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Termites as Bioindicators of Habitat Quality in the Caatinga, Brazil: Is There Agreement Between Structural Habitat Variables and the Sampled Assemblages?

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Abstract

The composition of termite assemblages was analyzed in three caatinga sites of the Estação Ecológica do Seridó, located in the municipality of Serra Negra do Norte, in the state of Rio Grande do Norte, Brazil. These sites have been subjected to selective logging, and cleared for pasture and farming. A standardized sampling protocol for termite assemblages (30h/person/site) was conducted between September 2007 and February 2009. At each site we measured environmental variables, such as soil pH and organic matter, necromass stock, vegetation height, stem diameter at ankle height (DAH) and the largest and the smallest crown width. Ten species of termites, belonging to eight genera and three families, were found at the three experimental sites. Four feeding groups were sampled: wood-feeders, soil-feeders, wood-soil interface feeders and leaf-feeders. The wood-feeders were dominant in number of species and number of encounters at all sites. In general, the sites were not significantly different in relation to the environmental variables measured. The same pattern was observed for termite assemblages, where no significant differences in species richness, relative abundance and taxonomic and functional composition were observed between the three sites. The agreement between composition of assemblages and environmental variables reinforces the potential of termites as biological indicators of habitat quality.

Introduction

The Caatinga covers an area of around 800,000 km^2 in Northeast Brazil. Its climate is semiarid, with high rates of potential evapotranspiration (1500-2000 mm/year) and low rainfall (300-1000 mm/year), often concentrated over a three-to-five month period (Sampaio 1995). This biome was traditionally stigmatized as being homogeneous and characterized by low species diversity and endemism. However, the results of recent studies contradict this belief and classify Caatinga as a very heterogeneous biome with a biodiversity composed of several endemic species (Leal *et al* 2003). Even though it is biologically significant, the Caatinga is one of Brazilian biomes that has been most altered by human activities (Leal *et al* 2005).

The effects of environmental degradation in the Caatinga on the biological communities are practically unknown. Thus, analysis of the effects of anthropic disturbance on all the taxa of a caatinga community poses practical obstacles. Termites exhibit several characteristics that underscore their potential as a bioindicator taxon of habitat quality suitable for use in monitoring programs in tropical ecosystems (Brown Jr 1997, Bandeira *et al* 2003, Vasconcellos *et al* 2010). Among the main attributes that justify their characterization as biological indicators of habitat quality are: (i) widespread geographic distribution; (ii) high abundance; (iii) low locomotor capacity; (iv) functional importance; (v) ease of sampling using standard protocols; (vi) short response time to anthropic disturbances; and (vii) it is taxonomically treatable (Brown Jr 1997, Constantino 2005).

In some arid and semiarid ecosystems, the termite pedologic activity significantly increases soil water retention, a fact that directly reflects in plant structure and local primary productivity. Thus, these insects are considered essential for maintaining the structural and functional integrity of these ecosystems (Holt & Conventry 1990, Whitford 1991).

The aim of the present study was to analyze the structure of termite assemblages at three sites with different land use histories. Eleven environmental variables were measured in each of these sites to determine if type of land use could result in different environmental characteristics and if these possible differences between sites could significantly affect the composition of termite assemblages. If termites are in fact good indicators of environmental quality, they would be expected to reflect structural variations in the habitat, that is, if sites have different environmental parameters, it would follow that termite assemblages would also exhibit different compositions, reflecting habitat parameters, as observed in humid tropical forest sites (Eggleton *et al* 2002, Jones *et al* 2003) and another caatinga site (Vasconcellos *et al* 2010).

Material and Methods

The study was conducted at the Estação Ecológica do Seridó (ESEC-Seridó), located in the municipality of Serra Negra do Norte, state of Rio Grande do Norte, Brazil (6°33'30" to 6°37'00"S and 37°14'30" to 37°16'30"W). ESEC-Seridó occupies 1166.4 ha and was formerly used for cattle breeding and logging. Its dominant vegetation is hyper-xerophilous, arboreal-shrubby caatinga. The local climate is hot and semiarid, with mean annual temperature of 27.5°C and mean annual rainfall of 744.7 mm. The highest rainfall occurs between February and May. With respect to soils, there is a predominance of luvisols, eutrophic inceptisols and vertisols, in addition to sparsely scattered rocky outcroppings (Ministério da Agricultura 1978).

The study was conducted between September 2007 and February 2009 in three caatinga sites, chosen based on reports of residents about the history of each site and the type of current land use. The sites were inserted in a matrix composed by caatinga vegetation and pasture, and the distance between them ranged from 2 km to 6 km. Thus, the sites were arbitrarily categorized into: (i) Site A_1, with secondary vegetation, subjected to different levels of cattle breeding for the last 30 years; (ii) Site A_2, with secondary vegetation and regeneration time similar to that of A_1, currently bordered by dirt roads. Furthermore, until mid-2006 part of its site was used for growing elephant-grass (*Pennisetum* sp.); (iii) Site A_3, located outside the ESEC. It shows signs of considerable anthropic disturbance and is sporadically used for cattle breeding.

Termite sampling

A rapid standardized sampling protocol of termite biodiversity (30h/person/site) was applied in each of the sites. This protocol consisted of delimiting six 65m transects. Five 5 x 2m parcels, spaced 10 m apart, were marked in each of the transects, for a total of 300 m^2 sampled per site. The termites were collected in several microhabitats (soil, tree trunks and branches, active and abandoned nests, undergrowth, under tree bark, dead roots, etc.). Species identification was based on taxonomic studies conducted by Constantino (1998) and species comparison relied on specimens from the Isoptera collection of the Bioscience Center, Universidade Federal do Rio Grande do Norte.

Feeding groups

The species were categorized into four food groups, according to in situ observations, mandibular morphology of the workers (Deligne 1966), analysis of intestinal content (Bandeira 1989) and studies carried out in ecosystems of Northeast Brazil (Bandeira *et al* 2003, Sena *et al* 2003, Mélo & Bandeira 2004, Vasconcellos *et al* 2008, 2010). The four feeding groups were: (i) wood-feeders, which feed on wood at different stages of decomposition and have no silt or sand particles in their intestine; (ii) soil-feeders, which feed predominantly on organic particles mixed with soil. The intestinal content of the specimens has a large amount of silt and sand mixed with the organic matter ingested; (iii) wood/soil-feeders, which consume predominantly, wood in advanced stages of decomposition, usually mixed with mineral soil. They generally carry soil into the trunk that is being consumed; and (iv) leaf-feeders, which feed mainly on dry leaves found in the undergrowth.

Nest density

To estimate termite nest density, five 100 x 20m parcels were delimited in each study site, for a total of 1 ha per site. All the nests with active populations were counted, irrespective of size. Vasconcellos *et al* (2008) showed that the composition of termite nests may also provide information on the disturbance level in a particular area.

Abiotic and vegetation variables

The following environmental variables related to the soil of each site were measured: (i) granulometry (sand-silt-clay ratio); (ii) organic matter in the soil; (iii) pH, using a pHmeter (Instrutherm pH 2500); and iv) necromass stock of 13 transects (four in A_1, five in A_2 and four in A_3) that contained five 0.5 x 0.5m parcels spaced 10 m apart.

The vegetation physiognomy of each site was described for the five 20 x 10m parcels, totaling 1000 m^2/site. In each parcels all the live individuals with diameter ≥ 5 cm that were 10 cm above soil level were sampled. The following tree parameters were then measured: (i) diameter at ankle height (DAH); (ii) tree height; (iii) largest crown width; and (iv) smallest crown width.

Analyses

Once biological data, such as species richness, feeding groups, taxonomic groups and number of encounters of a given species, were obtained, the latter considered an indirect measure of relative abundance, the ecological measures of frequent use in the environmental monitoring were calculated using Primer 5 and Estimated softwares (Clarke & Warwick 2001, Colwell 2005). Species richness estimated for each site was calculated using nonparametric Jacknife 1 and Chao 2 estimators, considered two of the best nonparametric estimators of species richness (Walther & Moore 2005). Sample-based species accumulation curves were also built to compare species richness. Accordingly, 500 randomizations were performed from the initial data collected in each parcels.

The environmental variables of the sites were compared using ANOVA, with Turkey's test *a posteriori,* if there was a significant difference between the sites. The number of species found per transect inside each site was compared using the Kruskal-Wallis nonparametric test and the number of feeding and taxonomic groups found in each site were compared using the chi-square test. All of these tests were conducted using Statistica 7.1 software (StatSoft 2005).

Principal component analysis (PCA), based on the structural parameters of the three study sites, was used to determine if there was spatial segregation between the sites analyzed (Clarke & Warwick 2001). Abiotic and vegetation data were normalized before PCA was carried out. In PCA, the variables silt and smallest crown width were excluded because of their high correlation (> 0.95) with the variables sand and largest crown width, respectively. This procedure is recommended when there is a strong correlation between the variables analyzed, because no information is lost in the analysis (Clarke & Warwick 2001). ANOVA with the scores of the first PCA component was performed to check for the existence of a significant difference between the environmental attributes measured in the sites.

Results

Ten species of termites were found in the three study sites, seven in A_1, six in A_2 and seven in A_3. Five species occurred simultaneous in the three sites. Two were exclusive from A_1, one from A_2 and two from A_3 (Table 1). The species *Anoplotermes* sp. and *Ruptitermes reconditus* (Silvestri) are new records for ESEC-Seridó.

The family Termitidae was dominant in species richness in the three sites, with eight species, followed by Kalotermitidae and Rhinotermitidae, with only one species each. The most dominant subfamily of Termitidae was Termitinae, with four species, followed by Apicotermitinae and Nasutitermitinae, with two species each. The most abundant species in the three sites was *Heterotermes sulcatus* (Mathews), present in 73.3%, 66.7% and 50% of the parcels analyzed in sites A_1, A_2 and $A_{3,}$ respectively. Moreover, the organic matter from cattle feces found in A_3 may be partially responsible for the presence of a number of species associated to this matter, such as *Amitermes nordestinus* (Mélo & Fontes).

According to nonparametric Jackknife 1 and Chao 2 estimators, estimated species richness in the three study sites was very close to the richness observed (Table 1). Additionally, the species accumulation curve demonstrated that the species richness of each site was not significantly different (Fig 1). There was also no significant difference between the number of encounters per transect (Kruskal-Wallis H = 5.39; P > 0.05).

The wood-feeders were dominant in the three sites analyzed in terms of number of species (three in each site) and relative abundance. On the other hand, only one species each of soil-feeder and leaf feeder (*Anoplotermes* sp. and *R. reconditus*, respectively) was found. A_1 was the only site to contain all the feeding groups. The number of encounters was not significantly different between the

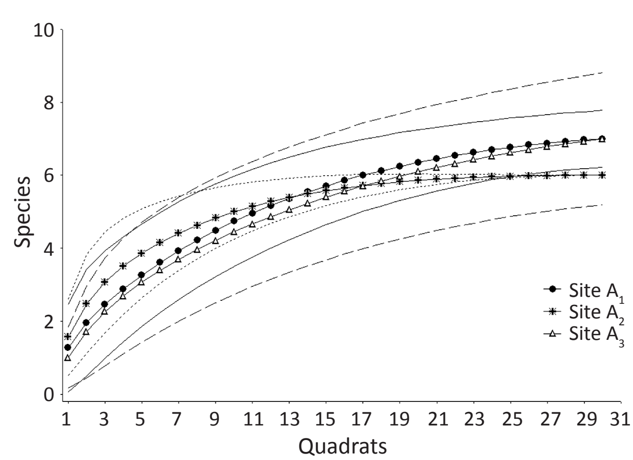

Fig 1 Rarefaction curve of termite species richness in three caatinga sites, Rio Grande do Norte, Brazil. Continuous line: confidence interval of A_1; dotted line: confidence interval of A_2; and dashed line: confidence interval of A_3.

Table 1 Termite assemblages in three caatinga sites (A_1, A_2 and A_3) in Rio Grande do Norte, Brazil. Feeding groups: W = wood-feeders; S = soil-feeders; F = leaf-feeders; and WS = wood/soil feeders.

Species	A_1	A_2	A_3	Nest site	Feeding groups	Distribution[1]
Kalotermitidae						
Neotermes sp.	2	2	3	Wood	W	?
Rhinotermitidae						
Heterotermes sulcatus (Mathews)	22	20	15	Subterranean	W	AF, CA
Termitidae						
Apicotermitinae						
Anoplotermes sp.	4	3	2	Subterranean	H	?
Ruptitermes reconditus (Silvestri)	2	0	0	Subterranean	L	AF, CA and CE
Nasutitermitinae						
Nasutitermes corniger (Motschulsky)	0	4	0	Arboreal	W	AF, HH, CA, CE and AR
Nasutitermes macrocephalus (Silvestri)	2	0	0	Arboreal	W	AF, CA, CE and AR
Termitinae						
Amitermes amifer Silvestri	5	13	6	Wood	WS	AF, CE and CA
Amitermes nordestinus Melo & Fontes	0	0	1	Wood	WS	CA
Microcerotermes strunckii (Sörensen)	0	0	1	Arboreal	W	CA, CE and AR
Termes fatalis (L.)	1	5	2	Wood	WS	AF and AR
Number of species	7	6	7			
Number of encounters	38	47	30			
Jackknife 1	7.97 ± 0.97	6.00 ± 0.00	8.93 ± 1.34			
Chao 2	7.00 ± 0.12	6.00 ± 0.05	7.32 ± 0.90			

[1]Distribution in the Brazilian ecosystems: HH, Humid highland forest; CA, Caatinga; CE, Cerrado; AR, Amazon Rainforest; AF, Atlantic Forest.

sites for the feeding groups (χ^2 = 11.49, gl = 6, P > 0.05) and taxonomic groups (χ^2 = 3.47, gl = 4, P > 0.05).

Estimated termite nest density in the three sites was 0.7 active nests/ha. All the nests were considered arboreal, given that they were built on live or dead trees, without direct contact with the soil. The nest-building species were *Microcerotermes strunckii* (Sörensen) and *Nasutitermes corniger* (Motschulsky). The only site with nests was A_1, with a density of 2 active nests/ha, whereas in the other sites no nests were found in the parcels analyzed. However, the presence of *N. macrocephalus* and *M. strunckii* nests in A_3 and of *N. corniger* nests in A_2 was observed, but not within the gradients.

Of the eleven environmental variables collected in the three sites (Fig 2), only mean plant density in A_3 showed a significant difference compared to the other sites ($F_{2, 12}$ = 11.59; P < 0.05). Principal component analysis (PCA) showed no clear separation between the sites in terms of their abiotic attributes and vegetation structure (Fig 3). The sites were not significantly different according to the scores of the first principal component ($F_{2, 11}$ = 2.96; P = 0.22).

Discussion

The species richness found at ESEC-Seridó was relatively low, when compared to other caatinga sites in Northeast Brazil (Mélo & Bandeira 2004, Vasconcellos *et al* 2010). Including the present study, 30 species of termites have been recorded in the literature for the Caatinga (Martius *et al* 1999, Mélo & Bandeira 2004, Vasconcellos *et al* 2010). Specifically for these studies, species richness may be higher, since the samples collected by Kalotermitidae and Apicotermitinae were at morphospecies level and were not compared among the sites. In addition, these studies were conducted only in the ecoregions of the "Depressão Sertaneja Setentrional" (Martius *et al* 1999, Mélo & Bandeira 2004) and on the edge of the Borborema Plateau (Vasconcellos *et al* 2010) even though there are six other ecoregions with different climatic, geomorphological and vegetation characteristics in the Caatinga (Velloso *et al* 2002).

The assemblages of ESEC-Seridó, composed of few species and trophic groups and low relative species abundance, were considered structurally simple.

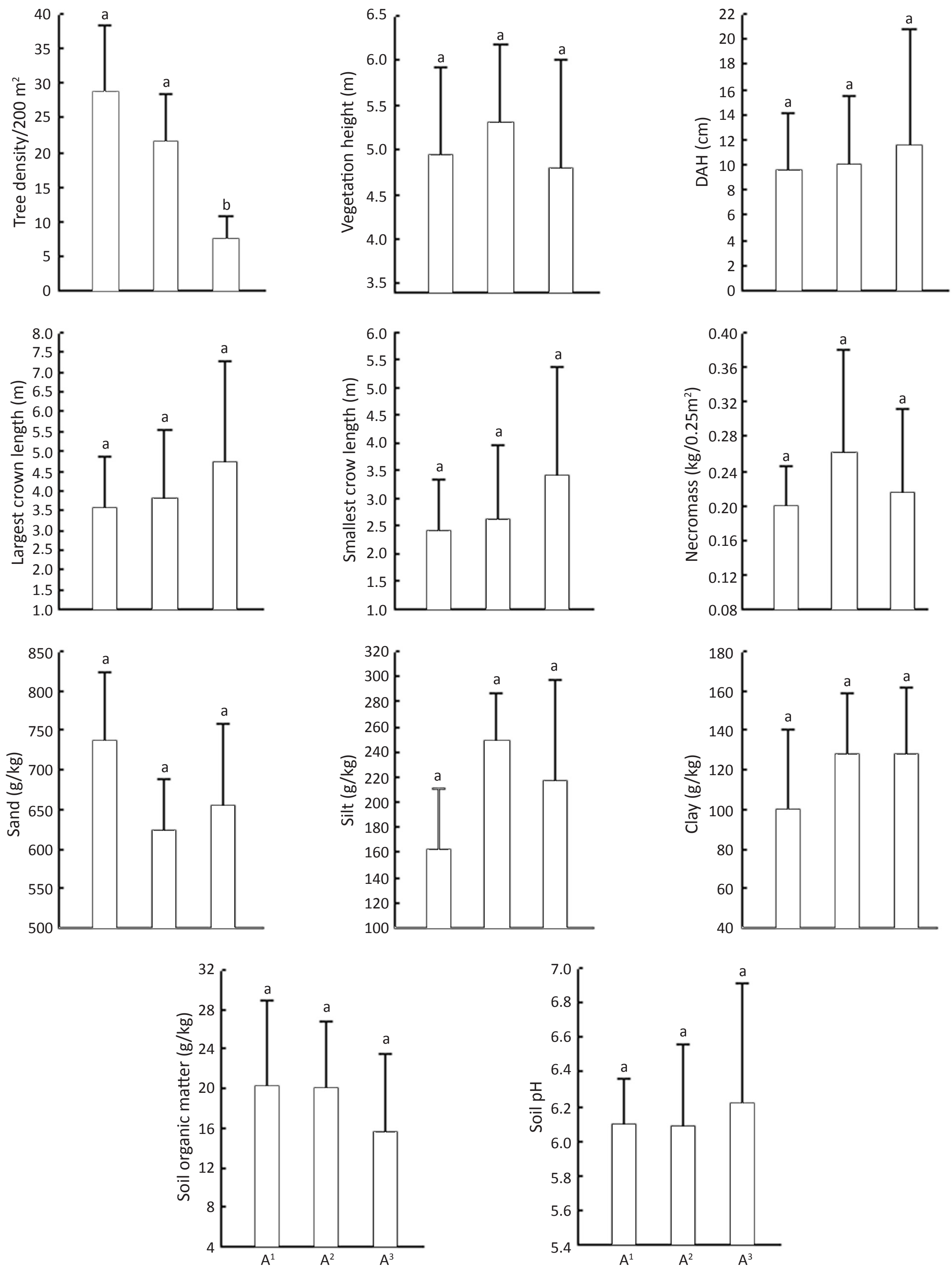

Fig 2 Means and standard deviation of eleven environmental variables recorded in three caatinga sites, Rio Grande do Norte, Brazil. Different letters indicate statistical difference between the means of the variables.

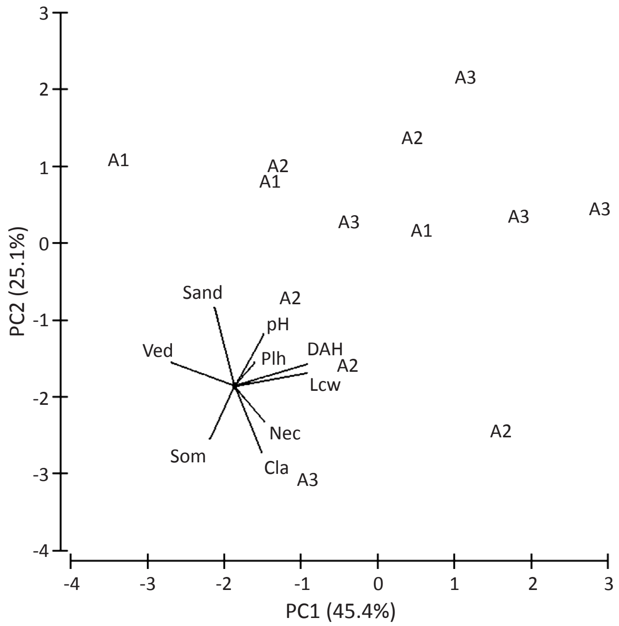

Fig 3 Principal component analysis (PCA) of environmental variables in three caatinga sites (A_1, A_2 and A_3), Rio Grande do Norte, Brazil. Environmental variables: Ved, vegetation density; SOM, soil organic matter; Cl, clay; Nec, necromass; Lcw, largest crown width, DAH, diameter at ankle height; Plh, plant height; pH and sand.

Moreover, most species, except A. *nordestinus*, are widely distributed geographically, occurring in at least two distinct biomes. The low species richness of termites at ESEC-Seridó may be related to the low mean annual rainfall, usually concentrated into three months (Ministério da Agricultura 1978), and low concentration of organic matter in the soil, owing to the low productivity of this ecosystem and the anthropic disturbances that have been imposed on this region for decades (Vasconcellos *et al* 2010).

The greater relative abundance of *H. sulcatus* in the three sites examined suggests that the species is one of the most important in wood cycling at ESEC-Seridó and the most resistant to anthropic disturbance. Its colonies can resist high soil temperatures (mean = 34°C) and consume around 98.8 kg of dry wood/ha/year. It exhibits a preference for exotic wood species, such as the mesquite tree (*Prosopis juliflora*) (Mélo & Bandeira 2007). These attributes may explain the dominance of this species in all the parcels, mainly in A_3.

At ESEC-Seridó in the late 1990s, Martius *et al* (1999) recorded the presence of a species of *Constrictotermes,* later identified as *Constrictotermes cyphergaster* (Silvestri), and *Inquilinitermes* spp., with a density of two active nests of *C. cyphergaster*/ha. Species of *Inquilinitermes* are obligatory inquilines of nests built by the species *Constrictotermes* (Mathews 1977). In the present study, none of these termite colonies were found, suggesting a significant decrease in the abundance of these species at ESEC-Seridó.

The causes of the drastic local reduction or extinction of these termite populations are unknown. However, the absence of *C. cyphergaster* nests negatively affects many other populations of animals, since their active and abandoned nests serve as sites of refuge, predation and nest building for several invertebrates and even vertebrates such as a number of psittaciform birds that build their nests in the abandoned structure (Mathews 1977, Cunha & Brandão 2000, Barreto & Castro 2007). The reduced populations of *C. cyphergaster* at ESEC-Seridó could also affect nutrient cycling and energy flow in the site. Moura *et al* (2008) estimated consumption of 44.5 ± 14.70 kg of wood/ha/year only for populations of *C. cyphergaster* in a site of caatinga located in the state of Paraíba, Northeast Brazil. In this same site, a density of 59.0 ± 22.5 active nests/ha was estimated only for *C. cyphergaster* (Vasconcellos *et al* 2007).

At ESEC-Seridó, Martius *et al* (1999) estimated a density of one nest/ha for *Nasutitermes* and *Microcerotermes*. A similar result was obtained in site A_1, where one active nest per hectare was recorded for the species *N. corniger* and *M. strunckii*. Vasconcellos *et al* (2010), in turn, found a density that was sixteen times higher than the value obtained for the three sites analyzed at ESEC-Seridó, equivalent to 11 nests/ha, in a caatinga site submitted to selective timber cutting (± 30 years ago) located at Almas Farm, a Reserva Privada do Patrimônio Natural (RPPN) in the state of Paraíba.

The composition of feeding groups was not different between the sites. It is known that the anthropic disturbance of habitats can decrease nest-building sites and resource availability for a number of termite populations (Bandeira & Vasconcellos 2002, Junqueira *et al* 2008). In humid tropical forests there is a tendency for soil-feeding species to be more affected by habitat disturbance (Souza & Brown 1994, Bandeira *et al* 2003, Jones *et al* 2003, Vasconcellos *et al* 2008). On the other hand, wood-feeding termites were the most affected by habitat disturbance in a caatinga site located in the state of Paraíba (Vasconcellos *et al* 2010).

Even though disturbance time was different, no statistical support was found to substantiate the idea that the sites are different in relation to the environmental variables measured and disturbance levels. The same pattern was observed for termite assemblages, in that no significant difference was observed in species richness, relative abundance, and composition of feeding and taxonomic groups between the three sites. Vasconcellos *et al* (2010) found a significant difference between caatinga sites with different levels of habitat disturbance caused by extensive vegetation cutting and cattle/goat trampling. These disturbances resulted in the presence of structurally different termite assemblages in the sites, in accordance with the difference in environmental variables measured in each site.

In the present study, the habitats were quite similar, showing no significant differences between their structural attributes or termite assemblage composition. The similarity of these results reinforces the potential of termites as biological indicators of habitat quality in the Caatinga.

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