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Source: Florida Entomologist, 103(3) : 384-391

Published By: Florida Entomological Society

URL: <https://doi.org/10.1653/024.103.0311>

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Dry forest fragmentation in Brazilian Cerrado and its effects on communities of ground foraging ants

Enilton José Bernardes Júnior¹, Ednaldo Cândido Rocha¹, Flávio Gonçalves Jesus², Marco Antônio Oliveira³, and Márcio Silva Araújo^{1,*}

Abstract

Ants can represent a useful model for studies on the impact of forest fragmentation because these organisms are found abundantly in soil and plants sensitive to changes in environmental conditions. Our study characterized the structure of ground foraging ant communities present in 10 fragmented areas of dry forest surrounding areas under soybean and maize cultivation. Using baited pitfall traps, our study identified 60 ant morphospecies, distributed in 21 genera. Species richness of ground foraging ants was not influenced by size of dry forest fragment. Fragment edge traps captured fewer species when compared with traps located in the center of the fragment. Species richness and species composition differed significantly between dry forest fragments and both cultivated crops as well as inter-crop periods. Dry forest fragments had the greatest ant species richness. Integrated knowledge of the mechanisms through which fragmentation effects alter ant communities can be useful for the development of strategies to mitigate harmful effects on those species affected, and to improve methods that can be used to evaluate the conservation value of the remaining natural environment.

Key Words: bioindicators; epigeic ants; richness; similarity; habitat structure

Resumo

As formigas podem representar um modelo para estudos sobre o impacto da fragmentação florestal, pois são abundantemente encontradas no solo e nas plantas e, também, sensíveis às mudanças das condições ambientais. Nosso estudo caracterizou a estrutura de comunidades de formigas epigêicas presentes em 10 áreas fragmentadas de floresta seca e suas respectivas matrizes circunvizinhas (áreas sob cultivo de soja e milho). Por meio de armadilhas iscadas no solo, identificamos 60 morfoespécies de formigas distribuídas em 21 gêneros. A riqueza de formigas forrageadoras de solo não foi influenciada pelo tamanho do fragmento de floresta seca. Armadilha de borda de fragmento capturou menos espécies quando comparado a armadilhas localizadas na região mais ao centro do fragmento. Diferença significativa foi observada na riqueza e na estrutura da comunidade de formigas epigêicas entre os fragmentos de floresta seca e as matrizes com as duas espécies agrícolas cultivadas e na entressafra. Fragmentos de floresta seca apresentaram maior riqueza de espécies de formigas. O conhecimento integrado dos mecanismos pelos quais os efeitos de fragmentação alteram as comunidades pode ser útil para o desenvolvimento de estratégias para mitigar esses efeitos nocivos e para melhorar os métodos que podem ser usados para avaliar o valor de conservação desse ambiente natural remanescente.

Palavras Chave: bioindicadores; formigas de serapilheira; riqueza; similaridade; estrutura de habitat

Brazil is known worldwide for the scientific value of its biodiversity. In its vast territory, the Cerrado biome has an area greater than 2,000,000 square km, which represents about 23% of the country's total area (Ramos et al. 2018). This region is characterized mainly by savanna that occupies 80 to 90% of its total area. However, gallery forests, dry forests and the dense bushy vegetation known as "Cerradão" also is present (Eiten 1986). The rapid expansion of Brazilian agricultural frontiers seen in the last 3 decades, notably in the Cerrado region (MMA 2018), has caused fragmentation of forest areas leading to a loss of natural habitat with consequential isolation of these native sites (Bagliano & Luiz 2013). After fragmentation, the environment generally undergoes changes in heterogeneity, community dynamics, and species diversity that changes the original abundance of populations that may increase, decrease, or be locally extinguished (Kapos 1989).

Understanding the population dynamics of animals and plants in these fragments of the Cerrado and their surrounding environments may be useful for proposing conservation or protection measures for them. In this context, species that have a close relationship with their surroundings can be considered bioindicators (Oliveira et al. 2014; Tiede et al. 2017). Insect groups have been used to check the level of disturbance in native areas and sites where environmental quality is desired (Oliveira et al. 2014). There are various studies that report the importance of ants as bioindicators (Leal et al. 2012; Ribas et al. 2012; Groc et al. 2017; Paolucci et al. 2017; Tiede et al. 2017; Pérez Sanchez et al. 2018; Andersen 2019). Their usefulness in this capacity may be due to the fact that ants are sensitive to changes in local environmental conditions (Andersen & Sparling 1997; Delabie et al. 2000; Tiede et al. 2017; Andersen 2019). Additionally, there are broadly accepted sam-

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pling strategies that make ants excellent organisms when comparing ecosystems (Agosti & Alonso 2000; Lach et al. 2010).

One of the adverse effects of habitat fragmentation is the isolation of areas and consequent extinction of species, possibly because the size of the fragment may not support subpopulations of certain species (Suarez et al. 1998). The cascade effect that these lost subpopulations may have on the dynamics of communities remaining in the fragment is very important. Studies have shown a decrease in species richness among ants, to which habitat fragmentation contributes (Carvalho & Vasconcelos 1999; Sobrinho et al. 2003; Vasconcelos et al. 2006). Another possible event to consider is the adverse consequences of invasive species on non-natives in the fragment (Suarez et al. 1998, Schmidt et al. 2008; Madureira et al. 2012). In general, invaders can have multiple effects on native competitors without necessarily producing strong negative impacts (Petren & Case 1996). As a rule, the disorderly increase of certain species may cause significant destruction in an agricultural habitat, while in the native habitat this does not occur. Native habitats generally are more heterogeneous, which fosters equilibrium among the species present there by means of parasites, competitors, predators, and others (Maciel et al. 2011).

Understanding the factors that organize the diversity and dynamics of ant communities' structure is critical to preserving ecosystem functions and services provided by ants in the dry forest. Studies on the

effects of forest fragmentation in Brazil generally have concentrated on areas of dense forest and have investigated the Cerrado environment only partially (Lima-Ribeiro 2008). In this context, the present study characterized the structure of ground foraging ant communities in distinct fragments of dry forest and their adjacent agricultural areas during crop and inter-crop periods in the southeastern region of Goiás State, Brazil.

Materials and Methods

STUDY SITES AND CHARACTERIZATIONS

The fragments of dry forest investigated in this study are situated in a region of the Brazilian Cerrado (see geographic coordinates, Fig. 1). These fragments (10) presented different sizes and distances between each that were considered sufficient to guarantee independence of samples. The local climate is classified as tropical savannah AW under the Köppen classification system (Alvares et al. 2014), with annual rainfall between 1,600 and 1,900 mm and mean temperature of about 23 °C, presenting 2 well-defined seasons, a dry one from Apr to Sep and a wet one from Oct to Mar.

Dry forest fragments were adjacent to cultivated fields that produced soybean as the main crop and maize as a second crop imme-

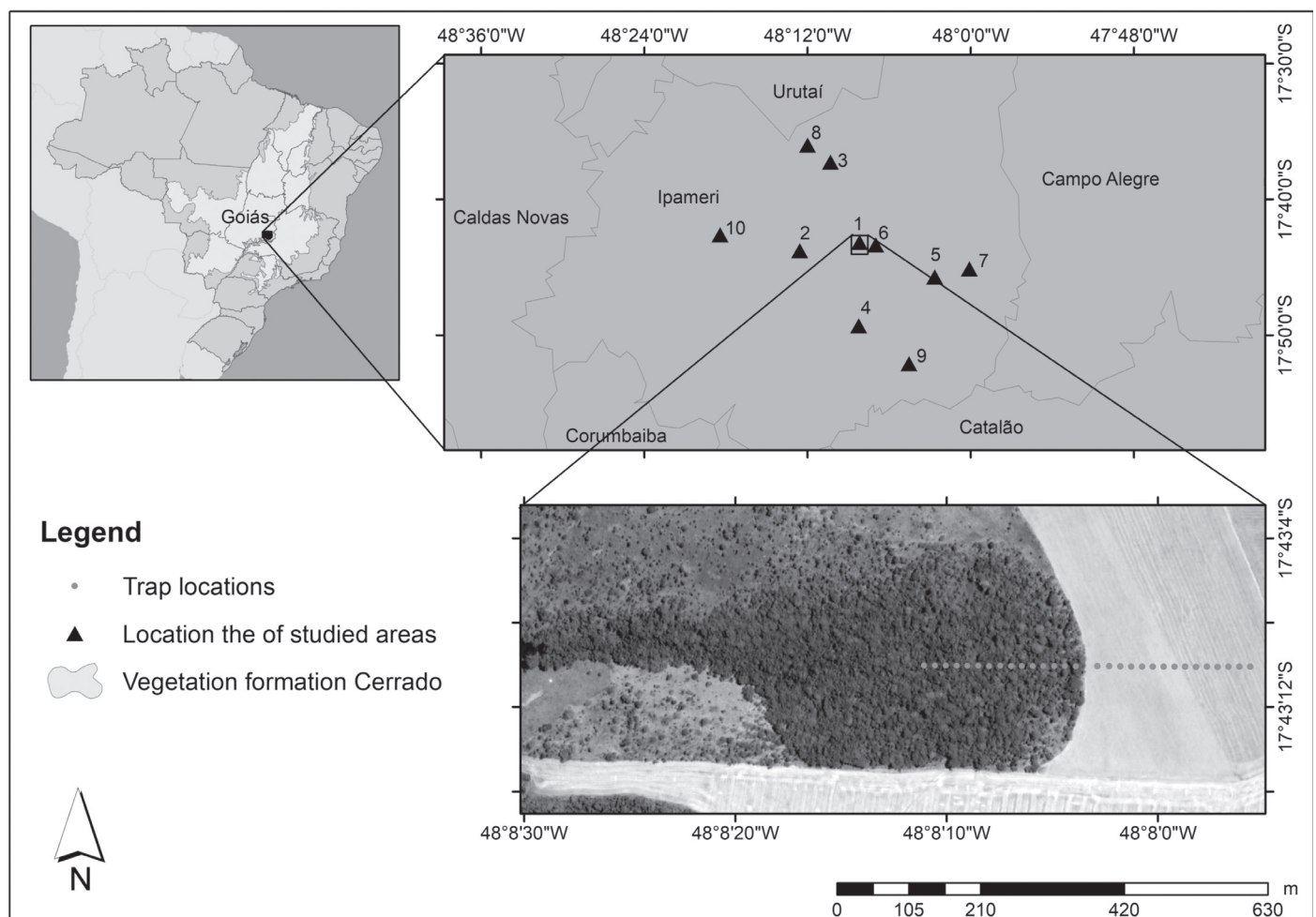


Fig. 1. Geographical location of the experimental areas. The dry forest fragments with their respective areas ([1] = 16.4 ha; [2] = 20.9 ha; [3] = 38.8 ha; [4] = 8.5 ha; [5] = 4.22 ha; [6] = 55.4 ha; [7] = 13.3 ha; [8] = 33.4 ha; [9] = 10.3 ha; [10] = 47.4 ha). One of the dry forest fragments and part of the surrounding cropland is highlighted where pitfall traps were located (Ipameri, Goiás). Red dots represent sites where pitfall traps were installed along the transect.

diately after soybean harvest. Both crops were planted using the no-tillage method. Soybean sowing occurred in Nov 2016, and was harvested in Mar 2017. Maize was sown immediately (Mar 2017) then harvested in Jun 2017. To correlate species richness of ants within the dry forest, 1.0 m² leaf litter samples were collected at randomly chosen points, near pitfall traps on the d of trap collection. This litter was transported to the laboratory in paper bags, dried in an oven, and weighed.

ANT SAMPLING

Two pitfall trap collections of ants were carried out when the soybean and maize crops were in full flower. The third collection was carried out during the inter-harvest period (without crop between Aug and Oct) in Sep 2017. Traps were separated by 15 m along a transect starting from the edge of the dry forest fragment. Fifteen traps were placed in the interior of the fragment and another 15 traps within the cultivated field. Each trap consisted of a plastic 200 mL cup, positioned into the soil by a metal clamp, containing sardines, biscuits, and honey as an attractive bait. All traps were operated for 1 h, between 8:00 and 10:00 AM, as recommended by Oliveira et al. (1995). Prolonged exposure times of attractive baits to capture ants were avoided because some ant species recruit nestmates more rapidly, thus dominating the space occupied by the bait. Traps containing captured ants were collected from the field and placed inside plastic bags, which were sealed and transported to the Entomology Laboratory of the State University of Goiás, Câmpus Ipameri, Ipameri, Goiás, Brazil, for identification using the taxonomic keys proposed by Palacio & Fernández (2003) and Bacaro et al. (2015). In addition, specimens were confirmed with those from the collection of the same laboratory where voucher specimens were deposited. Classification of ant communities based on functional groups were inferred from our field observations and adapted from those of Andersen (1995), Delabie et al. (2000), and Silvestre et al. (2003).

STATISTICAL ANALYSIS

Comparison of species richness in the various dry forest fragments and surrounding crops and inter-crop periods was conducted with the Jackknife1 estimator software, following the method presented by Heltshe & Forrester (1983). Comparative treatments that showed no overlap of confidence intervals and means were considered significantly different. To test the influence of species richness regarding the size of dry forest fragments and distance from the edge to the agricultural areas on quantity of litter, a simple linear regression was used. Comparison of ant diversity between environments was accomplished using the Jaccard Similarity Index, which expresses similarity between habitats based on the number of common species. The resulting similarity matrix of ants was used for the cluster analysis, using the Unweighted Pair Group Method with Arithmetic Mean. According to Valentin (2012), the quality of the group analysis was evaluated by the cophenetic correlation coefficient. It is important to point out that in our study only the capture frequency of the morphospecies in each trap was considered. This, according to Benson & Harada (1988), should prevent the over-estimation of species that have a high recruitment capacity.

Mean data obtained were summarized, using the non-metric multidimensional scaling technique proposed by Gotelli & Ellison (2011). The aim of this ordering was to arrange the samples on the basis of similarity in terms of species composition and frequency of occurrence in each habitat. To test if a significant difference existed between ant samples, an analysis of similarity (ANOSIM), as proposed by

Clarke (1993), was applied. According to Valentin (2012), in both these analyses the Jaccard index was used as a measurement of similarity among the samples.

Cluster analysis, obtained from frequency of capture among species in traps, was used to form groups based on the composition of ant assemblage. The construction of the cluster was carried out using the mean distance linkage method (Unweighted Pair Group Method with Arithmetic Mean) mentioned earlier. For all analyses, differences were considered significant, $P < 0.05$. R software, vers. 3.4 (R Core Team 2017), using the Vegan package (Oksanen et al. 2017), was used to perform all statistical tests.

Results

In both environments, 60 morphospecies of ground foraging ants were captured from 7 subfamilies and 21 genera (Table 1). The subfamily with the greatest number of morphospecies was Myrmicinae (24), followed by Formicinae (19), Ponerinae (6), Ectatomminae (4), Dolichoderinae (4), Pseudomyrmecinae (2), and Heteroponerinae (1). The genera that stood out from the others in relation to the frequency of capture in traps were *Camponotus* (15 morphospecies) and *Pheidole* (9 morphospecies) (both Hymenoptera: Formicidae). The remaining genera were represented by either 1 or 2 morphospecies (Table 1).

Jackknife 1 data estimated that 64 and 56 morphospecies of ants were present in dry forest fragments and surrounding cropland, respectively (Fig. 2A). For dry forest fragments and surrounding cropland, we recovered 21 and 11 morphospecies from pitfall traps, respectively. Ant species richness was significantly greater in dry forest fragments than in cropland.

Ant species richness from the dry forest fragment during the driest period of the yr (inter-crop period, C3_F) was significantly lower than during periods of rain (C1_F and C2_F) (Fig. 2B). In the surrounding cropland, when maize was present (C2_C), ant species richness was significantly lower than C1_C (soybean) and C3_C (without crop).

Size of the dry forest fragment did not significantly influence ant species for observed ($F = 3.376$; $P = 0.104$) and estimated richness ($F = 4.814$; $P = 0.060$). Many of the ants sampled made their nests in the dry forest litter (Table 1) where a positive and significant linear relationship was observed with quantity of litter in dry forest fragment and species observed ($F = 4.639$; $P = 0.050$; $y = 9.496 + 13.717x$) and estimated richness ($F = 5.686$; $P = 0.033$; $y = 11.149 + 27.613x$).

No significant difference in species richness occurred between cropland collection points P1 and P15 (estimated $F = 0.5236$; $df = 13$; $P = 0.4821$, observed $F = 0.2067$; $df = 13$; $P = 0.6568$) or dry forest fragment collection points P16 and P30 (observed $F = 2.749$; $df = 13$; $P = 0.1212$, estimated $F = 3.569$; $df = 13$; $P = 0.0814$). However, the Jaccard Similarity Index suggested a significant change in the composition of ant species as one moved toward the interior of the surrounding cropland (points P1 to P14 in relation to P15; $F_{1,12} = 5.821$; $P = 0.033$). Using the same similarity index, a significant difference in the ant community composition was not confirmed, as one moved toward the interior of the fragment (points 17 to 30 in relation to point 16; $F_{1,12} = 2.818$; $P = 0.119$).

Non-metric multidimensional scaling ordered the samples from the dry forest and matrix environments in a relatively distinct way, and the analysis of similarity indicated that these environments differ in species composition ($R = 0.55$; $P = 0.001$) (Fig. 3). Differences also were found in the composition of the community of ground foraging ants (dry forest fragment + surrounding cropland) at the different capture collection periods (C1, C2, and C3) and in the different dry forest fragments (cluster analysis – Unweighted Pair Group Method with Arithmetic Mean) (Fig. 4A, B).

Table 1. Ground foraging ants captured in pitfall traps from 10 fragments of dry forest and surrounding cultivated fields, with and without agricultural crops, in Cerrado biome, Goiás State, Brazil.

Subfamilies	Genera	Function groups ¹	Total morphospecies	Frequency (%)	
				Dry forest	Cropland
Dolichoderinae	<i>Dolichoderus</i> Lund, 1831	SD	2	0.66	2.00
	<i>Dorymyrmex</i> Mayr, 1866	SD	2	4.22	22.67
Ectatomminae	<i>Ectatomma</i> F. Smith, 1858	SD/GP	3	11.78	3.55
	<i>Gnamptogenys</i> Roger, 1863	SD/GP	1	0.67	0.00
Formicinae	<i>Brachymyrmex</i> Mayr, 1868	SD/O	3	9.32	15.78
	<i>Camponotus</i> Mayr, 1861	AD/O	15	14.86	11.97
	<i>Paratrechina</i> Motschulsky, 1893	SD	1	1.11	0.22
Heteroponerinae	<i>Heteroponera</i> Mayr, 1877	GP	1	0.67	0.00
Mirmicinae	<i>Acromyrmex</i> Mayr, 1865	CF	1	0.00	0.22
	<i>Atta</i> Fabricius, 1804	CF	2	1.78	1.56
	<i>Cephalotes</i> Latreille, 1802	AD	1	0.89	0.00
	<i>Crematogaster</i> Lund, 1831	AD	3	4.67	0.89
	<i>Monomorium</i> Mayr, 1855	AD	5	36.17	32.21
	<i>Mycocepurus</i> Forel, 1893	CF	1	1.11	0.22
	<i>Pheidole</i> Westwood, 1839	SD/O	9	42.54	20.21
	<i>Solenopsis</i> Westwood, 1840	SD/O	1	1.78	2.00
	<i>Trachymyrmex</i> Forel, 1893	CF	1	0.44	0.00
Ponerinae	<i>Hypoponera</i> Santschi, 1938	GP	1	0.00	0.22
	<i>Odontomachus</i> Latreille, 1804	SD/O	3	2.23	0.00
	<i>Pachycondyla</i> F. Smith, 1858	GP	2	2.23	0.44
Pseudomyrmecinae	<i>Pseudomyrmex</i> Lund, 1831	AD	2	0.89	0.44

¹Guild or specialization, modified from Andersen et al. (1995), Delabie et al. (2000), and Silvestre et al. (2003). SD = Soil dominant; GP = Generalist predators; AD = Arboreal dominant; O = Omnivores; CF = Cultivators of fungi. Frequency of ant genera in traps used the formula $(a \times 100)/n$, where (a) represents the number of traps in which a certain species was captured and (n) represents the total number of traps (450).

Discussion

Understanding the dynamics of the complex ant communities in natural environments fragmented by agricultural activity in the Brazilian Cerrado biome and their relationship with the metric or structural variables of these environments may be an important tool for inferring the adverse effects of human interference. However, studies of this nature are rarely carried out in tropical forests (Leal et al. 2012) despite the relative ease of execution (Silva 2014). We identified here perceptible alterations in the composition of ant communities in relation to environmental heterogeneity, suggesting these insects as efficient biological indicators.

The ants most frequently captured in our study were Myrmicinae and Formicinae. The predominance of these subfamilies can be explained by the fact that the representatives of each group is extremely adaptable to the most diverse ecological niches in the Neotropical region, as reported by Fowler et al. (1991). In terms of morphospecies richness and frequency of capture, the genera *Camponotus* and *Pheidole* stood out within these groups. The greater diversity of both genera was mentioned by Wilson (2003) who drew attention to the phenomenon of their hyperdiversity.

Species richness of our study areas provided results similar to those of Rodrigues (2014) for ant communities in the Cerrado in Goiás State.

That author identified 51 ground foraging species and estimated that the region possesses about 58 species. In agreement with this number, Neves et al. (2013) also identified 58 species of epigeic ants in Cerrado areas in Minas Gerais State, a transition region from the Cerrado to the Caatinga biome. It is important to note that the capture method employed by these authors was a pitfall trap. Thus, data from these authors provided additional evidence that our sampling method provided the same representation of ground dwelling ants in the Cerrado.

In our study, the greatest richness of ant species was found in dry forest fragments when compared with and without areas of agricultural cultivation. According to Oliveira et al. (1995), monoculture environments are simplified whereas greater species richness usually is associated with greater heterogeneity of habitat (Tews et al. 2004; Dias et al. 2008). Majer et al. (1984) also observed a correlation between the species richness of ants and that of plants. In their study, ant recolonization of rehabilitated bauxite mines was positively associated with plant species richness and diversity over time where percentage plant cover and percentage litter cover had progressively increased. Regarding diversity, Battistola et al. (2005) drew attention to the fact that coexistence of different species in a single habitat depends on the ecological range of each within the community. In the dry forest fragments from our study, we found that species richness of ants increased when the quantity of leaf litter increased in those habitats. This is pos-

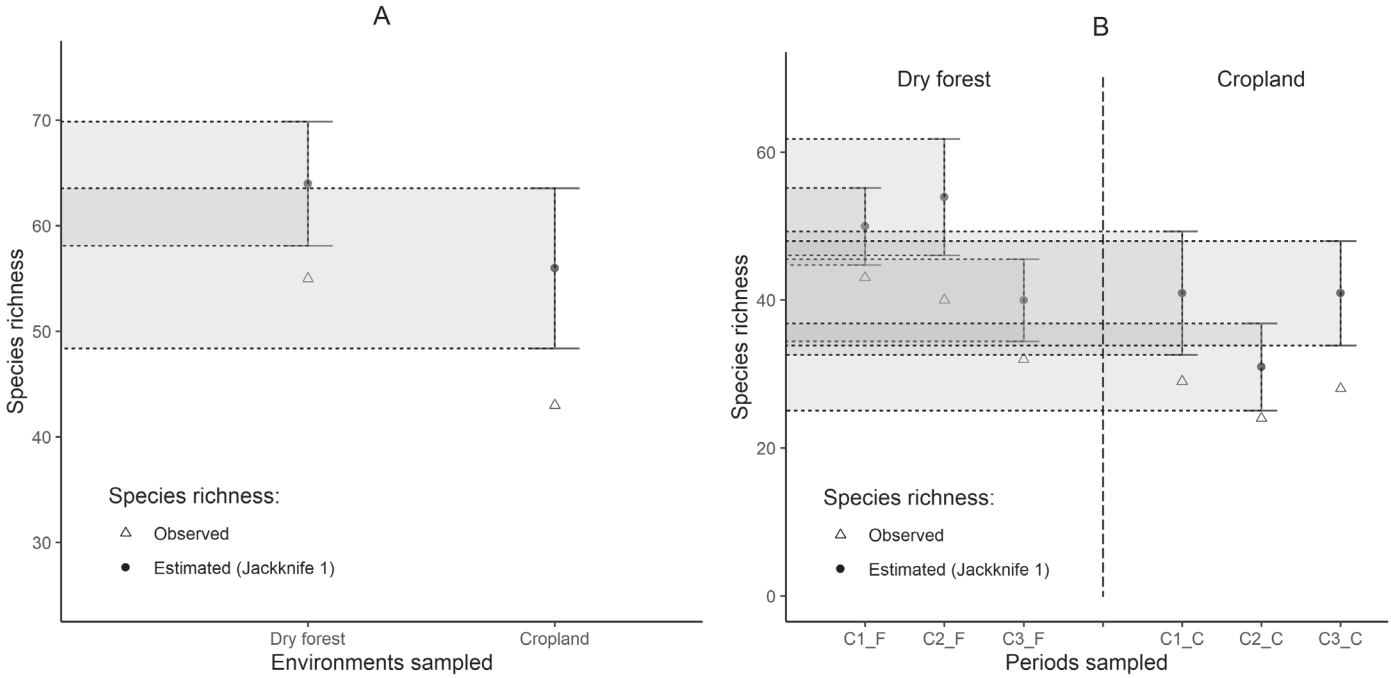


Fig. 2. Observed and estimated species richness of ground foraging ants (Jackknife1 data); from (A) dry forest and surrounding cultivated land; (B) general ants collected in different periods over time - C1 (first crop), C2 (second crop), and C3 (inter-crop).

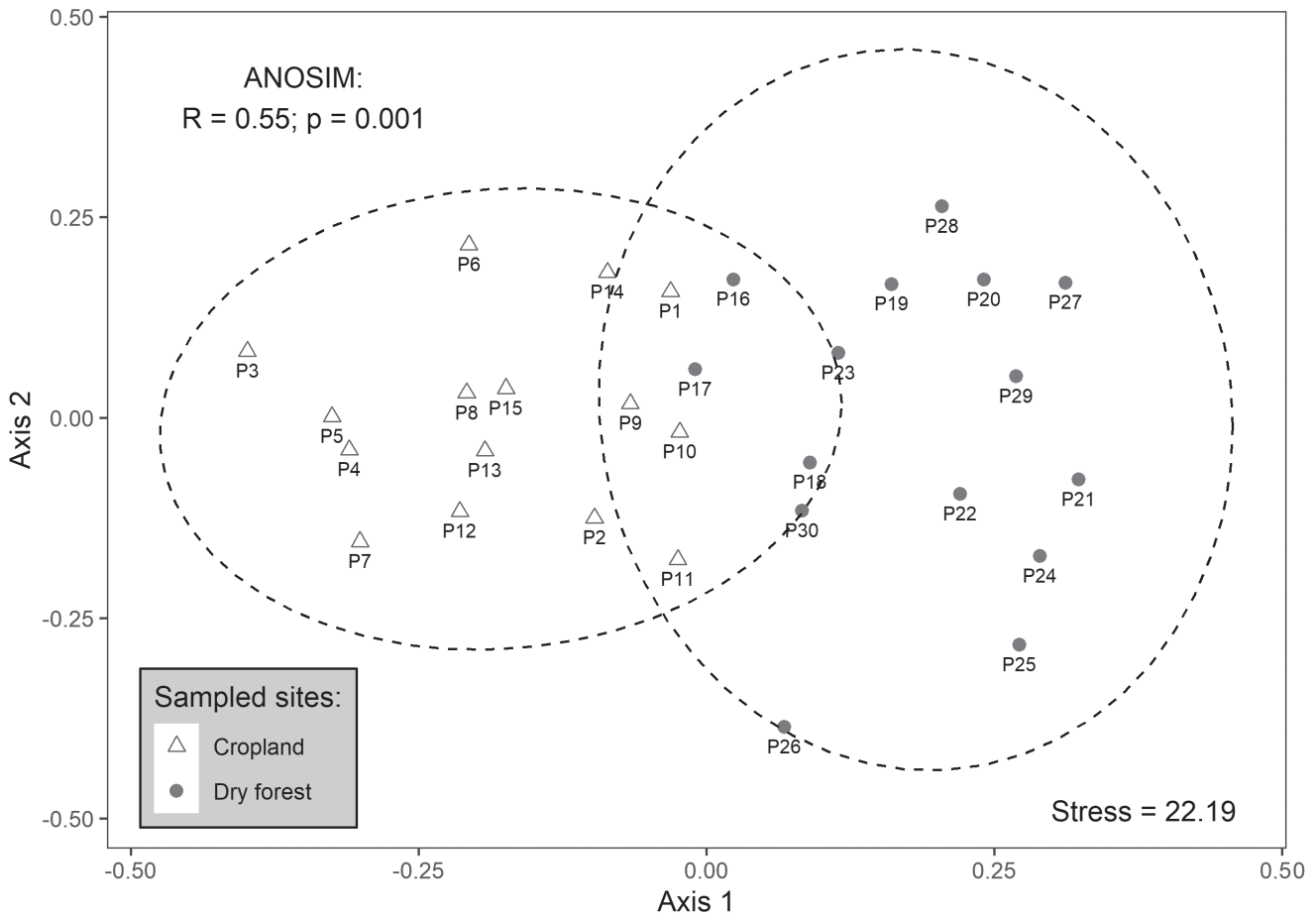


Fig. 3. Non-metric multidimensional scaling scores, obtained from data on the composition of ants recorded at sampling points in the dry forest area (P16 to P30) and in the surrounding matrix (P1 to P15), in the southeastern region of Goiás, Brazil. The dotted lines represent the confidence intervals for the fragment and surrounding cultivated fields compared by the similarity test, analysis of similarity ($P = 0.001$).

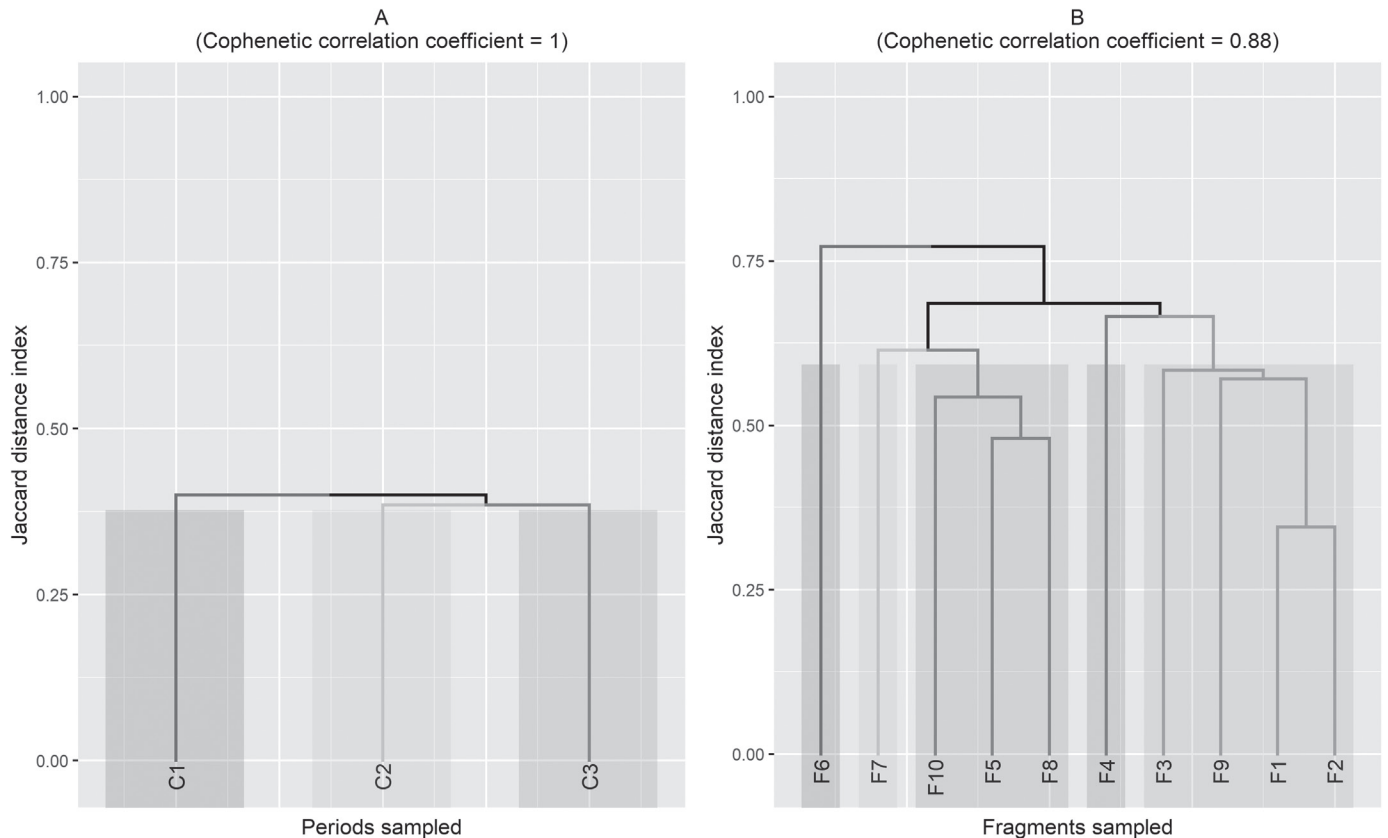


Fig. 4. (A) Dendrograms from standard hierarchical clustering based on the Jaccard Similarity Index of the ant assemblages associated with dry forest fragments and croplands of the whole community of ground foraging ants captured with baited traps at 3 different times: C1 = soybean (first crop), C2 = maize (second crop), and C3 = fields without crops. (B) F1 to F10 represent the different fragments of dry forest.

sibly due to greater availability of feeding and nesting sites. Moreover, Marinho et al. (2002) and Santos et al. (2006) stated that volume of leaf litter indirectly indicated the conservation level of local biodiversity.

We found that size of the dry forest fragment did not significantly influence the observed and estimated richness of ant species (Jackknife1) that appeared to contradict the dominant hypothesis where larger fragments host greater number of species (MacArthur & Wilson 1967). For example, Sobrinho et al. (2003) observed a positive and significant relationship between size of habitat fragment and species richness of ants in the Atlantic forest of Minas Gerais, Brazil. This dominant hypothesis is also mentioned by Magnus & Cáceres (2012) for small rodents in fragments of the Atlantic and Meridional forest found in the Brazilian states of Rio Grande do Sul, Espírito Santo, and Minas Gerais. However, results from our ant study indicated that coexistence of a greater number of species may be linked to more than their territorial dimension.

Non-metric multidimensional ordering, together with cluster analysis, indicated significant differences in the composition of the ant community in dry forest fragments and the surrounding cultivated land. A significant difference in structure of the community also was confirmed when ants were captured from both habitats during of the first, second, and inter-crop periods. It is known that species arrangement within a community is influenced by the distribution of resources and strategies adopted by the ants to obtain and exploit them (Fowler et al. 1991; Camara et al. 2016). In our study, the distribution of resources (mainly cultivated plants) was notably spatially and temporally different in the surrounding cropland.

The Jaccard Similarity Index showed that 1 fragment of dry forest (F6) stood out from the others (Fig. 4B). Curiously, this fragment is the

second largest in terms of area (44.4 ha) with the lowest number of genera (8) of ground foraging ants in the area. This value is relatively low when compared with smaller fragments of dry forest such as F4 where 14 genera were collected that included 33 morphospecies. In the same fragment (F4), 11 morphospecies of *Camponotus* and 6 of *Pheidole* were found, once again reinforcing the fact that species composition was not defined by fragment size only. According to Soares & Schoereder (2001), microclimate, the spatial arrangement of food resources, and type of soil can affect species diversity. Araújo et al. (2004) also reported the significant effects of climatic conditions, which were not analyzed in our study, certainly influenced the foraging pattern of ground dwelling ants.

It is important to note that some ant subfamilies, such as Ponerinae, Ectatomminae, and Heteroponerinae occurred almost exclusively within dry forest fragments (see capture frequency, Table 1). Extrapolating this situation to the universe of other organisms (plants, invertebrates, and vertebrates), there is a clear need to preserve the biodiversity of these remaining areas especially for the maintenance of specific taxonomic groups. Therefore, a better understanding of the mechanisms through which the effects of fragmentation alter ant communities can be advantageous for the development of strategies to mitigate these harmful effects and to improve methods that can be used to evaluate the conservation value of natural environments.

Acknowledgments

We thank the Federal Goiano Institute, the State University of Goiás and the Federal University of Viçosa for financial support. We

also thank Susan Casement Moreira for reviewing the English version of the manuscript.

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