant abundance positively influenced the richness and the abundance of galling insects in the plots. Our findings suggest that the distribution of ants and galling insects in Caatinga forest edge and interior environments did not differ likely due the opening of the canopy gives the arboreal Caatinga relatively homogeneous climatic characteristics throughout the forest. Already the structure of vegetation positively influences galling insects due to the high degree of dependence that endophagous life-form generates on these insects. Our results show that despite similar responses to the edge effect, ants and galling insects respond differently to vegetation structure, indicating that the structuring of these insect communities is guild-dependent.

Key words: Ants, galling insects, plant-animal interactions, forest structure.

Introduction

Caatinga has an approximate area of 826,411 km², being the main semi-arid biome in Brazil, occupying 70% of the northeast region of the country (Rodrigues et al., 2018). It is considered a mosaic of thorny shrubs and seasonally dry forests (Leal et al., 2005), having few rainy periods resulting in severe droughts (Chiang & Koutavas, 2004). It also has a substantial occurrence of endemic flora and fauna, with many species recently described for the region (Leal et al., 2003; Fonseca & Venticinque, 2018). Nevertheless, among the Brazilian biomes,

Caatinga has the largest study lag (Santos et al., 2011a), although it has priority areas for biodiversity conservation (Silva et al., 2004). Also, recent evidence indicates that anthropogenic threats to Caatinga have grown in recent years, and there are still gaps in the knowledge of how these effects alter biodiversity (Fonseca & Venticinque, 2018).

Anthropic effects may affect natural vegetation causing disturbances in their climatic and structural characteristics and, consequently, modify the conditions for the occurrence of fauna (Benítez-Malvido & Arroyo-Rodríguez, 2008;

Laurence et al., 2013). Fragmentation of forest environments, for example, can expose forest edge areas to conditions of higher insolation, higher temperature, and lower unit (Murcia, 1995; Lima-Ribeiro, 2008; Arruda & Eisenlohr, 2016), which affects the occurrence of many animal populations (Benítez-Malvido & Arroyo-Rodríguez, 2008). In this context, some insect groups may be susceptible to anthropogenic changes on the edges of natural vegetation and are often used as habitat modification bioindicators (Brown, 1997). Besides, certain types of land use near forest edges can make these environments more severe for bioindicator insects to occur (Dauber & Wolters, 2004). It is the case with agricultural plantations where recurrent pesticide use can end up contaminating forest edges and negatively affect the occurrence of bioindicator insects.

Besides the anthropic effects, studies in different environments have shown that the structural complexity of the vegetation can influence the occurrence of insects in a locality (Lawnton, 1983). Vegetation structure is sometimes more determinant than abiotic or anthropic effects (Kemp & Ellis, 2017) because they affect different insect groups and trophic levels (Obermaier et al., 2008). In this sense, there is evidence that environments with more complex vegetation may have a greater diversity of insects (Borges & Brown, 2001; Diniz et al., 2010), mainly herbivores (Leal et al., 2016; Bergamini et al., 2017). It is because more complex environments have greater habitat heterogeneity and thus greater resource availability (Grez & Gonzalez, 1995).

In this context, the study aimed to evaluate the distribution of bioindicator insects in a Caatinga area under the influence of a monoculture in Brazil. The bioindicator insect

groups used were the ants (Formicidae) (Andersen et al., 2002; Ribas et al., 2012) and galling herbivorous insects (insect herbivore guild) (Fernandes et al., 1995; Julião et al., 2005). These groups were selected, as there are several pieces of evidence in the literature indicating their sensitivity to anthropic changes, with ants responding negatively to habitat anthropization (Dauber & Wolters, 2004) and galling insects responding positively to the edge effect (Araújo et al., 2011; Araújo & Espírito-Santo Filho, 2012; Altamirano et al., 2016; Souza et al., 2016; Souza et al., 2019). Specifically, the following hypotheses were tested: 1) There is less diversity of ants on the forest edge than in the forest interior; 2) The diversity of galling insects is higher in edge than in the interior environments; 3) The composition of species of galling insects and ants differ between the edge and interior environments of the forest; 4) The vegetation structure positively influences the occurrence of ants and galling insect species.

Material and Methods

The study was carried out in an area of arboreal Caatinga located in Lagoa Cercada village, in the city of Colônia do Gurgueia, Piauí, Brazil (8°12'33.9"S 43°36'53.7"W, Figure 1A). The climate of the region is semi-arid tropical, characterized by scarce and irregular rainfall with long periods of drought and high average annual temperatures (Alvares et al., 2013). The arboreal Caatinga studied (Figure 1B) is characterized by xerophilic vegetation, with predominance of deciduous trees and shrubs (Sanchez-Azofeifa et al., 2013). This fragment is located on the edge of a cornfield, and there is evidence of burning, deforestation, and the use of pesticides in monoculture (Figure 1C).

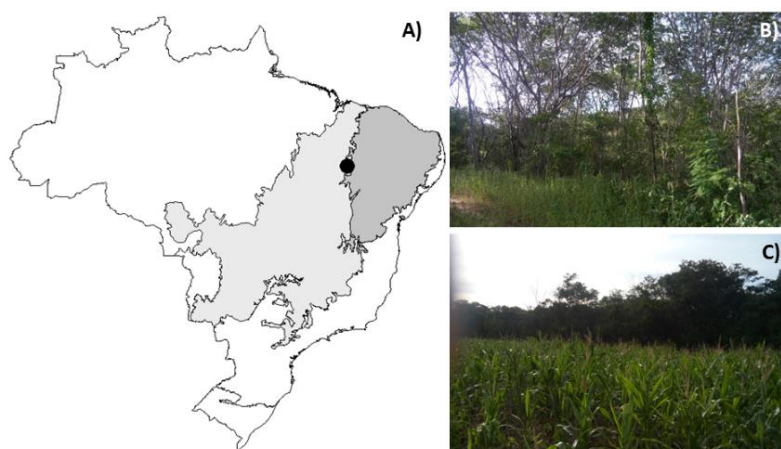


Figure 1. Location of the study area in the municipality of Colônia do Gurgueia, Piauí, Brazil (A). The area is situated in the Caatinga biome (dark gray) in a transition zone with the Cerrado biome (light gray). The fragment is characterized by forest vegetation called “Caatinga arborea” (B) and is surrounded by a corn monoculture at the edge (C). Font: Oliveira et al. (2019).

For the sampling of the insects (May 2016), two transects were established with 10 plots of 10x10m each, with each plot 10m apart. One transect was established at the edge of the natural vegetation at five meters from the monoculture, and another within the natural vegetation at 50 m from the edge. This edge distance has been established based on some studies that point out that 50m is the maximum penetration distance of microclimatic changes in tropical forest fragments (e.g., Laurance et al., 2002; Araújo et al., 2011). In each plot, all plants with a circumference at breast height greater than or equal to 15 cm were sampled, from which the plant species were identified, and the total height (m) was estimated. This procedure aimed to characterize the vegetation structure by estimating, for each, the following parameters: plant abundance (number of plants), vegetation height (average height), and vegetation cover (average of circumferences).

To sampling the ants, disposable plates containing sardines were used as attractive bait, being allocated four baits per plot. Each bait remained in the field for one hour, after which time it was collected and stored in plastic bags, adequately identified with the collection plot. The sampling of galling insects was done through active search, where all plants in the plot were inspected for insect induced galls. The collected galls were characterized by their morphology (organ of occurrence, shape, and color), photographed, and stored in plastic bags with information of the plot and the host plant. After collection, all sampled material was taken for screening and identification in the laboratory of the Federal University of Piauí (UFPI). Ants were identified to the lowest possible taxonomic level using specialized literature (Baccaro et al., 2015), while gall insects were separated according to the species-specific gall morphotype (Araújo et al., 2013).

The variables used to describe insect diversity were abundance and richness. For galling insects, the number of galled plants was used as a proxy for abundance (Dalbem & Mendonça, 2006). The explanatory variables used were plot type (edge vs. interior) and structural parameters of vegetation (plant abundance, vegetation height, and vegetation cover). Generalized linear models (GLM's), were constructed to test the effect of plot type and vegetation structural parameters on the richness and abundance of ants and galling insects. All created models were subjected to residual analysis

for error distribution adequacy and simplified to the appropriate minimum model by omitting non-significant explanatory variables (Crawley, 2007).

In order to compare the species composition between edge and interior plots, analyses of Non-metric Multidimensional Scaling (nMDS), were used to order the samples based on the Jaccard similarity index. Subsequently, non-parametric permutation procedures (ANOSIM), were applied with 1,000 permutations, also based on the Jaccard index, to test the significance of the groups formed in the nMDS (Hammer et al., 2001). The values of p and r were obtained, and the similarity patterns between the species of ants and galling insects in the studied plots were determined. All analyzes were performed using R software (R Core Team, 2018).

Results

A total of 2,131 ant specimens were sampled, distributed in 10 species, seven genera, and five subfamilies. The species *Solenopsis* sp. (Westwood, 1840) was the most abundant with 682 individuals, which corresponds to 32% of the total ants sampled in the study. The most abundant species in the border plots was *Pheidole* sp. (Westwood, 1839), totalizing 564 individuals (62% of the individuals of the forest edge). In the interior plots, the most prominent species was *Solenopsis* sp. with 456 individuals (31% of the individuals of the forest interior).

For galling insects, 117 individuals and 17 plant species were analyzed, and 29 insect galls belonging to 11 distinct morphotypes were recorded. Insect gall morphotypes occurred in four host plant species, which were *Combretum leprosum* (Mart.), *Thiloua glaucocarpa* (Mart.) (Combretaceae), *Miconia albicans* (SW.) (Malastomataceae) Stewd, and one undetermined species. Most gall morphotypes occurred on the stem (70%) and had an ellipsoid shape (36%). The ellipsoid stem gall of *C. leprosum* was the morphotype most abundant on edge (N = 8; 44%), while the discoid gall of *T. glaucocarpa* was the most abundant on the interior plots (N = 7; 63%).

Species richness and abundance of ants did not differ between forest edge and interior (Figure 2A and B, respectively) and were not affected by the structural parameters of vegetation (plant abundance, vegetation cover, and vegetation height) (Table 1). The species composition of ants also not differed between the edge and interior plots (Figure 3A, Stress = 0.131; ANOSIM: $r = -0.081$, $P = 0.927$).

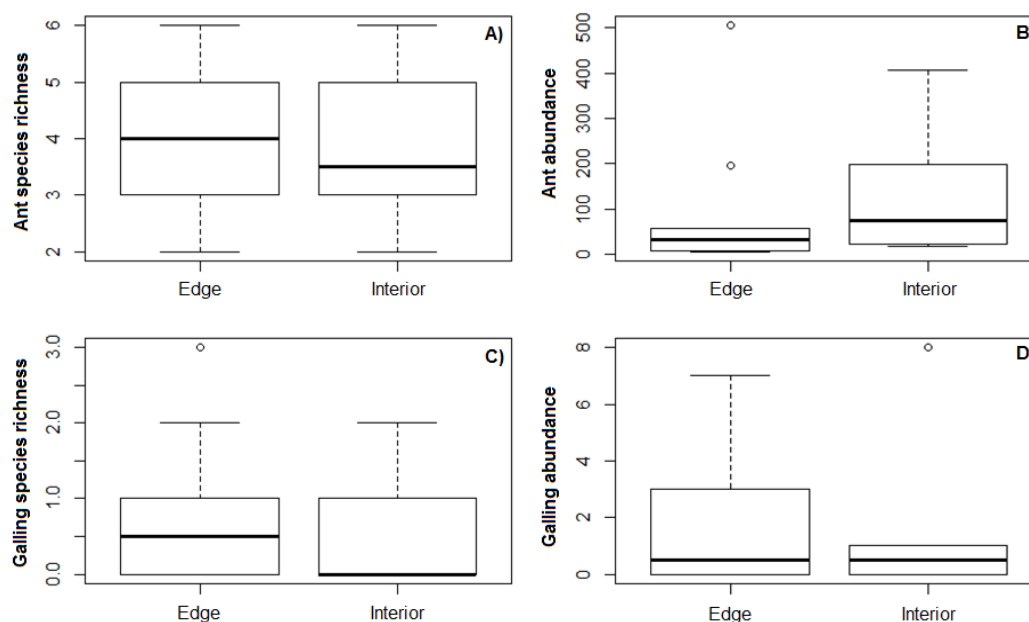


Figure 2. Comparison of ant species richness (A), ant abundance (B), galling species richness (C), and galling insect abundance (D) among plots located on the edge and interior an area of arboreal Caatinga, Colônia do Gurguéia, Piauí, Brazil. Central lines represent the medians, the upper and lower fences in the boxes represent values more and less than 75th and 25th percentiles (3rd and 1st quartiles, respectively), and the points represent outliers (values outside the confidence interval). Font: Oliveira et al. (2020).

The richness and abundance of galling insects also did not differ between the edge and interior plots of the forest (Table 1; Figure 2CD). Similar results also were obtained for the composition of galling species that not differed between the edge and interior plots (Figure 3B, Stress = 0.000; ANOSIM: $r = -0.031$, $P = 0.692$).

On the other hand, the plant abundance positively influenced the richness ($R^2 = 0.42$; $p < 0.01$; Figure 4A) and the abundance of galling insects in the plots ($R^2 = 0.40$; $p < 0.01$; Figure 4B). Plant cover and vegetation height did not influence galling insect diversity (Table 1).

Table 1. Generalized linear models showing the effects of environment type (edge vs. interior) and vegetation structure (plant abundance, vegetation cover, and vegetation height) on the diversity (richness and abundance) of ants and galling insects in an area of arboreal Caatinga, Colônia do Gurguéia, Piauí, Brazil. Font: Oliveira et al. (2020).

Response variables	Explanatory variables	df	Residual Deviance	F-value	P-value
Ant species richness	Plots (edge vs. interior)	18	36.5	0.028	0.870
	Plant abundance	17	33.34	1.744	0.206
	Plant cover	16	29.744	1.985	0.179
	Vegetation height	15	27.173	1.419	0.252
Ant abundance	Plots (edge vs. interior)	18	382878	0.245	0.628
	Plant abundance	17	365444	0.817	0.380
	Plant cover	16	343419	1.033	0.326
	Vegetation height	15	319954	1.100	0.311
Galling species richness	Plots (edge vs. interior)	18	14.1	0.934	0.349
	Plant abundance	17	7.9313	15.021	0.001
	Plant cover	16	7.5483	0.223	0.644
	Vegetation height	15	7.2307	0.659	0.430
Galling abundance	Plots (edge vs. interior)	18	117.2	0.429	0.522
	Plant abundance	17	66.933	14.002	0.001
	Plant cover	16	64.452	0.385	0.544
	Vegetation height	15	62.907	0.368	0.553

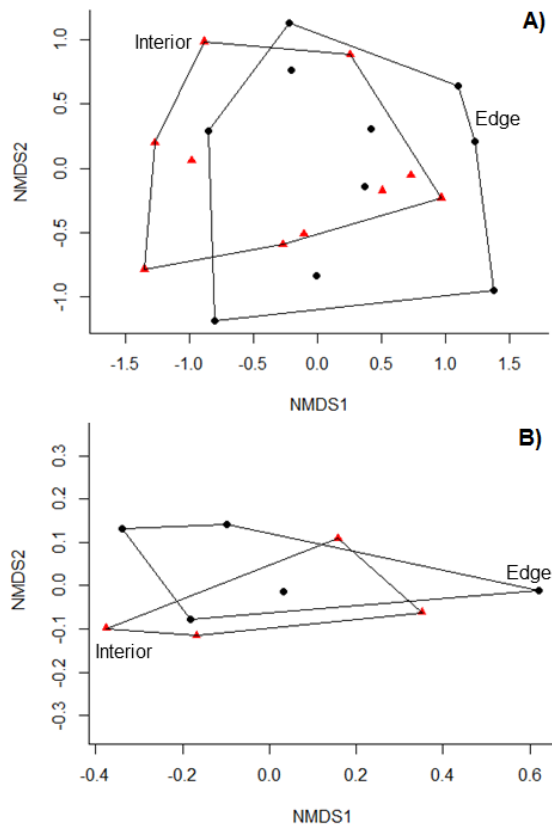


Figure 3. Non-Metric MultiDimensional Scaling (nMDS) showing the ordination of ants (A) and galling insects (B) sampled in plots located on edge (black circles) and interior (red triangles) an area of arboreal Caatinga, Colônia do Gurguéia, Piauí, Brazil. Font: Oliveira et al. (2020).

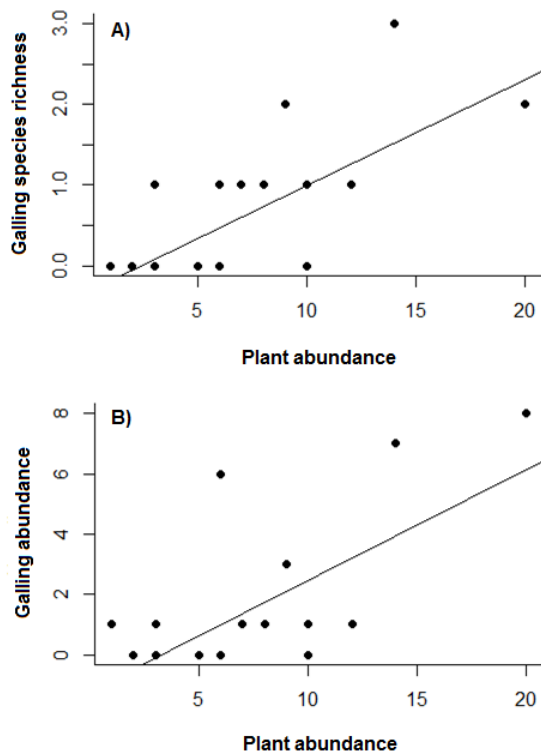


Figure 4. Effect of plant abundance on the richness (A) and abundance (B) of galling insects in an area

of arboreal Caatinga, Colônia do Gurguéia, Piauí, Brazil. Font: Oliveira et al. (2020).

The results show that the diversity and composition of the insects studied do not differ between the edge and interior environments of the forest.

Discussion

Although previous studies indicate that ant diversity is greater in the interior of the vegetation (Marinho et al., 2002; Oliveira et al., 1995; Vieira & Almeida, 2020), no effect of border anthropization on ant richness and abundance. These results may be due to the great diversity and heterogeneity of the Formicidae, which allows many species to be positively influenced by fragmentation (Rocha et al., 2015). The presence of a large abundance of generalist ants may have contributed to the similarity between the studied sites (Lopes et al., 2010; Soares et al., 2010), which can also be explained by the fact that these insects are very territorial (Paula & Lopes, 2013) and widely distributed (Wilson, 2005).

It was also found that insect gall diversity did not differ between forest edge and interior environments, unlike results from other studies conducted in tropical forests (Araújo et al., 2011, Araújo & Espírito-Santo Filho, 2012). This result may be due to the larger uniform opening of the deciduous forest canopy, causing a microclimate homogeneity in the Caatinga arboreal vegetation, which precludes significant differentiation between habitats (Arruda & Eisenlohr, 2016). In this context, due to the intrinsic characteristics of the vegetation, the edge effect can be so subtle that it does not significantly affect the plants (Arruda & Eisenlohr, 2016). Corroborating this, other studies comparing insect gall diversity among Caatinga areas with different degrees of anthropization also found no significant results (Carvalho-Fernandes et al., 2012; Brito et al., 2018).

Although we did not find significant differences in species composition, it was found that dominant species in edge and interior environments are different for both ants and galling insects. These results corroborate previous studies showing that some species are sensitive to the edge effect (Araújo et al., 2011; Brandão et al., 2011). In the border environments, the ants of the genus *Pheidole* were the most abundant, while ants of the genus *Solenopsis* dominated the interior. However, there is evidence in the literature that these two genera have species tolerant of anthropogenic changes (Ribas et al., 2012). Both genera *Pheidole* and *Solenopsis* have a widespread diet that allows them to better adapt to adverse conditions, and they

have a high level of abundance, factors that are a strategy for better colonization of the environment (Wilson, 2005).

The diversity of insect galls recorded in the present study (11 species) is lower than in other areas of northeastern Brazil (e.g., Santos et al., 2011b; Carvalho-Fernandes et al., 2012; Brito et al., 2018), but comparable to that observed in other studies conducted at Caatinga (e.g., Alcântara et al., 2017). The galling insect fauna was dominated by *C. leprosum* stem galls in the border environment and by *T. glaucocarpa* leaf galls within the vegetation. In a previous study, Araújo et al. (2011) also recorded distinct galling insect morphotypes dominating edge and interior environments of semi-deciduous forests in Brazil. Structurally the wall of stem galls tends to be thicker and lignified than the wall of leaf galls (Isaias et al., 2014). Thus, the dominance of stem galls in forest edge environments may indicate that this type of gall may be more tolerant of the climatic conditions of this environment.

Studies in tropical ecosystems indicate that vegetation structure may have an important effect on ant diversity (e.g., Oliveira et al., 1995; Vasconcelos et al., 2008) and galling insects (e.g., Gonçalves-Alvim & Fernandes, 2001; Cuevas-Reyes et al., 2004; Souza et al., 2019). The results partially corroborate these studies as it was found positive effects of vegetation structure on the diversity of galling insects, but no effect was observed for ant diversity. This result may be due to galling insects using them directly from plants because they are herbivores and depend on occurrence because they are endophagous (Araújo et al., 2013). Therefore, the greater the abundance of plants, the greater the availability of food resources and meristematic sites for galls, which positively influences the abundance and richness of galling insects (Gonçalves-Alvim & Fernandes, 2001; Araújo & Guilherme, 2012). In the case of ants, this dependence on plant abundance and other structural parameters was not observed, probably because these insects have different eating habits and high mobility, which allows them to use the environment much more dynamically.

Conclusion

The distribution of ants and galling insects in a dry forest edge and interior environments differ from the observed patterns for rainy tropical forests. The opening of the canopy gives the arboreal Caatinga relatively homogeneous climatic characteristics throughout the forest. Additionally, previous studies indicate that vegetation structure has noticeable effects on the richness and abundance of galling insects, which

are very dependent on their host plants. On the other hand, different responses of ants and galling insects to vegetation structure, indicates that the structuring of these insect communities is guild-dependent. Future studies may investigate whether these patterns are observed for other herbivorous and non-herbivorous insect groups.

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