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Effect of habitat quality on the biodiversity of ant genera and functional groups in a riparian forest area of the Tauarizinho River in Eastern Amazonia

Efeito da qualidade do habitat sobre a biodiversidade de gêneros e grupos funcionais de formigas em uma área de mata ciliar do rio Tauarizinho na Amazônia Oriental

Efecto de la calidad del hábitat sobre la biodiversidad de géneros y grupos funcionales de hormigas en un área de bosque ribereño del río Tauarizinho en la Amazonía Oriental

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Abstract
In view of the scenario of human disturbances and regional climate change, we intend to verify whether habitats that are structurally more heterogeneous, complex and of higher quality, such as riparian forests, support a higher biodiversity of ant genera and their respective functional groups, when compared to more homogeneous environments and of low habitat quality such as abandoned pasture areas, as well as the effects of seasonality. A total of 4,865 ants belonging to 7 subfamilies and 15 ant genera were collected. The subfamilies that showed the highest representativeness (abundance) were Myrmicinae (4,436), followed by Formicinae (282), Ectatomminae (97), Dolichoderinae (18), Pseudomyrmecinae (15), Dorylinae (9) and Ponerinae (8). The high-quality habitat, which corresponds to riparian forest, had the highest richness of genera, characterized by the genus *Nylanderia*, with a higher occurrence of the functional group Generalist Myrmecinae, with high values of relative humidity in both seasons. On the other hand, the low-quality habitat showed less richness of genera, being the genus that caracterizes this environment the *Crematogaster*, with higher occurrence of the functional group of Tropical Climate Specialists and low values of relative humidity. In view of the above, this study provides subsidies for conservation work in riparian forest areas in the humid tropical forest biome. Besides warning about the reduction in the richness of ant genera due to the conversion of natural areas into pasture.
Keywords: Human disturbance; Seasonality; Ant assemblages; Tropical rain forest.

Resumo
Diante do cenário de perturbações antrópicas e mudanças climáticas regionais, pretendemos verificar se habitats estruturalmente mais heterogêneos, complexos e de maior qualidade, como mata ciliar suportam uma maior biodiversidade de gêneros de formigas e seus respectivos grupos funcionais, quando comparado a ambientes mais homogêneos e de baixa qualidade de habitats como áreas de pastagem abandonadas, bem como os efeitos da sazonalidade. No total foram coletadas 4.865, formigas pertencentes a 7 subfamílias e 15 gêneros de formigas. As subfamílias que apresentaram uma maior representatividade (abundância) foram Myrmicinae (4.436), seguido de Formicinae (282), Ectatomminae (97), Dolichoderinae (18), Pseudomyrmecinae (15), Dorylinae (9) e Ponerinae (8). o habitat de alta qualidade que corresponde a mata ciliar obteve maior riqueza de gêneros, sendo caracterizado pelo gênero *Nylanderia*, com maior ocorrência do grupo funcional Myrmecinae Generalista e apresenta valores altos de umidade relativa do ar em ambas as estações do ano. Enquanto, no habitat de baixa qualidade apresentou menor riqueza de gêneros, sendo *Crematogaster* o gênero que caracteriza este ambiente, com maior ocorrência do grupo funcional das Especialistas de Clima Tropical e baixos valores de umidade relativa do ar. Diante do exposto, o presente estudo fornecer subsídios para trabalhos de conservação de áreas de mata ciliar no bioma de Floresta tropical úmida. Além de alertar sobre diminuição da riqueza de gêneros de formigas perante a conversão de áreas naturais em pastagem.
Palavras-chave: Perturbação antrópica; Sazonalidade; Assembleias de formigas; Floresta tropical úmida.

Resumen
Teniendo en cuenta el escenario de perturbaciones antropogénicas y el cambio climático regional, pretendemos comprobar si los hábitats estructuralmente más heterogéneos, complejos y de mayor calidad, como el bosque ribereño, soportan una mayor biodiversidad de géneros de hormigas y sus respectivos grupos funcionales, en comparación con entornos más homogéneos y de baja calidad de hábitat como las zonas de pastos abandonados, así como los efectos de la estacionalidad. En total, se recogieron 4.865 hormigas pertenecientes a 7 subfamilias y 15 géneros de hormigas. Las subfamilias con mayor representatividad (abundancia) fueron Myrmicinae (4.436), seguida de Formicinae (282), Ectatomminae (97), Dolichoderinae (18), Pseudomyrmecinae (15), Dorylinae (9) y Ponerinae (8). El hábitat de alta calidad que corresponde al bosque ribereño obtuvo la mayor riqueza de géneros, caracterizándose por el género *Nylanderia*, con mayor presencia del grupo funcional Myrmecinae generalista y altos valores de humedad relativa en ambas estaciones. En el hábitat de baja calidad, la riqueza de géneros fue menor, y el género que caracteriza este ambiente fue *Crematogaster*, con mayor presencia del grupo funcional de Especialistas en Clima Tropical y bajos valores de humedad relativa. En vista de lo anterior, este estudio proporciona subsidios para el trabajo de conservación en las zonas forestales ribereñas en el bioma del bosque tropical húmedo. Además de alertar sobre la disminución de la riqueza de géneros de hormigas debido a la conversión de zonas naturales en pastos.
Palabras clave: Perturbación antropogénica; Estacionalidad; Conjuntos de hormigas; Selva tropical.

1. Introduction

Human disturbances are actions related to human economic activities, and the transformations and degradations of natural habitats resulting from these activities are considered one of the greatest threats to the conservation of biodiversity and the functioning of ecosystems (Queiroz & Ribas, 2016). In recente decades there has been increasing attention to the effects of human disturbances on the degradation of natural ecosystems. Mainly due to supplying the food and housing needs of a human population growing at ever higher rates, in areas of natural vegetation, especially in tropical rainforests (Laurance et al., 2014). Where, natural habitats are being transformed into other types of land use causing habitat loss and fragmentation to be considered the main causes of the decrease in biodiversity and consequent homogenization of biota (Ganem, 2011; Laurance et al., 2014). Currently the main anthropic activity is the conversion of the forest to pasture areas and agriculture (Barona et al., 2010), which cause climate changes that result in negative impacts, affecting ecosystems, biodiversity and the socio-economic area, from a local, regional and global scale (Lawrence & Vandecar, 2014).

Allied to changes resulting from human disturbances we have climate change, which influences the structure and shaping of biological communities, resulting in environmental modifications at the landscape scale (Amaral & Vale, 2010). In conjunction with global climate change are regional and local variations in temperature averages, which are natural characters, as well as changes in precipitation and evaporation rates and soil characteristics (i.e. moisture retention capacity) (Nobre et al., 1991). These regional climatic variations also modify ecosystem processes, which alter the responsiveness of different environments to environmental changes (Thuiller, 2007).

In contrast, species and/or groups that are adapted to disturbances and regional climate change become increasingly dominant in landscapes modified by these two structuring forces. Thus, only a subset of species originally from the ecosystem must tolerate the new environmental conditions imposed (e.g. human disturbances, regional climate change) culminating in more taxonomically, phylogenetically and functionally homogeneous biota (Aleixo et al., 2010; Lôbo et al., 2011).

To try to understand the effects of anthropogenic disturbances and regional climate change, we will use ants as an ecological model. Ants have characteristics (e.g. abundance, easy sampling and identification) that make them a valid group to test ecological models and hypotheses, and the use in environmental monitoring, in order to describe the ecological factors responsible for the patterns of diversity and dominance of terrestrial communities, from local to global scale. Furthermore, ants are sensitive to changes in biotic and/or abiotic environmental factors (Nowrouzi et al., 2016; Tiede et al., 2017). Studies using ants as models have shown that they respond significantly to environmental changes (Fisher et al., 2014; Tiede et al., 2017).

Facing the scenario of human disturbances and regional climate change, we intend to verify whether habitats that are structurally more heterogeneous, complex and of higher quality, such as riparian forest, support greater biodiversity of ant genera and their respective functional groups, when compared to more homogeneous environments and of low habitat quality, such as abandoned pasture areas, as well as the effects of seasonality. We expect that habitats of low quality will present lower taxonomic and functional group biodiversity than habitats of higher quality. Moreover, the effect of dominance of genera and functional groups will be greater in low-quality habitats, resulting in a lower coexistence among species, since the low-quality habitat will provide a lower availability of resources. Thus, the dominant ants and functional groups will monopolize the available resource and prevent other species and functional groups from using the resources. In addition, the effects of seasonality will amplify the differences between habitats especially in the dry season.

2. Methodology

Study area

The samples were collected in two different areas in the surroundings of the Universidade Federal do Sul e Sudeste do Pará - Campus III (5 ° 21'54.4" S 49 °01'27.3" W), being the areas corresponding to the tropical rainforest biome. The areas were classified according to their environmental quality in terms of vegetation heterogeneity. The area 1 (Figure 1) represents the control area of the study, composed of a fragment of the riparian forest of the Tauarizinho River (5 ° 21'42.4 "S 49 °01'27.8" W), the predominant stratum being tree, followed by herbaceous and shrub vegetation and containing a total area of 330,000 m², corresponds to the habitat of highest environmental quality. And area 2 (Figure 2) was classified as a disturbed environment (homogeneous), which contains the dominance of pasture with emphasis on (grass/pasture), its total area is 202,000 m², corresponding to the habitat of lower environmental quality. Both areas are in the municipality of Marabá, in the southeast region of Pará State. In the region of Marabá the predominant climate is tropical semi-humid (Aw) with an annual average of 27°C and rainfall around 1900 mm, the average temperature in the dry season is 27.6°C and in the rainy season 26.4°C, with rainfall concentrated in the months of December to April (INMET, 2019).

Climate data collection

The climate variables (air temperature and humidity) were collected with the help of a thermo-hygrometer, positioned at the last point of the transect at a height of 1.5 m from the ground. Climatic data were collected at the beginning of each collection and after the 1-hour interval given for collecting the ants and baits.

Data collection

To perform the surveys in both areas of the study, a transect containing 5 stations 20 m apart was laid out. At each of the stations, three types of bait were placed so that there would be a greater coverage for the diet of ants, all were 5 cm apart. The bait 1 was a portion of peanut candy (paçoca) plus honey, the bait 2 containing crushed "paçoca" (i.e. peanut candy) and the bait 3 was a compacted sliced paçoca (Figure 3). After distribution of the baits on the transect, an interval of 1 hour was given to collect the ants and collect the baits. Collections were carried out for one year (2018-2019) bi-monthly, totalling three months for each season (dry and wet season), in order to verify the effect of seasonality. The ants were identified to the genus level and morphotyped, following the taxonomic key "Guia Para Os Gêneros de Formiga do Brasil" (Baccaro et al., 2015).

Functional Groups

The ants were classified according to recruitment behaviour into 6 functional groups (for the New World), according to a methodology adapted from Andersen et al. (2000), Delabie et al. (2000) e Silvestre (2000). These are Tropical Climate Specialists, Dominant Dolichoderinae, Nomads, Critical Species, Opportunists, Generalist Myrmicinae, Generalist Predators and Arboreal ants.

Data analysis

To verify the effect of different habitats and seasonality on ant biodiversity, we used the following response variables: genera richness, equability index (Pielou), Shannon-Weaver index, Chao1 richness estimator, Simpson dominance and the abundance data were converted to relative abundance (we calculated using the abundance of each transect of the study transects containing 5 points, during the 3 months of the rainy and dry seasons for each area, totaling 6 replicates for each area, after which, we used the abundance of each replicate separately, multiplied by 100 and divided by the sum total of the abundance of each season within its respective area (3 replicates for dry and wet seasons). Thus, we used a 2-factor ANOVA (factor 1 = habitat and factor 2 = seasonality. We used a Principal Components Analysis to understand which climatic (temperature and humidity) and biotic (occurrence of genera and functional groups) factors are characteristic of high- and low-quality environments.

To verify which variables are influencing the habitat in each studied area the Principal Components Analysis (PCA) was carried out, the variables were divided into two ordering axes by this analysis, so that there was the selection of the components that best explained the variation of the data. Chi-square tests were used to verify the variation in the frequency of occurrence of functional groups among habitats by season. We calculated the expected frequencies considering the percentage of occurrence of the functional groups by habitat. We used the occurrence of the functional groups for each one of the areas between the dry and wet seasons, we put the quantity of observed occurrence for each group, we summed and divided by the quantity of group that occurred, thus calculating the expected occurrence. After this calculation we applied the chi-square test between observed and expected (Zar, 2010). We performed all the analyses with the support of the program R 2.11.1 using the packages: vegan, nlme, stats, mlmRev, lme4, gplots, psych and Rcmdr (R Development Core Team 2010).

3. Results

The total number of ant specimens sampled was 4,865, belonging to 7 subfamilies and 15 ant genera. The subfamilies with the highest representativity (abundance) were Myrmicinae (4,436), followed by Formicinae (282), Ectatomminae (97), Dolichoderinae (18), Pseudomyrmecinae (15), Dorylinae (9) and Ponerinae (8). The abundance in the high quality habitat (i.e. riparian forest) was 1,713, while in the low-quality habitat (i.e. grassland) had 3,152 ant specimens. The most abundant genera in the high-quality habitat were *Solenopsis* (1,154), *Nylanderia* (250) and *Ectatomma* (81). While in the low-quality habitat they were *Solenopsis* (2,776), *Crematogaster* (289) and *Pheidole* (35).

Regarding the total number of specimens between seasons, we found 3,619 individuals in the wet season (e.g. November, January and April) and 1,246 in the dry season (e.g. June, August and October). In the wet season the most abundant genera were *Solenopsis* (3,091), *Nylanderia* (201) and *Pheidole* (77). While in the dry season was *Solenopsis* (839), *Crematogaster* (252) and *Nylanderia* (51). In relation to the occurrence of the functional groups, in total we found 8 groups, these being: Tropical Climate Specialists (3,930, specimens), Dominant Dolichoderinae (5), Generalist Myrmicinae (762), Generalist Predatory (105), Arboreal (28), Nomadic (9), Opportunistic (25) and Critical Species having the least number of individuals (1).

The highest quality habitat obtained the highest richness values, with a mean of 3.28 (± 0.96, standard deviation), and when compared with low-quality habitat, the mean richness was 1.90 (± 0.42) (Table 1, Figure 1a). There was no variation in richness between seasons and for the interaction between habitat and seasonality (Table 1).

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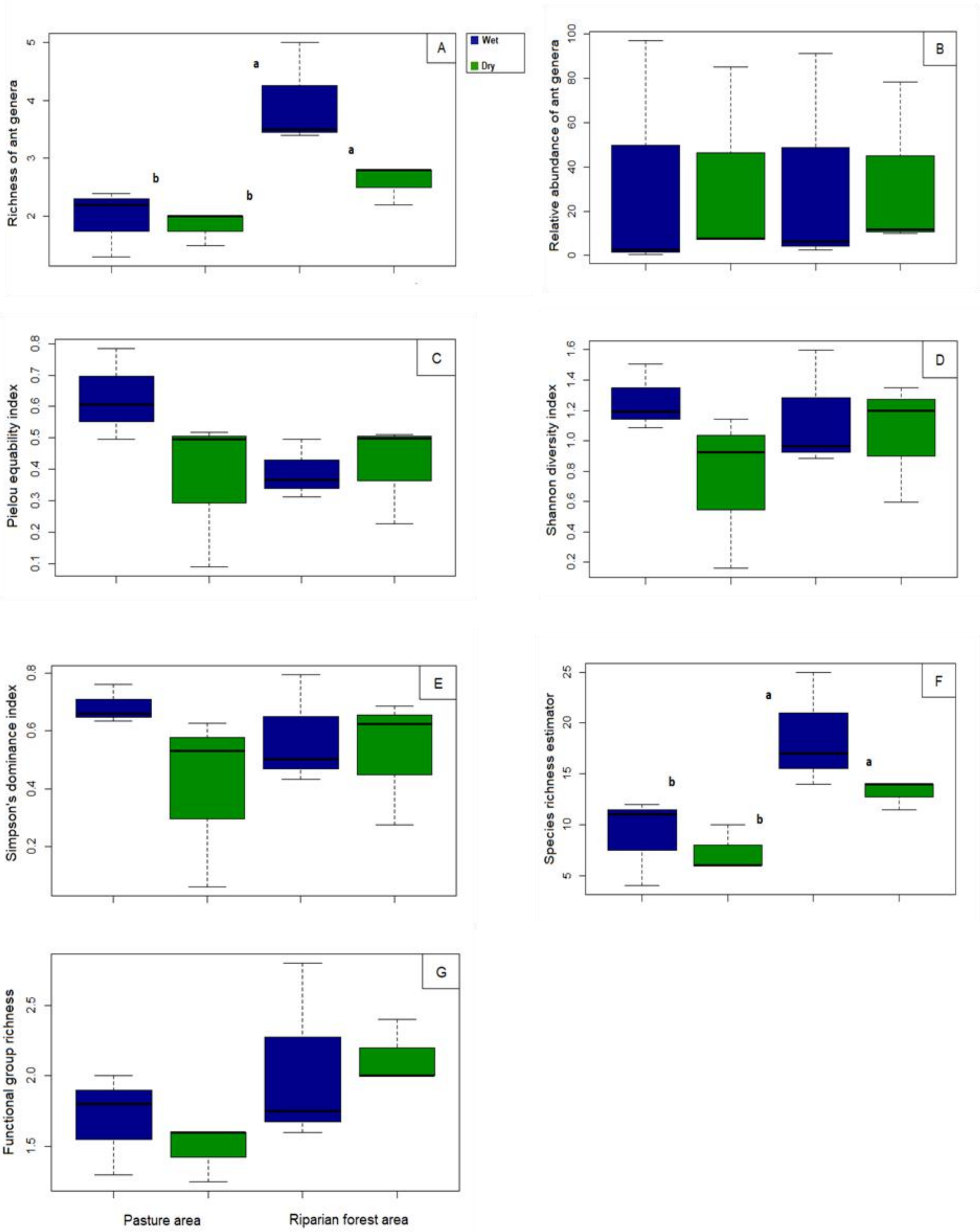
Figure 1 - Boxplot showing the results of ant genera richness among areas and seasons (A), relative abundance of ants (B), Pielou's equability index (C), Shannon's diversity index (D), Simpson's dominance index (E), Chao1 estimator (F) and ant functional group richness (G) plotted in relation to the Tauari riparian forest area and pasture area, located in the municipality of Marabá, state of Pará, Brazil. Different letters mean differences by Tukey test (p <0.05).



Source: Authors.

Table 1 - Results of the ANOVA of two factors regarding the effects of area, seasonality and interaction between the factors on the response variables: relative abundance, Pielou's equability index, Simpson's dominance index, richness, functional group richness, Shannon diversity index and Chao1 estimator on the areas, seasons and the interaction between the treatments. Significant effects are marked in bold (P <0,05).

Response Variable	Treatment	Df	*F*	*P*
Genera richness	Area	1	17.01	**0.003**
	Season	1	5.00	0.055
	Area*Season	1	3.38	0.103
Relative ant genera abundance	Area	1	0	1
	Season	1	0	1
	Area*Season	1	0	1
Pielou's Equability Index	Area	1	0.978	0.352
	Season	1	1.524	0.252
	Area*Season	1	2.103	0.185
Simpson's dominance index	Area	1	0.004	0.950
	Season	1	1.774	0.220
	Area*Season	1	0.869	0.379
Functional Group Richness	Area	1	4.757	0.060
	Season	1	0.035	0.856
	Area*Season	1	0.000	1.000
Shannon Diversity Index	Area	1	0.179	0.683
	Season	1	1.849	0.211
	Area*Season	1	0.842	0.386
Chao1 Estimator	Area	1	12.27	**0.008**
	Season	1	2.623	0.144
	Area*Season	1	0.750	0.411

Source: Authors.

When analyzing the relative abundance among ants, the habitats of high and low quality, presented similar results, both for areas, seasonality and interaction (Table 1; Figure 1b). Where the mean for the high-quality habitat was 33.3 (± 40.2. While for the low-quality habitat was 33.3 (± 45.1).

The values of Pielou's equability, Shannon-Weaver Index and Simpson dominance did not show differences between area, seasonality and interaction of factors (Table 1). The high-quality habitat presented the following values respectively: 0.41 ± 0.08 (Figure 1c), 1.06 ± 0.22 (Figure 1d) and 0.56 ± 0.08 (Figure 1e). While the low-quality habitat presented the following values respectively: 0.56 ± 0.08 (Figure 1c), 1.04 ± 0.23 (Figure 1d) and 0.58 ± 0.08 (Figure 1e).

When we analyzed the richness estimator Chao1, the high-quality habitat presented a value of 15.5 (± 2.12), which corresponds to 1.78 times higher than the estimated value for the low-quality habitat, which was 8.50 (± 3.54). However, there was no difference between seasonality and interaction between treatments (Table 1; Figure 1f).

Analyzing the richness of functional groups we did not find any variation among the areas, seasons of the year and the interaction among treatments (Table 1). Thus, the habitat of higher quality presented an average of 2.09 (± 0.44), while the habitat of low quality had an average of 1.59 (± 0.29).

The frequencies of functional groups in comparison with the observed and expected values. For the highest quality habitat during the wet season the groups that had the highest frequency were respectively Generalist Myrmicinae (48%), Generalist Predator (36%), Arboreal ants (7%), Tropical Climate Specialists (3%) together with Nomads (3%), Dominant Dolichoderinae (2%) and Cryptic species (1%) (Table 2; Figure 2a). Regarding low quality habitat during the wet season the group with the highest frequency was Tropical Climate Specialists (59%) followed by Generalist Myrmicinae (19%), Generalist Predatory (16%) and Arboreal ants (6%) (Table 2; Figure 2a). During the wet season in the higher quality habitat the groups that had a frequency were Myrmicinae Generalists (47%), Predator Generalists (36%), Tropical Climate Specialists (9%), Opportunists (6%) and Arboreal ants (2%) (Table 2; Figure 2b). While in the low-quality habitat during the dry season were Myrmicinae Generalists (58%), Tropical Climate Specialists (28%), Predatory Generalists (7%) and Opportunistic (7%) (Table 2; Figure 2b).

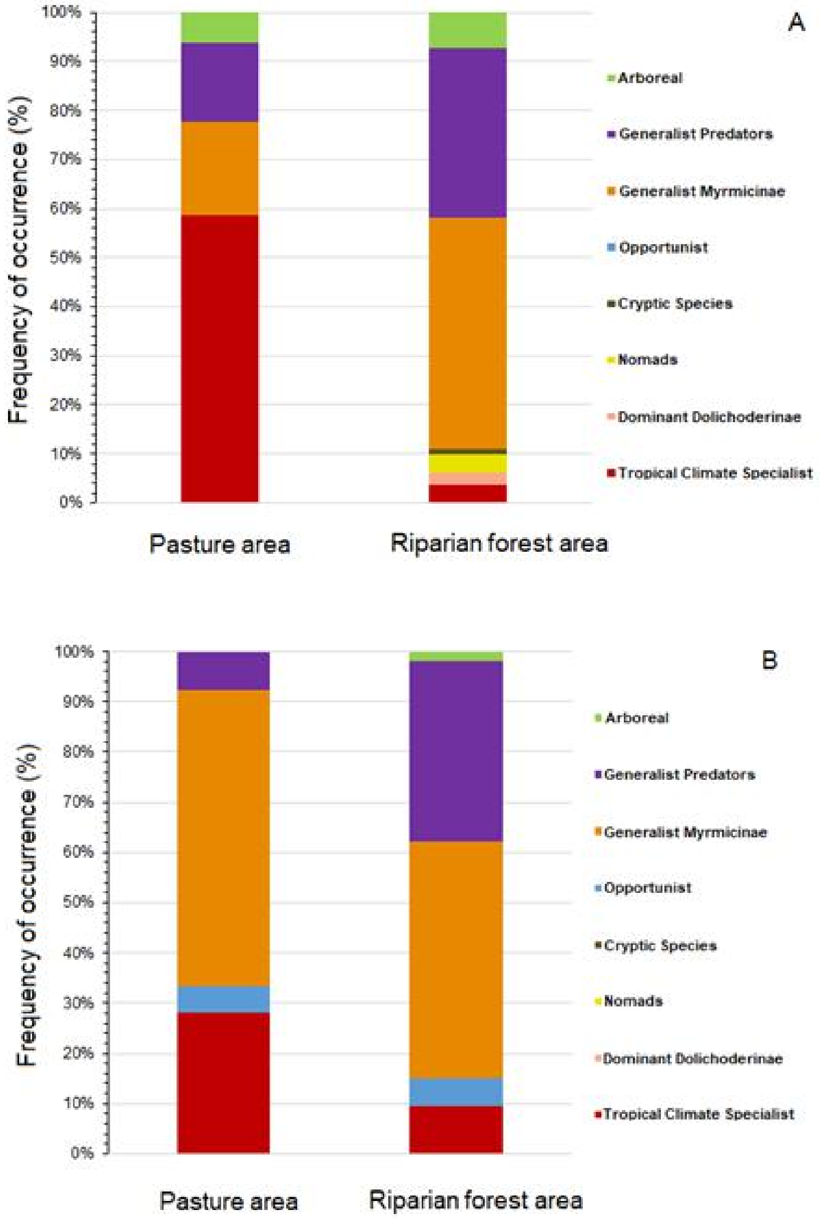
When comparing groups between seasons and habitat. The functional group of Tropical climate specialists occurred more frequently in low-quality habitat when compared to high-quality habitat during the wet season (Table 2; Figure 2a). While the functional group of Generalist Myrmicinae were more frequent in high-quality habitat than in low-quality habitat (Table 2; Figure 2a).

Table 2 - Chi-square analysis in relation to the frequency of functional groups during the rainy and dry seasons in habitats of high and low quality located in the city of Marabá, Pará State, Brazil. Significant effects are marked in bold (P <0,05).

Treatment	Functional Groups	Season	Df	*F*	*P*
Riparian forest area	-	Wet	6	48.3	**0.0001**
Pasture area	-	Wet	3	17.3	**0.0006**
	Tropical Climate Specialists	Wet	1	15.6	**0.0001**
	Myrmicinae Generalists	Wet	1	6.2	**0.0129**
	Generalist Predators	Wet	1	3.57	0.0589
Riparian forest area	-	Dry	4	22.4	**0.0001**
Pasture area	-	Dry	3	14.1	**0.0027**
	Tropical Climate Specialists	Dry	1	0.52	0.4716
	Myrmicinae Generalists	Dry	1	0	1

Source: Authors.

Figure 2 - Chi-square analysis of the frequency of occurrence of functional groups in the Tauari River Riparian Forest and Pasture areas during the wet season (A) and dry season (B), located in the municipality of Marabá, state of Pará, Brazil.



Source: Authors.

The results of habitat characterisation in relation to the occurrence of ant genera and climatic factors (Table 3; Figure 3a) showed that axis 1 (PC1) explained 96.62% and was most related to the occurrence of *Solenopsis*. While axis 2 (PC2) explained 3.23% and was more related to humidity in dry and wet seasons (Table 4).

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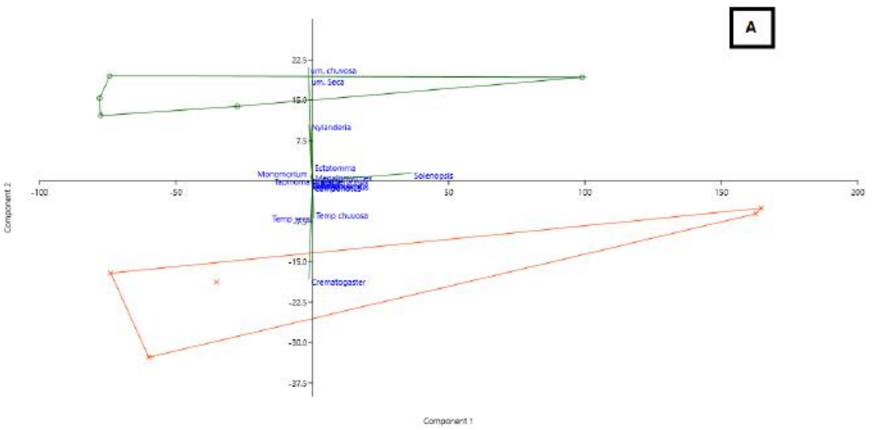
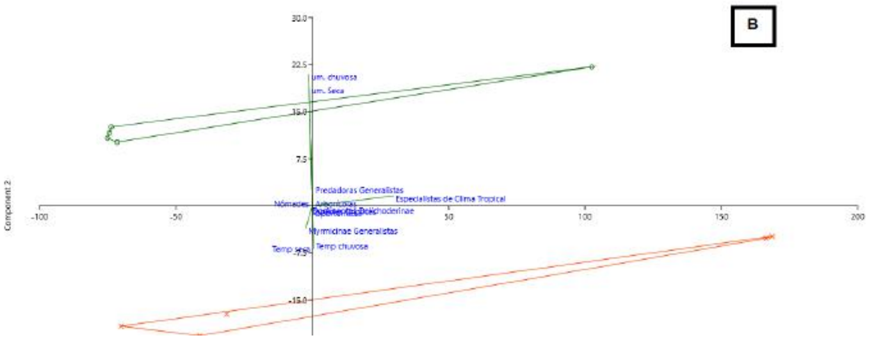
Figure 3 - Principal Component Analysis characterizing the high quality habitats (green circles) with clustering among the points (green polygon) and the low quality habitat (red letter X) with clustering among the points (red polygon). Taking into consideration: a) the ant genera and climatic factors, and b) the ant functional groups and climatic factors.





Source: Authors.

Table 3 - Result of Principal Component Analysis for habitat characterization taking into account the occurrence of ant genera and climatic factors. Reports the values of the axes of PCA with the results of Eigenvalue and the percentage of Variation.

PC	Eigenvalue	Variation (%)
1	10229.3	95.616
2	345.155	3.2263
3	62.3761	0.58305
4	52.628	0.49193
5	5.4205	0.050667
6	1.87391	0.017516
7	1.21913	0.011396
8	0.160312	0.0014985
9	0.125806	0.001176

Source: Authors.

Table 4 - Representativeness values of each ant genera and climatic factors in Principal Component Analysis.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9
Crematogaster	-0,032	-0,501	0,808	0,253	0,098	-0,060	0,044	0,069	0,006
Ectatomma	-0,006	0,076	0,058	-0,131	0,118	0,040	0,790	-0,440	0,117
Forelius	0,000	0,004	-0,003	0,017	-0,081	-0,018	-0,078	-0,179	0,475
Megalomyrmex	0,000	0,015	0,005	0,047	-0,193	-0,020	-0,155	-0,258	0,328
Nylanderia	-0,032	0,286	0,390	-0,819	0,206	-0,035	-0,144	0,089	0,012
Odontomachus	1,82e-29	-3,90e-23	-1,31e-19	6,86e-19	-3,13e-17	-7,79e-17	1,81e-17	4,11e-16	-2,51e-16
Pheidole	-0,016	0,028	-0,208	0,092	0,249	-0,553	0,202	0,335	-0,133
Pseudomyrmex	-0,001	0,021	0,015	-0,002	0,078	0,019	0,079	0,177	-0,478
Solenopsis	0,997	0,038	0,055	0,008	0,017	-0,009	0,005	0,012	-4,11E-05
Tapinoma	0,001	-0,002	0,022	0,038	0,107	-0,007	0,044	-0,531	-0,496
Labidus	-0,002	0,010	0,009	-0,018	-0,015	-0,120	0,454	0,382	0,307
Monomorium	-0,008	0,035	-0,108	0,194	0,882	0,269	-0,145	-0,030	0,222
Camponotus	-0,002	-0,024	-0,033	-0,016	-0,132	0,774	0,214	0,322	-0,103
Brachymyrmex	-0,001	0,004	-0,012	0,022	0,098	0,030	-0,016	-0,003	0,025
Dry season temperature	0,013	-0,189	-0,085	-0,104	0,018	-0,002	-0,005	0,018	0,022
Wet season temperature	0,011	-0,163	-0,073	-0,090	0,016	-0,002	-0,004	0,016	0,019
Dry season humidity	-0,034	0,515	0,231	0,283	-0,049	0,006	0,013	-0,050	-0,061
Wet season humidity	-0,038	0,574	0,257	0,314	-0,048	-0,002	-0,007	0,122	0,037

Source: Authors.

Table 5 - Representation values of each functional ant group and climate factors in Principal Component Analysis.

PC	Eigenvalue	Variation (%)
1	10665,3	79
2	238,602	21,696
3	903,986	0,822
4	169,109	0,015377
5	109,554	0,0099618
6	0,189856	0,0017264
7	0,0662054	0,00060201
8	0,0377562	0,00034332
9	0,00120655	1,10E-01

Source: Authors.

In contrast to the occurrence of functional groups and climatic factors (Table 5; Figure 3b) axis 1 (PC1) corresponds to 79 % of the variation and was more related to the functional group of Tropical climate specialists (Table 6). While axis 2 (PC2) explained 21.7 of the variation and was more related to the humidity values in the dry and wet seasons. According to the results of the PCAs (Figure 3a and 3b) the high-quality habitat presents high humidity (both seasons) and a higher occurrence of the genus *Nylanderia*. While the low-quality habitat is represented by low humidity values (both seasons) and higher occurrence of the genus *Crematogaster*. Ants of the genus *Solenopsis* and the functional group of Tropical climate specialists occur in both areas with high representativeness.

Table 6 - Result of Principal Component Analysis for habitat characterization taking into account the occurrence of functional groups of ants and climatic factors. Reports the values of the axes of PCA with the results of Eigenvalue and the percentage of Variation.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9
Arboreal ants	9,02e-05	0,014	0,038	0,076	-0,083	-0,384	0,794	0,417	0,182
Dominant Dolichoderinae	-0,001	0,006	-0,015	-0,107	0,013	0,130	-0,412	0,891	0,084
Tropical Climate Specialists	0,995	0,053	0,087	0,000	0,008	0,003	-0,003	0,000	-0,001
Critical Species	-4,08e-20	3,87e-17	-9,55e-17	1,48e-16	-3,89e-17	3,25e-16	2,73e-15	3,99e-15	-2,04e-14
Generalists Myrmicinae	-0,080	-0,122	0,987	-0,024	0,057	0,022	-0,025	0,000	-0,005
Nomads	-0,002	0,010	0,013	0,222	-0,304	0,862	0,333	0,060	-0,005
Opportunists	-0,002	-0,027	-0,038	0,568	0,810	0,115	0,052	0,062	0,013
Generalist Predators	-0,006	0,096	0,057	0,778	-0,485	-0,271	-0,269	0,016	-0,002
Dry season temperature	0,015	-0,230	-0,026	0,013	-0,018	0,008	-0,029	-0,033	0,230
Wet season temperature	0,013	-0,198	-0,022	0,011	-0,016	0,007	-0,025	-0,029	0,199
Dry season humidity	-0.040	0,626	0,070	-0,035	0,050	-0,022	0,080	0,091	-0,626
Wet season humidity	-0.044	0,699	0,078	-0,054	0,058	0,064	-0,070	-0,117	0,689

Source: Authors.

4. Discussion

In this study we examined whether structurally more heterogeneous, complex and high-quality habitats (e.g. riparian forest), could support higher ant biodiversity and its respective functional groups, in detriment to low-quality habitats (e.g. abandoned pasture), as well as the effects of seasonality. We observed that in the conversion of natural areas such as riparian forest to pasture, there is a decrease in the richness of ant genera. This can be explained by a decrease in habitat complexity. Where more complex habitats, with greater availability of food resources and habitat structure provide better environmental conditions for a greater wealth of ant species due to the greater availability of resources and conditions (Carrascosa, 2014). In general, the richness of the functional groups was uniform. However, the frequencies at which the groups occur in the habitats and seasons are distinct. Being the groups Myrmicinae generalists, Predatory generalists and Tropical climate specialists are the most representative. Due to the predominance of these groups among the areas, we found that the main factor that characterizes areas is the climatic factor of relative humidity in both seasons. Where the high-quality habitat is characterized by high air humidity and the inverse for the low-quality habitat. These results of genera diversity and occurrence of functional groups between high and low quality habitats provide subsidies for the environmental management of tropical rainforest areas affected by human disturbance.

The most representative subfamilies of the study were Myrmicinae, Formicinae and Ectatomminae. The high representativeness of Myrmicinae for both areas can be explained by the fact that this subfamily constitutes the dominant group among the ants with diversified feeding habits and presents high species richness in surveys carried out in Neotropical environments, containing more than 55% of the species in the world (Fernàndez, 2003; Silvestre et al., 2003). Besides being a group of ants extremely adaptable to the most diverse ecological niches in the Neotropical region (Fowler et al., 1991). Several studies point the subfamily Myrmicinae as the most frequent and abundant one observed in Neotropical regions (Bruhl et al., 1998; Da Silva & Lopes, 1997; Silva & Silvestre, 2000). The subfamily Formicinae, is the third with more specimens described in the world, abundant in the tropical region (Leal, 2017) and are characteristic of more open environments (Marinho et al., 2002; Leal, 2002, 2003). Species of this subfamily can be arboreal, soil, burrowing or subterranean inhabitants (Cereto et al., 2008). Thus, presenting a variety of niches. The species that make up the subfamily Ectatomminae are distributed in all zoogeographic regions and occupy many ecological niches (Ouellette et al., 2006), are characteristic of forested environments, such as Atlantic Forest (Leal, 2002; Bieber et al., 2006) and Amazonian (Vasconcelos, 1999). They may represent about 25% of the local diversity of Formicidae in tropical environments (Delabie et al., 2015).

The genera that stood out in the riparian forest area were *Solenopsis* and *Nylanderia*. The genus *Solenopsis* can also be found in natural areas, being composed of ants with characteristics of dominant species in the environments where they occur, and in most cases produce negative effects on other species that coexist with them, due to competition (Ilha et al., 2017), thus explaining its great abundance in both areas studied. The genus *Nylanderia* is composed of 27 species recorded for the Neotropical region, of these 12 are found in Brazil (Baccaro et al., 2015). The ants of this genus are fast foraging, with massive recruitment behavior nesting in burlap and rotten wood (Lapolla et al., 2011). They inhabit a wide variety of habitats, ranging from deserts to tropical forests, with their highest degree of diversity in forested and warm environments (Lapolla et al., 2011). While in the abandoned pasture area the most abundant genera were *Solenopsis* and *Crematogaster*. The species belonging to the genus *Solenopsis* are generalists and opportunistic, and it is common to find them in degraded environments or in open areas with few trees (Morini et al., 2007). The high abundance of this genus in the collections indicates the anthropization of the environment, which benefits species with generalist habits (Martins et al., 2011). In turn, *Crematogaster* species occur in all zoogeographic regions, those that occur in tropical regions are found in various forest strata, from the soil to the canopy, nesting in living or decomposing trunks, burlap and branches, having interaction with other animals and plants of some species, and are common in the urban environment (Felizardo 2010). In most studies, sites that are disturbed or more homogeneous are dominated by species that are generalists or opportunists, as these species can take advantage of changes at the base of the food chain, especially when disturbance brings competitive advantage (Philpott et al., 2010).

The difference between habitat quality was an important predictor for ant diversity, as we found differences in ant genera richness between areas. Where high-quality habitat showed higher genus richness (Figure 1a). High-quality environments have a greater heterogeneity of vegetation structure that leads to a greater availability of resources and environmental conditions for ants (Santos et al., 2012). Thus, the riparian forest promotes greater richness and coexistence of ant species.

Although we did not find any difference between the habitats in relation to the Shannon-Weaver index. The value of 1.06 shows us that there is a low concentration of ant genera in general and an irregular distribution among them. This is of concern for high-quality habitat, since in conserved environments or those with low human disturbance, values greater than 3 are expected for the Shannon-Weaver index (Magurran, 2013). Thus, human disturbances events may be occurring in this environment at a local scale that can reduce its diversity over time at a regional scale when compared to other well-conserved areas (Barros, 2021). Similar to the results for genus richness, when we performed an estimation of richness by the Chao 1 estimator, we observed that the richness estimated by Chao 1 for the high-quality habitat was approximately twice as high as for the low-quality habitat. This reinforces the idea that high quality habitats, with less disturbance (compared to areas of abandoned pasture) provide environments with better conditions, greater quantity of niches and enable a greater diversity of ant species. Allied to this, the conversion of areas of higher complexity (e.g. forests) into areas of lower complexity leads to the homogenization of the biota in terms of species richness and ecosystem services (Gomes et al., 2013).

We observed that the habitats presented uniformity in the occurrence of the genera. This uniformity may have occurred due to the high occurrence of the genera *Solenopsis* and *Nylanderia* in the high-quality habitat, which together correspond to about 82% of the sampled individuals. On the other hand, for the low-quality habitat, the genera *Solenopsis* and *Crematogaster* had the highest occurrence, which together correspond to about 97% of the individuals. As we can see, the genus *Solenopsis* occurred in both areas, which probably inflated the Pielou values for uniformity among the habitats. The genus *Solenopsis* generally has a higher richness in anthropized areas, however they are also present in preserved environments, due to the tolerance of some species of the genera to variations in environmental conditions (Estrada et al., 2019). The ants belonging to the genus *Nylanderia* are omnivorous and have generalist habits, have small size and massive recruitment behavior, live in habitats ranging from deserts to tropical forests and nest in foliage, soil or rotting wood (Baccaro et al., 2015), which favor their dominance by food sources, and thus may explain their large occurrence in riparian forests. The genus *Crematogaster* presents a great diversity (767 species) and of adaptations, thus it presents an extensive geographical distribution and high abundance in the environments it lives, for these reasons, they are considered more prevalent on a global scale (Hosoishi et al., 2009). When they occur in anthropic environments, they show dominance (Peixoto, 2010).

Besides the uniformity among the areas, we did not find dominance (Simpson index) of any genus or functional group. Although the genus *Nylanderia* presented a higher occurrence for the high-quality habitat and *Crematogaster* for the lower quality habitat. As we did not find dominant organisms, being it genus or functional group among the areas, these results explain why we did not find different values for abundance (Table 1; Figure 2b). This shows that the genera are occurring with similar abundance among the areas. Probably due to the high presence of the genus *Solenopsis* in both habitats combined with its extremely aggressive, fast and many individuals foraging behavior (Fowler et al., 1991; Martins, 2011).

In relation to functional groups, the richness of functional groups among habitats and seasons was constant. At the local scale, the quantity and variety of resources do not seem to be a determining factor for the occurrence of functional groups but rather environmental factors that lead to competition (Ribas & Schoereder, 2007). Probably the ant fauna found is very resilient which allows them to maintain high levels of abundance and several foraging forms independent of habitat quality. This gives them high plasticity because the species and respective functional groups that do not tolerate the environmental conditions resulting from disturbances can be readily replaced by species that tolerate these same conditions (Schmidt et al., 2013).

In general, the distribution of functional groups is uniform among the areas, being the groups Tropical climate specialists, Generalist Myrmicinae and Generalist predators, except for the functional group of Arborial ants which showed a higher occurrence in the wet season of the riparian forest. Species belonging to the Generalist Myrmicinae group have a wide distribution in warm temperature areas (Andersen, 2000) and have an extremely wide diet (Brandão et al., 2012), are the most abundant ants in most habitats, being extremely competitive (Hallack, 2010), with some species preferring more open habitats (Lassau; Hochuli, 2004). Moreover, the impacts caused by anthropic activities not only alter the richness and composition of species, but also promote the occurrence of generalist taxa to the detriment of species with more specialized behavior (Sanchez-Gálen et al., 2010). This explains the high occurrence of this group in both study areas.

Ants belonging to the Generalist Predator group can be found nidifying and foraging in the soil, decomposing wood, abandoned termite mounds and branches in the burlap (Baccaro et al., 2015). They are ants that need a wide variety of arthropods to feed (Brandão et al., 2012). Thus, they can consume a wide diversity of prey and establish themselves in the environment, unlike the specialists. It is a group that occurs preferentially in rainforests, however, some species may occur in disturbed environments (Barbosa; Fernandes, 2003; Michereff-filho et al., 2004). The group is benefited in the riparian forest area of the study, since it is rich in litter and possibly provides these resources to them. The fact that this group feeds on different types of prey, may have enabled the large occurrence of this group in the low-quality area and because they also occur in disturbed environments.

Tropical climate specialists are found in humid tropical regions, characteristic of habitats where the abundance of Dominant Dolichoderinae is low, and outside their tolerable habitat, often being non-specialist ants (Andersen, 1995). The large occurrence of the group in our study can be explained due to the great abundance of the genus *Solenopsis* in which it is part of the group, which represented about 80% of the total number of genera found for both areas.

We verified that the main factor that characterizes the environment is the air humidity. The high-quality habitat presents higher humidity values in both seasons and a higher occurrence of the genus *Nylanderia*. While the low-quality habitat presents lower humidity values and a higher occurrence of the genus *Crematogaster*. This shows that the occurrence of the other genera and all functional groups occurs in a similar way among the habitats. Thus, both habitats seem to have feeding and nesting niches that allow the coexistence of different genera and functional groups. Although habitat simplification reduces ant richness, less intensive agro-systems, such as pasture, may carry species composition and possibly guilds and functional groups similar to natural areas (Frizzo & Vasconcelos, 2013). We did not find a higher genus richness in the grassland area, but this may explain the overall similarity between the ant composition in riparian forest and grassland areas.

Considering the above, this study provides subsidies for conservation studies of riparian forest areas in the Rainforest biome. Besides warning about the reduction in the richness of ant genera due to the conversion of natural areas into pasture, which becomes extremely worrying since most studies report a reduction in species richness.

5. Conclusion

With the present study, we can conclude that the conversion of the native vegetation of a tropical rainforest into pasture area can cause a local loss in the genus diversity. Specifically, the high-quality habitat that corresponds to riparian forest obtained higher genus richness, being characterized by the genus Nylanderia, with higher occurrence of the functional group Generalist Myrmecinae and presents high values of relative humidity in both seasons of the year. In the low-quality habitat, the richness of genera was lower, being Crematogaster the genus that characterizes this environment, with higher occurrence of the functional group of Tropical climate specialists and low values of relative humidity. We suggest that future studies should address inventories of ant communities (diversity: taxonomic, functional and phylogenetic) of the canopy, epigeic and hypogeic. In addition to understand how the gene flow occurs between areas with different levels of disturbance.

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