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Soil-sampled termites in Two Contrasting Ecosystems within the Semiarid Domain in Northeastern Brazil: Abundance, Biomass, and Seasonal Influences

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Abstract
Termites are important in tropical terrestrial ecosystems due to their role in fragmenting organic material and thus in energy and nutrient flows. The present study compared soil-sampled termites in two contrasting ecosystems in the Brazilian semiarid domain: humid highland forests (“Brejo de Altitude”) and seasonally dry tropical forests (“Caatinga”). Thirty soil core samples (12 L each), divided into three soil levels (A: 0-10; B:10-20; C: 20-30 cm), were analyzed in each area, 15 during the rainy season and 15 during the dry season. Twenty-two termite species were encountered in the soil core samples, belonging to the Termitidae (20 species) and Rhinotermitidae (2 species). The abundance and biomass of termites in the humid highland forests were significantly greater during the rainy season (6080 individuals.m^{-2} and 18.53 g.m^{-2} fresh weight) than in the dry season (2215 individuals.m^{-2} and 5.45 g.m^{-2} fresh weight). The greatest abundance and biomass was encountered at the 0 and 20 cm depths. Abundance and biomass did not differ significantly among the different seasons in the seasonally dry tropical forests (rainy season: 862 individuals.m^{-2} and 1.4 g m^{-2} fresh weight; dry season: 250 individuals.m^{-2} and 0.45 g m^{-2} fresh weight) nor among the different soil levels. The observed increase in termite numbers and biomass during the rainy season in the humid highland forest indicates that their decomposition activities are asymmetrical during the year. The quantitative similarity of termite numbers and fresh weights during the year in the seasonally dry tropical forest area suggests that other factors beyond climatic differences influence the abundance and biomass of these termites, at least at a local scale.

Introduction

Termites are among the most abundant arthropods in tropical ecosystems, and their densities can exceed 8000 individuals.m^{-2} (Martius, 1994; Bignell & Eggleton, 2000). Termites have very important functions in most terrestrial ecosystems due to their roles in decomposition processes and in energy and nutrient fluxes (Matsumoto, 1976; Bignell & Eggleton, 2000; Bandeira & Vasconcellos, 2002). These organisms also influence the soil by redistributing material both horizontally and vertically and by increasing soil porosity (Lee & Wood, 1971; Wood & Sands, 1978; Jones *et al.*, 1994). It is estimated that up to 50% of the decomposition of plant organic detritus in tropical forests can be attributed to termites (Bignell & Eggleton, 2000). More water is retained in the soil in arid and semiarid ecosystems due to the activities of termites, which is believed to be directly reflected in vegetation structures and local primary productivity (Holt & Conventry, 1990; Whitford, 1991).

Though few, quantitative studies at different times of the year in the same ecosystem have revealed seasonal variations in abundance and assemblage composition that may impact the temporal contributions of termites to processes such as organic decomposition (Matsumoto, 1976; Matsumoto & Abe, 1979; Collins, 1989; Dibog *et al.*, 1998; Martius, 1998; Vasconcellos, 2010).

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Seasonally dry tropical forests are characteristic of tropical environments with marked water restrictions during the dry season (Dirzo *et al.*, 2011). These dry forests occur widely in the semiarid region of northeastern Brazil, which itself covers an area of approximately 735,000 km^2 extending from 2° 54' W to 17° 21' S (Andrade-Lima, 1981; Prado, 2003). This region is characterized by high temperatures and high evapotranspiration potentials that compound the effects of the low and irregular rainfall rates – resulting in low water availability in the soil for 7 to 11 months (Andrade-Lima, 1981). However, the regional landscape is actually a mosaic of different phytophysiognomies such as seasonally dry tropical arboreal, shrub, and spiny forests that are adapted to these very dry conditions (Coimbra-Filho & Câmara, 1996).

Additionally, there are "islands" of highland humid forest within the semiarid region of northeastern Brazil that are associated with landscapes that rise above 600 m, locally known as "Brejos de Altitude" (Andrade-Lima, 1982; Tabarelli & Santos, 2004). These highlands and plateaus offer more amenable environmental conditions, with greater soil and atmospheric humidity and denser vegetation cover (Andrade-Lima, 1966; Tabarelli & Santos, 2004; Rodal & Sales, 2008). As such, these unique landscapes function as biodiversity refuges, especially in the dry season, for organisms having a certain degree of mobility (Andrade-Lima, 1981).

The present study sought to quantify the abundance, biomass, and vertical stratification of soil termites in two areas within the Brazilian semiarid domain – one with seasonally dry tropical forest vegetation (Caatinga), and the other with highland humid forest vegetation (Brejos de Altitude) – to determine the influences of the dry and rainy seasons on these arthropods.

Materials and Methods

The study sites were located in the Fazenda Almas Private Nature Reserve (seasonally dry tropical forest) and in the Mata do Pau Ferro State Ecological Reserve (highland humid forest) in Paraiba State, Brazil. The Fazenda Almas is a private protected area located in the municipality of São José dos Cordeiros (07°28' S 36°52' W) that encompasses 3,505 ha of seasonally dry tropical forest vegetation at altitudes ranging from 600 to 720 meters a.s.l. The mean annual precipitation, temperature, and humidity there are 560 mm ± 230 (*sd*), 25 ºC, and 65% respectively (Governo do Estado da Paraíba, 1985), with rainfall concentrated between February and April. The Mata do Pau Ferro ecological reserve is located in the municipality of Areia (6° 58' S, 35° 42' W) and encompasses 607 ha of ombrophilous forest communities at altitudes between 400 and 600 m a.s.l. (Oliveira *et al.*, 2006). It is situated within a micro-region of montane forests with mean annual rainfall, temperatures, and humidity of 1400 mm, 22 °C, and 85% respectively (Embrapa, 1972).

Termites were collected in the Mata do Pau Ferro site during December 1998 and January 1999 during the dry season, and in June and July 1999 during the rainy season. Collections at the Fazenda Almas site were undertaken in May 2007 and November 2008 during the rainy and dry seasons respectively. The difference of the sampling period between the areas was about 8 years. However, for over 30 years, the areas have been free of human disturbance. Fifteen collection points were established at minimum distances of 10 m from each other, spaced along a transect, and termites were collected using the methodology proposed by the Tropical Soil Biology and Fertility Program (TSBF) (Anderson & Ingram, 1989), as modified by Silva and Bandeira (1999). Blocks of soil (20 cm x 20 cm x 30 cm: 12 liters) were extracted at each collection point and divided into three strata: A (0-10 cm), B (10-20 cm), and C (20-30 cm), resulting in 45 samples each season (90 for each forest type). The three different soil strata were separated and broken up in plastic trays, and the termites encountered were manually collected and preserved in 75% alcohol. The specimens were removed to the laboratory to be counted and weighed (fresh weight in $g.m^{-2}$). The specimens were subsequently deposited in the permanent collection of the Termite Laboratory at the Federal University of Paraiba.

The abundance and biomass data were log (x+1) transformed to guarantee the normality and homogeneity of variance. The t-test was performed to compare abundance and biomass of the dry tropical forest and humid highland forest sites. Analysis of variance (Factorial ANOVA), with the *a posteriori* Tukey test, was performed to determine any significant differences between the seasons and between the different strata within each study area. The statistical tests were performed using STATISTIC 5.0 software (Statsoft, 1995).

Results

Twenty-two termite species were encountered overall, belonging to 13 genera comprising 20 species of the family Termitidae and distributed among the subfamilies Apicotermitinae (7 species), Nasutitermitinae (6), Syntermitinae (3), and Termitinae (3), and two species of the family Rhinotermitidae. Only *Diversitermes diversimilis* (Silvestri) and *Amitermes amifer* Silvestri were encountered in both forest types (Table 1). Abundance (t test = - 6,7; df = 178; $P < 0.001$) and biomass (t test = - 5,7; df = 178; $P < 0.001$) were significantly higher in the humid highland forest.

The Fazenda Almas site (seasonally dry tropical forest) yielded 10 termite species distributed among seven genera, of which eight species were encountered during the rainy season and seven during the dry season. The species *Anoplotermes* sp. 3*, Grigiotermes* sp. 2, *Ruptitermes silvestrii* (Emerson), and one unidentified species (of the family Termitidae), were only encountered in the soil during the rainy season. *Constrictotermes cyphergaster* (Silvestri) and *Heterotermes sulcatus* Mathews, on the other hand, were only encountered during the dry season. *Amitermes amifer* was predominant during both seasons in terms of both its abundance and biomass

(Table 1). During the rainy season, the mean abundance and biomass of the termites was 862 ± 532 individuals.m^{-2} and 1.40 ± 1.02 g.m^{-2} (fresh weight), respectively, while during the dry season these values were 250 ± 195 individuals.m^{-2} and 0.45 ± 0.38 g.m^{-2} (fresh weight) respectively. Nonetheless, termite abundance and biomass did not differ significantly between the two seasons in this vegetation type ($F_{1.84}$=1.91; P=0.17 and $F_{1.84}$=0.93; P=0.33 respectively), nor between the different soil levels ($F_{2.84}$=1.06; P=0.35 and $F_{2.84}$=0.65; P=0.52 respectively). The same results were encountered when considering the interactive effects of the seasons and the soil strata on the termite fauna ($F_{2.84}$=0.87; P=0.41 and $F_{2.84}$=0.07; P=0.92 respectively) (Fig 1).

The Mata do Pau Ferro site (humid highland forests) yielded 14 termite species distributed among 11 genera, of which nine were encountered during the rainy season and 12 in the dry season. *Nasutitermes jaraguae* (Holmgren) and *Neocapritermes* sp. were encountered only during the rainy season, while five species were only observed during the dry season (*Diversitermes diversimiles*, *Embiratermes neotenicus* (Holmgren), *Ibitermes inflatus* Vasconcellos, *Subulitermes microsoma* (Silvestri), and *Amitermes amifer)*. The termite species *Grigiotermes* sp. 1 and *Embiratermes parvirostris* Constantino were predominant during both seasons, in terms of both their abundance and biomass (Table 1). A total of 6080 ± 1477 individuals.m^{-2} and 18.53 ± 6.18 g.m^{-2} (fresh

Table 1 - Abundances (individuals.m-²) and biomasses (g fresh weight.m-²) of termites in two forest types within the Brazilian semiarid domain: humid highland forest ("Brejo de Altitude" - Mata do Pau Ferro) and seasonally dry tropical forest ("Caatinga" - Fazenda Almas).

Taxa	Mata do Pau Ferro					Fazenda Almas					Feeding groups
	Abundance		Biomass		Layer	Abundance		Biomass		Layer	
	Rainy	Dry	Rainy	Dry		Rainy	Dry	Rainy	Dry		
TERMITIDAE											
Apicotermitinae											
Anoplotermes sp 1	234	189	0.44	0.36	A,B,C						S
Anoplotermes sp.2	331	243	0.62	0.46	A,B,C						S
Anoplotermes sp.3						6		0.01		B	S
Grigiotermes sp. 1	1044	250	4.18	1.00	A,B,C						S
Grigiotermes sp. 2						5		0.01		A	S
Ruptitermes reconditus (Silvestri)	332	38	1.23	0.14	B,C						L
Ruptitermes silvestrii (Emerson)						5		0.02		A	L
Nasutitermitinae											
Constrictotermes cyphergaster (Silvestri)							9		0.02	A,B	W
Diversitermes diversimiles (Silvestri)		50		0.10	A	4	4	0.00	0.00	A,C	W/L
Nasutitermes callimorphus Mathews	226	23	0.58	0.06	A						W
Nasutitermes jaraguae (Snyder)	105		0.30		A,B						W
Subulitermes microsoma (Silvestri)		28	0.04		A						S
Velocitermes sp.	306	2	0.38	0.00	A						L
Syntermitinae											
Embiratermes neotenicus (Holmgren)		10		0.04	A,B						W/S
Embiratermes parvirostris Constantino	989	242	1.56	0.38	A,B,C						S
Ibitermes inflatus Vasconcellos		224	1.36		A,B						S
Termitinae											
Amitermes amifer Silvestri		30	0.09		A,B	314	118	0.61	0.23	A,B,C	W/S
Amitermes nordestinus Melo and Fontes						23	2	0.02	0.00	B,C	W/S
Neocapritermes sp.	81		0.34		A,B						S
Termitidae sp.						7		0.01		A	
RHINOTERMITIDAE											
Heterotermes longiceps (Snyder)						68	2	0.07	0.00	A,B	W
Heterotermes sulcatus Mathews							15		0.02	C	W
Total	3648	1329	11.12	2.54		432	150	0.75	0.27		

Feeding groups: W= wood-feeders; S= soil-feeders; L= leaf-feeders; W/S= wood-soil interface feeders; W/L= wood-leaf interface feeder weight) were encountered during the rainy season, while 2215 ± 1099 individuals.m^{-2} and 5.45 ± 3.04 g.m^{-2} (fresh weight) were found during the dry season. Termite abundance and biomass were both significantly greater during the rainy season ($F_{1,84}$=7.21; P<0.01 and $F_{1.84}$= 8.35; P<0.01 respectively), and vertical stratification was also identified ($F_{2.84}$= 7.04; P<0.01 and $F_{2.84}$= 3.13; P<0.05 respectively) (Fig 1). However, when considering the interactive effects of the season and the soil strata on the termite fauna, it was observed that their abundances and biomasses did not vary significantly ($F_{2.84}$=0.73; P=0.41 and $F_{2.84}$=0.07; P=0.92 respectively).

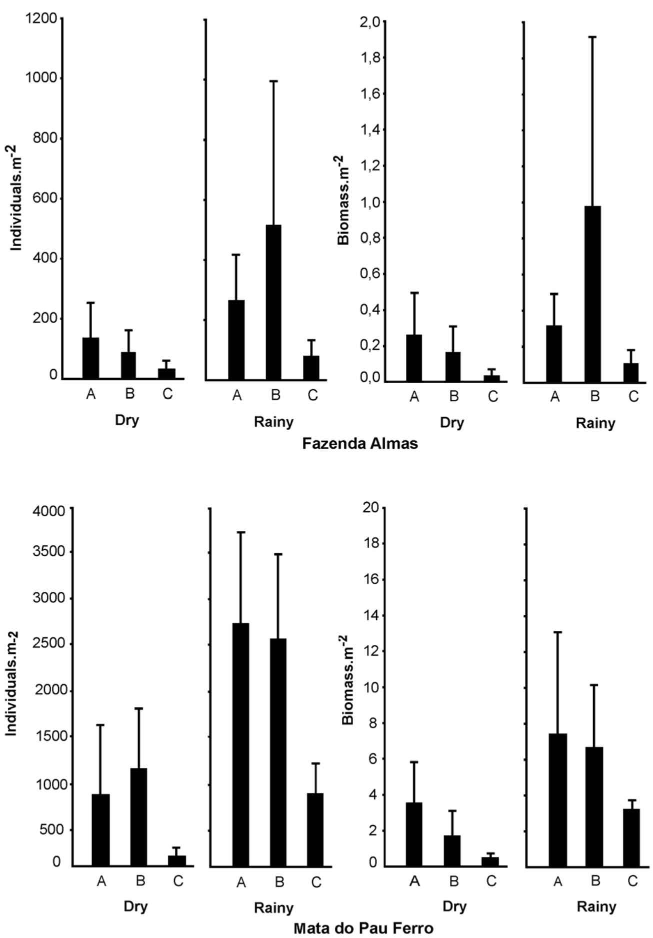

Fig 1. Biomasses (biomass density, g.m^{-2}) and abundances (numerical density, individuals.m^{-2}) of termites in different soil strata (A: 0-10 cm; B: 10-20 cm; C: 20-30 cm), in two forest types in the semiarid domain of northeastern Brazil: seasonally dry tropical forest ("Caatinga" - Fazenda Almas) and thumid highland forest ("Brejo de Altitude" - Mata do Pau Ferro).

Discussion

Although they are both located within the Brazilian semiarid domain, the dry tropical forest and humid highland forest sites demonstrate distinct climatic characteristics and consequently very little similarity between their termite species (two species), abundances, and biomasses. Arthropods occupying the leaf litter/soil complex are generally influenced by the climatic characteristics of the host ecosystems (Adis *et al.,* 1989; Harada & Bandeira, 1994; Dibog *et al*., 1998; Pinheiro *et al.,* 2002; Doblas-Miranda *et al.,* 2007). The assemblage structure and foraging of termites in the Neotropical region have been observed to be associated with climatic elements, especially temperature and rainfall regime, both in humid forests (Torres & Bandeira, 1985; Cancello *et al.,* 2014) and in semiarid ecosystems (Moura *et al.*, 2006; Araújo *et al.,* 2010), yet the humid forest sites show higher rates of biomass and abundance of termites.

Termite abundance in the soil at the dry tropical forests site was 862 individuals.m^{-2} during the rainy season and 250 individuals.m^{-2} during the dry season, while their biomass was 1.40 g.m^{-2} and 0.45 g.m^{-2} respectively. These values were larger than those reported by Melo and Bandeira (2004) for a number of microhabitats (soil, leaf litter, nests and wood) in another area of seasonally dry tropical forest experiencing anthropogenic pressure. In a study undertaken at the dry tropical forests site that considered only nest populations, Vasconcellos *et al.* (2007) recorded abundance and biomass values of 278.2 individuals.m^{-2} and 0.9 g.m^{-2}, respectively, for *C. cyphergaster*. By combining these values, the abundances and biomasses of termites in this seasonally dry tropical forest area appeared to oscillate between 428 and 610 individuals.m^{-2} and between 1.17 and 1.65 g.m^{-2} respectively. It is important to note that these values do not include other termite species that construct conspicuous nests in the area, or those that forage within tree trunks.

The abundance and biomass of termites found only in the soil in the humid highland forest site were larger than those previously recorded in other ecosystems in the Neotropical region (Martius, 1994; Bandeira & Vasconcellos, 2002; Vasconcellos, 2010). Other quantitative methods, including mounds and arboreal nests, would be likely to increase abundance and biomass data. Specifically in terms of the soil, the largest values recorded to the present time were 4331.54 individuals.m^{-2} and 7.65 g.m^{-2} fresh weights in an Atlantic Forest fragment in northeastern Brazil (Vasconcellos, 2010). Even including estimated values for other microhabitats (such as nests and decomposing wood), termite populations in humid highland forest were still the highest so far reported for the Neotropical region (Bandeira & Torres, 1985; Martius, 1994; Bandeira & Harada, 1998; Silva & Bandeira, 1999; Bignell & Eggleton, 2000).

The abundances and biomasses of termites at the dry tropical forests site did not demonstrate significant variations between the dry and rainy seasons. Other studies undertaken in seasonally dry tropical forests in the region, however, demonstrate an effect on vertical distribution, foraging and abundance of insects in general (Moura *et al*., 2006; Araújo *et al*., 2010; Vasconcellos *et al*., 2010a), including termites (Melo & Bandeira, 2004; Vasconcellos *et al*., 2010b). Apparently, other characteristics, such as food availability, soil moisture, and interspecific interactions, could minimize climatic effects on soil fauna in seasonally dry tropical forest ecosystems. The humid highland forest site, on the other hand, demonstrated significant variations in its termite population parameters between the dry and rainy seasons. Although there have been very few publications focusing on seasonal variations of the termite fauna in humid tropical forests, Eggleton and Bignell (1995) suggested that abundance and biomass values in these ecosystems were greater in the rainy season. Bandeira and Harada (1998), however, reported higher values for these same parameters among soil termites during the dry season in the Amazon forest.

In relation to the depth of the soil samples, it was observed that the greatest abundances and biomasses were encountered in the top 20 cm profiles, independent of the forest type (Walwork, 1970). According to Peterson and Luxton (1982), most of the edaphic biota is concentrated between 0 and 10 cm below the soil surface. This tendency does vary considerably, however, in different localities and when different taxa are considered (Walwork, 1970; Adis *et al.*, 1989; Dindal, 1990; Harada & Bandeira, 1994). A number of studies in the Neotropical region have found that a 20 cm soil depth is the most adequate for collecting termites, especially in terms of species richness (Vasconcellos, 2010; Bandeira & Vasconcellos, 2002; Silva & Bandeira, 1999).

The observed increase in termite numbers and biomass during the rainy season in the humid highland forest indicates that their decomposition activities are asymmetrical during the year. The quantitative similarity of termite numbers and biomass during the year in the seasonally dry tropical forest area suggests that other factors, beyond climatic differences, influence the abundance and biomass of these termites, at least at a local scale. The quantitative differences observed between the two forest types reflect the effects of different environmental variables on ecosystems, in spite of the fact that they are both embedded in the semiarid Brazilian domain.

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