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Termite assemblages in dry tropical forests of Northeastern Brazil: Are termites bioindicators of environmental disturbances?

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Abstract

Termites exhibit several characteristics that emphasize their potential as bioindicators of habitat quality for use in environmental monitoring studies, but little is known about this group in vegetations of semi-arid regions of Brazil. The present study was conducted in three areas of Caatinga under different levels of anthropogenic disturbance, in the High Backwoods of Sergipe State, aiming to verify whether termite communities create different groups associated with the conservation of the area, by analyzing richness, abundance, and composition. Twelve transects of 65 x 2 m were set up in each area, where each one consisted of five plots of 5 x 2 m, making it possible to collect termites in all potential nesting and foraging sites. Five feeding groups of termites were sampled: (WF) wood-feeders, (SF) soil-feeders, (SWF) soil/wood interface-feeders, (LF) litter-foragers, and (SPF) specialized-feeders. Soil samples were collected from each plot in order to measure the environmental variables particle size, moisture percentage, and soil pH. Overall, richness and abundance were significantly different in the three studied areas. Wood-feeders were the most dominant in number of species and number of encounters collected at all sites, whereas the composition of termites in each area, given the environmental disturbances, was distinct. The environmental variables reinforced that the areas are different in terms of degree of conservation. The agreement between environmental variables and ecological data for species composition fortifies the potential of termites as biological indicators of habitat quality in areas of Caatinga of Northeastern Brazil.

Introduction

Termites are among the most abundant insects in tropical ecosystems (Bignell & Eggleton, 2000). They are considered 'ecosystem engineers' because they have the ability to greatly modify their own habitats and to alter the structure of the ecosystems in which they live (Jones et al., 1994; Ferreira et al., 2011).

The ecological importance of termites is based on several aspects, which have been observed in arid and semi-arid ecosystems. They participate in the decomposition and in the flow of carbon and nutrients (Bignell & Eggleton, 2000; Bandeira & Vasconcellos, 2002), moving particles at different depths (Jouquet et al., 2011), increasing soil porosity (Holt & Lepage, 2000), and consequently increasing water retention, affecting directly the vegetation structure and the local primary productivity (Nash & Whitford, 1995). For these reasons, they are considered key organisms to maintaining the structure and functional integrity of ecosystems (Holt & Coventry, 1990; Whitford, 1991) and have been considered for ecological monitoring analysis (Brown Jr, 1997).

Termites had a score of 20, on a scale from 0 to 24 established by Brown Jr (1991), in analysis of potential bioindicators using some animal groups (being after butterflies and ants). This score was given following the attributes such as taxonomic and ecological diversity, easy identification, widespread geographic distribution, functional importance, sedentarism, and good response to disturbances (Brown Jr, 1991; 1997).

However, still little is known about the effects of environmental disturbances in areas of Caatinga affecting termites. It is common knowledge that Caatinga, despite being

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a Brazilian endemic biome, has been changed over decades. It used to occupy an area of about 840,000 km^2 (Santos et al., 2011), corresponding to 54% of the Northeastern Region and 11% of the national territory (Alves et al., 2009). Currently, about 45.3% of its area is degraded, being ranked as the third Brazilian biome most changed by humans, after the Atlantic Forest and the Cerrado (Leal et al., 2005), and it may have its status changed to the second most disturbed, according to Castelletti et al. (2003). Caatinga biome presents only eleven strictly protected areas, which correspond to less than 1% of the biome under legal protection, being the biome with fewer and lesser extent of protected areas in the country (Leal et al., 2005).

This study was conducted in three areas under different levels of anthropogenic disturbance, in two municipalities of Sergipe State, aiming to verify if termite communities are associated with areas of different levels of conservation. Some abiotic variables were also evaluated, in order to check, for example, if there was some sort of association between these variables and the established environmental structures. Also, it was investigated if termites could reflect, on their community composition, the variation of the habitat, as observed in other environments, like in humid (Eggleton et al., 2002; Jones et al., 2003) and dry tropical forest (Vasconcellos et al., 2010; Alves et al., 2011).

Material and Methods

Study site

This study was conducted from April to May 2012 and from November 2012 to January 2013, in two municipalities of the State of Sergipe, Northeastern Brazil: at the protected area named Monumento Natural Grota do Angico (9°39'S/37°41'W), in Poço Redondo, and at the permanent protection area named Fazenda São Pedro (10°02›S/37°24›W), in Porto da Folha. Both areas are characterized as dry tropical forests, with predominance of xeric vegetation, presence of cacti [*Pilosocereus gounellei* (A. Weber ex. K. Schum.) Bly. ex. Rowl., *Melocactus zehntneri* (Britton & Rose) Luetzelb, *Selenicereus grandiflorus* (L.) Britton & Rose], shrubs and trees [*Poincianella pyramidalis* (Tul.) Queiroz, *Aspidosperma pyrifolium* Mart., *Sideroxylon obtusifolium* (Humb. ex. Roem. & Schult.) TD Penn], and bromeliads [*Bromelia laciniosa* Mart. ex. Schult., *Bromelia pinguin* L.]. The average annual temperature goes up to 26°C, with annual average rainfall of 550 mm, being the period of rain concentrated from March to June. The choice of study areas was based according the land use and historic conservation; thus, the areas were classified as: A1, abandoned pasture area, characterized by sparse vegetation with predominance of herbaceous and shrubs plants, with presence of cattle; A2, area in regeneration process for five years, located in the Monumento Natural Grota do Angico, characterized by being more heterogeneous than the area A1, with presence of trees 4-6 m high, and presence of bromeliads; and A3, located at the Fazenda São Pedro, without disturbance for over 30 years, characterized by dense vegetation, with trees 20 m high, and presence of bromeliads.

Termite sampling

A protocol similar to that described by Jones and Eggleton (2000) was applied to each sampling site. Twelve transects of 65 x 2 m were installed in each area, subdivided into five plots of 5 x 2 m, spaced from each other by 10 m and alternating to the right and left, for a total sample of 60 spots and area of 600 m^2/area. Distances of 100 m between each transect and 50 m from the edge of the fragment was maintained. The number of plots where a given species was present was used as estimation for relative abundance (Jones, 2000; Bignell & Eggleton, 2000; Oliveira et al., 2013). As standard time scale, each plot was explored for 1h/person, making it possible to collect termites in all potential nesting and foraging sites. The specimens were identified to generic level with the aid of identification keys (Constantino, 1999), and to species level by comparisons with samples previously identified and housed at the Collection of the Laboratório de Agricultura e Pragas Florestais of the Universidade Federal de Sergipe, and at the Museu de Zoologia da Universidade de São Paulo (MZUSP).

Feeding groups

All genera and species identified were classified into five feeding groups, according to the classification suggested by Swift and Bignell (2001), and to information in the literature (Gontijo & Domingos, 1991; DeSouza & Brown, 1994; Mélo & Bandeira, 2004; Reis & Cancello, 2007; Vasconcellos et al., 2010; Alves et al., 2011), namely: (WF) wood-feeders (termites feeding on wood and wood litter, including dead branches still attached to trees); (SF) soil-feeders (termites feeding deliberately on mineral soil, with higher proportions of soil organic matter and silica, and lower proportions of recognizable plant tissue than in other groups); (SWF) soil/wood interface-feeders (termites feeding in highly decayed wood which has become friable and soul-like, or predominantly within soil under logs or soil plastered on the surface or inside of rotting logs or mixed with leaf litter in stilt-root complexes); (LF) litter-foragers (termites foraging on leaves and small woody items, often taken back and stored temporarily in the nest); and (SPF) specialized-feeders (species of termites that feed on fungi, algae, lichens on the bark of trees, manure and vertebrate carcasses).

Abiotic variables

The following abiotic variables related with soil were analyzed: particle size, moisture, and pH. For particle size analysis, 300 grams of soil were collected from each plot using an auger, totaling 30 samples/area. All samples were taken to the Instituto de Tecnologia e Pesquisa de Sergipe (ITPS), where the percentages of sand, silt and clay were measured. In each plot, moisture and soil pH measurements were taken using a pH meter (pH Instrutherm 2500).

Statistical analyses

An One-way ANOVA with Tukey's test a posteriori was conducted to verify significant differences in relative abundance and mean richness per transect between the three areas sampled.

Species richness was estimated for each site using the non-parametric richness estimator Jacknife1 (Colwell & Coddington, 1994), considered one of the best tools to estimate this parameter (Palmer, 1990; Walther & Moore, 2005). Based on samples from each plot, accumulation curves were constructed, with 1000 randomizations to compare richness between sampling sites.

To analyze the species composition, a non-metric multidimensional scaling (NMDS), with data ordered by transects, and a matrix of presence/absence of the species, were performed. An analysis of similarity (ANOSIM) was carried out with a significance level of 95%, to verify the existence of significant differences in species composition between sampling sites; Jaccard similarity index was used to measure distance (Muellerdombois & Ellenberg, 1974; Hammer et al., 2001).

Furthermore, a principal component analysis (PCA) with the abiotic data was used to verify if there was spatial segregation between the respective areas (Clarke & Warwick, 2001), for which the data were logarithmized. In the PCA, the variable sand was excluded due to high correlation with silt and clay (0.86 and 0.79, respectively). This procedure is advisable when there is a strong correlation between the variables analyzed, causing no loss of information (Clarke & Warkick, 2001). To verify that the variables differ statistically between the areas, an One-way ANOVA was performed with all five environmental variables (Tukey post hoc test, $p < 0.05$), and with the values of the first PCA components.

The statistical software R (R Development Core Team, 2008) was used to make ANOVA and Tukey's test. The richness accumulation curve was performed using the program EstimateS 9.1.0 (Colwell, 2009). The NMDS, ANOSIM and the PCA were performed with the aid of statistical software PAST (Hammer et al., 2001).

Results

One hundred and eighty samples of termites, classified in three families, 12 genera and 16 species, were found at the experimental sites. Termitidae was the most abundant and richest family, with 14 species collected, followed by Kalotermitidae and Rhinotermitidae, with one species each. Only three species were common for all areas, namely: *Nasutitermes macrocephalus* (Silvestri), *Heterotermes sulcatus* (Mathews), and *Amitermes amifer* Silvestri. Two of the sixteen species collected were exclusive of the area A1 (*Anoplotermes* sp. and *Amitermes* sp.), and five of the area A3 (*Rugitermes* sp., *Ruptitermes* sp., C*ylindrotermes* sp., *Inquilinitermes fur* (Silvestri), and *Microcerotermes* cf. *indistinctus* Mathews (Table 1).

Significant differences in relative abundance ($F2, 33=12.70$; $p < 0.01$), and in the richness of termites ($F2, 33 = 10.04$; $p < 0.01$), were found among the studied areas (Fig. 1).

From the values obtained by the non-parametric estimator Jacknife1, the estimated species richness was close to the observed (Table 1). From the observation of non-overlapping confidence intervals, it was found a difference in the richness between the areas A1 and A3 (Fig. 2). In relation to feeding groups, the wood-feeders were the most dominant in number of species and number of encounters collected at all areas, representing about 50% of the total fauna found. The most conserved area (A3) was the only one where all groups were found (Fig. 3).

The NMDS analysis showed differences in the species composition of termites when the sites A1 and A3 were compared (Fig. 4), while ANOSIM showed significant difference between all the three areas (Table 2).

The richness and relative abundance of termites varied positively with the degree of conservation of the area, i.e. the more conserved the area, more abundant and diverse was the termite community. The level of disturbance significantly altered the composition of species and the feeding groups present.

The abiotic factors associated with soil analyses (particle size, moisture, and pH) showed significant difference in at least one area (Table 3). Separation between sampling areas was evident through the principal component analysis (PCA) (Fig. 5), indicating that such areas can be considered different; ANOVA of the first components showed significant differences between the studied areas ($F2, 15 = 20.25$; $p < 0.001$).

Discussion

Results found by Araujo (1970) and Constantino (1998) showed Termitidae as the richest family of Isoptera with regards to number of species, abundance, and diversity in ecological terms, which is consistent with the results found here. In another hand, Kalotermitidae, a family that includes all drywoods and some dampwoods termites that do not require soil contact to survive, presented low abundance in the areas sampled. In this family, different species have different temperature and moisture requirements, but generally speaking, they inhabit and eat various types of dead wood (Cancello, 1996) and may nest in the treetops, hindering their sampling (Roisin et al., 2006), which could explain the lack of specimens in our samples.

Table 1. Termites collected in three areas of Caatinga, Sergipe State, Brazil: A1 (pasture area), A2 (scrub forest), and A3 (arboreal forest); Feeding groups: WF (wood-feeders), SF (soil-feeders), LF (litter foragers), SWF (soil/wood interface-feeders), SPF (specialized- feeders).

Species	Area A1	Area A2	Area A3	# of species found	Feeding group
Kalotermitidae					
Rugitermes sp.	0	0	2	2	WF
Rhinotermitidae					
Heterotermes sulcatus (Mathews)	10	18	8	36	WF
Termitidae					
Apicotermitinae					
Anoplotermes sp.	4	0	0	4	SF
Ruptitermes sp.	0	0	4	4	SPF
Nasutitermitinae					
Constrictotermes cyphergaster (Silvestri)	0	5	7	12	SPF
Diversitermes sp.	0	5	14	19	LF
Nasutitermes corniger (Motschulsky)	0	3	4	7	WF
Nasutitermes macrocephalus (Silvestri)	1	8	2	11	WF
Termitinae					
Amitermes amifer Silvestri	7	11	25	43	SWF
Amitermes nordestinus Mélo & Fontes	4	5	0	9	SWF
Amitermes sp.	1	0	0	1	SWF
Cylindrotermes sp.	0	0	2	2	WF
Inquilinitermes fur (Silvestri)	0	0	1	1	SF
Microcerotermes cf. *exiguus* (Hagen)	0	1	8	9	WF
Microcerotermes cf. *indistinctus* Mathews	0	0	11	11	WF
Termes sp.	0	2	7	9	SWF
Richness	6	9	13	16	
Number of encounters (relative abundance)	27	58	95	180	
Estimated richness (Jackknife 1)	7.97±2.76	9.98±1.96	13.98±1.96		

Kalotermitidae can also be absent in a disturbed environment, as it would have the number of trees and dead wood reduced, decreasing the likely nesting sites of the group (Vasconcellos et al., 2010). Even considering richness and relative abundance between the different areas analyzed, some species were common and had relatively high frequency.

The assemblages of termites include a great relative abundance of *H. sulcatus*, which appears to be one of the most important species to the wood cycle in dry areas and it is very resistant to disturbance (Alves et al., 2011). Melo and Bandeira (2007) measured the influence of this species in wood consumption in the Caatinga, and found that it was a generalist species that could consume wood in different stages of decomposition, even when already attacked by other species of termites.

The species *A. amifer* has been recorded in the Caatinga (Alves et al., 2011; Vasconcellos et al., 2010), Atlantic Forest, and Cerrado (Mélo & Bandeira, 2004), and may be considered of wide distribution.

N. macrocephalus is also considered to have a wide dis-

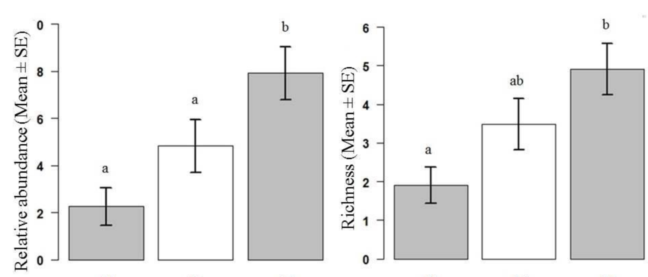

Fig 1. (A) Richness average; and (B) abundance per transect in three areas of Caatinga, Sergipe State, Brazil. Different letters indicate significant differences given by the Tukey test (p<0.05).

Table 2. Analysis of similarity (ANOSIM) for the species composition of termites communities sampled in three areas (A1, A2, and A3) of Caatinga, Sergipe State, Brazil.

Area	R-value	P-value
A1 x A2	0.14	0.01
A1 x A3	0.39	<0.01
A2 x A3	0.36	<0.01

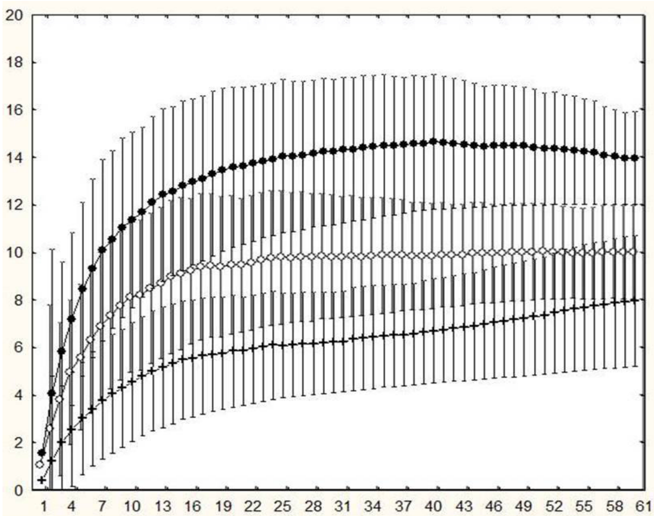

Fig 2. Accumulation species curves estimated for termites with confidence interval of 95%, in three areas of Caatinga, Sergipe State, Brazil, with different levels of disturbance. Area A1 (crosses); area A2 (open circles), and area A3 (closed circles).

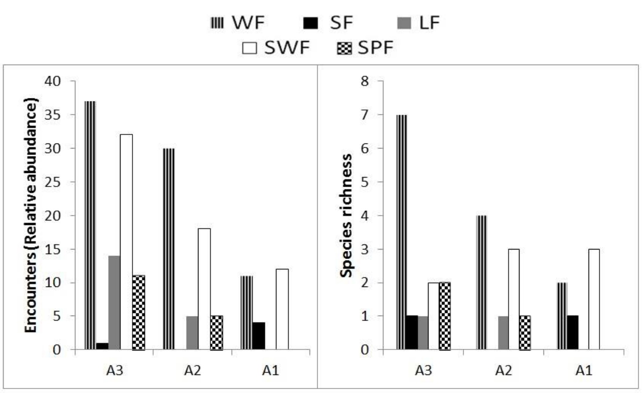

Fig 3. Termite species richness and relative abundance (encounters) by feeding group, in three areas of Caatinga under different levels of disturbance, Sergipe State, Brazil. A1, abandoned pasture area; A2, regeneration area; A3, conservation area. Feeding groups: WF, wood-feeders; SF, soil-feeders; LF, litter-feeders; SWF, soil/wood interface-feeders; SPF, specialized-feeders.

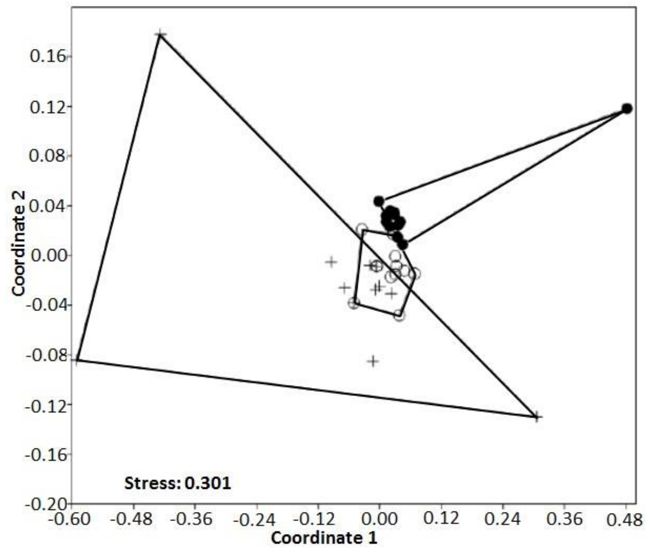

Fig 4. Analysis of non-metric multidimensional scaling (NMDS) for the species composition of termites in three areas of Caatinga, Sergipe State, Brazil: area A1 (crosses); area A2 (open circles), and area A3 (closed circles).

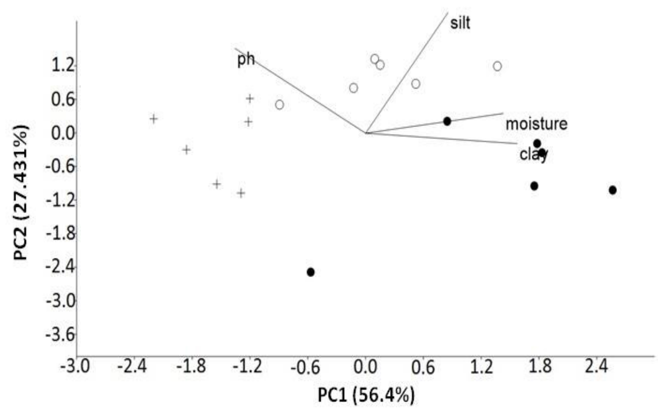

Fig 5. Principal component analysis (PCA) for environmental variables in three areas of Caatinga, Sergipe State, Brazil: area A1 (crosses); area A2 (open circles), and area A3 (closed circles).

tribution, since it was recorded in all three fragments sampled in this study, being already previously recorded in areas of Caatinga (Mélo & Bandeira, 2004), Amazon, Atlantic Forest, and Cerrado (Constantino, 2005; Alves et al., 2011; Souza et al., 2012). To date, there is no work with regards to its biology or ecology.

From the results of relative abundance, average richness per transect, and the accumulation curve, it is possible to suggest that the richness and abundance of termites can be changed by altering habitat, being directly related to the conservation of the area, in agreement with results observed in other researches on termites, in Savannah (Dosso et al., 2012; Cunha & Orlando, 2011; Carrijo et al., 2009; Brandão & Souza, 1998), Humid Tropical Forests (Ackerman et al., 2009; Eggleton et al., 1996; DeSouza & Brown, 1994; Bandeira & Torres, 1985) or Caatinga (Alves et al., 2011; Vasconcellos et al., 2010; Bandeira et al., 2003).

The abundance of wood-feeders, when compared to other groups, is already a result well discussed in the literature (Souza et al., 2012; Alves et al., 2011; Vasconcellos et al., 2005). Soil-feeders and soil/wood interface-feeders are more sensitive to environmental disturbances and natural weather fluctuations than wood-feeders in humid forests (DeSouza & Brown, 1994; Bandeira et al., 2003), but also, the small amount of organic matter in the soil (consequence of low leaf productivity) could be a contributing factor to the low abundance of those groups in the Caatinga environment (Mélo & Bandeira, 2004). However, the wood-feeders were the group most affected by disturbance in the Cerrado and Caatinga environments (Carrijo et al., 2009; Vasconcellos et al., 2010), as shown in the present study.

The variation in species composition in the three areas studied corroborates the hypothesis that anthropogenic changes

Table 3. Mean values (± standard error) of environmental variables collected in three areas of Caatinga, Sergipe State, Brazil. Different letters indicate significant differences between the means of the variables obtained by the Tukey test (p<0.05).

Area	pH (Mean±SE)	Moisture (Mean±SE)	Sand (Mean±SE)	Clay (Mean±SE)	Silt (Mean±SE)
A1	6.99 ± 0.03 a	0.66 ± 2.34 a	54.41 ± 1.41 a	11.59 ± 0.70 a	33.98 ± 0.95 a
A2	6.95 ± 0.05 a	11.26 ± 3.31 b	46.59 ± 2.00 b	13.65 ± 0.99 b	39.69 ± 1.35 b
A3	6.58 ± 0.05 b	47.53 ± 3.31 c	46.63 ± 2.00 b	17.58 ± 0.99 c	35.77 ± 1.35 a

(including deforestation and/or land use) may be responsible for changes in the availability of plant material and/or ecological niches for species (Junqueira et al., 2008). As a result, a direct and positive relationship between the local termite diversity and the conservation status of the area could be assumed, i.e., termites responded to disturbances occurred in Caatinga sites of the High Backwoods of Sergipe, mapped through the differences in richness, abundance and composition of species in the areas sampled.

Alves et al. (2011) analyzing three areas of Caatinga quite similar with regards to disturbance levels, observed, through a PCA (using eleven environmental variables), no significant difference on termites assemblage composition, whereas Vasconcellos et al. (2010) found that areas with different levels of disturbance presented different communities of termites. Thus, the results presented here, combined with data from literature, reinforce the potential of termites as biological indicators of environmental quality in the areas of Caatinga, which could be applied to other ecosystems.

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