Diversity of the ground-dwelling ant fauna (Hymenoptera: Formicidae) of a moist, montane forest of the semi-arid Brazilian "Nordeste"

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Abstract: Although the so called "green islands" of the semi-arid Brazilian "Nordeste" are economically, socially, and ecologically important, relatively little is known about their biodiversity. We present the results of the first survey of the ground-dwelling ant fauna of a secondary forest in the Serra de Baturité (4°05'-4°40' S / 38°30'-39°10' W), among the biggest of the moist, montane forests of the state of Ceará, Brazil. From February to March 2001, samples were taken every 50 m along twelve 200 m transects, each separated from the others by at least 50 m and cut on either side of a recreational trail. Where possible, two transects were cut from the same starting point on the trail, one on either side. At each sample site two methods were used, as recommended in the ALL protocol: a pitfall trap and the treatment of 1 m² of leaf litter with the Winkler extractor. The myrmeco-fauna of the Serra de Baturité is quite diverse: individuals from 72 species, 23 genera, and six subfamilies were collected. The observed patterns of specific richness show the same tendencies noted in other tropical regions, particularly the frequency of capture distribution with many rare and few abundant species. Differences with the Atlantic and Amazonian forests were also observed, especially the relative importance of the Ponerinae and Formicinae subfamilies, indicating a possible influence of the surrounding "caatinga" (savanna-like ecosystem) on the myrmecofauna of the moist, montane forest. Rev. Biol. Trop. 53(1-2): 165-173. Epub 2005 Jun 24.

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The use of indicator taxa, i.e. taxa that are theoretically representative of other taxa at a given site, has become important in studies of biodiversity in light of the need for rapid, reliable and cost-effective assessments that can be used in conservation and monitoring programs (Oliver and Beattie 1993, Kerr *et al.* 2000). Determining the level of diversity of these groups should permit predictions about the other taxa present to be made (Pearson and Carroll 1998, Lawton *et al.* 1998, Lindenmayer 1999, Kerr *et al.* 2000). Traditionally, the majority of studies used vascular plants and vertebrates as indicator taxa (Alonso 2000). Recently however, the importance and appropriateness of using invertebrate groups has been recognized (Pearson 1994, Oliver and Beattie 1996a, b).

Ants in particular are an excellent choice for use as an indicator taxon (Longino and Colwell 1997, Alonso and Agosti 2000) due to their high local diversity, numerical and biomass dominance in almost every terrestrial habitat, important functions in ecosystems, organization in communities that are sensible to variations in the environment, relatively good base of taxonomic knowledge, and ease of sampling (Carroll and Janzen 1973, Hölldobler and Wilson 1990, Bestelmeyer *et al.* 2000, Brown 2000, Schultz and McGlynn 2000). Ground-dwelling ants are a particularly promising group as they represent a large portion of

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165

the myrmecofauna and a standardized protocol for their sampling (the ALL protocol "Ants of the Leaf Litter") has been elaborated (Osborn *et al.* 1999, Agosti and Alonso 2000, Delabie *et al.* 2000a).

The ALL protocol was largely based on research carried out in Brazil. However, these studies mainly took place in the Amazonian basin and the littoral Atlantic Forest. The biodiversity of other areas in Brazil, especially that of ants and other invertebrates, is poorly known. The moist, montane forests of the Brazilian "Nordeste", and in particular those found in the state of Ceará, are a typical example of this situation. These forests are found in the most elevated parts of the state's mountains, in areas exposed to moisture-laden oceanic winds (Fernandes 1998). They are isolated from each other by the semi-arid "caatinga" that covers the rest of the state, making them veritable "green islands" in the semi-arid context. Despite their small size (102 411 ha, i.e. 0.69% of the total surface area of the state of Ceará), these forests are extremely important economically, socially, and ecologically (Anonymous 1994, Figueiredo 1998). According to data collected by the "Sociedade Nordestina de Ecologia", the state of Ceará contains the largest area of remnants of the Atlantic Forest in the Brazilian "Nordeste" except Bahia. Unfortunately, these remnants are extremely threatened and few active measures aimed at their protection exist, despite the fact that several of these remnants were identified as priority areas for conservation, in light of their biological importance and increasing anthropological pressures, by a workshop of the "Projeto de Conservação e Utilização Sustentável de Diversidade Biológica Brasileira (PROBIO)".

The moist, montane forests of Ceará are also valuable in a historical/evolutionary context since certain authors consider these forests to be isolated fragments of the Atlantic Forest (Figueiredo and Barbosa 1990, Figueiredo *et al.* 1995, Coimbra-Filho and Câmara 1996, Fernandes 1998). According to this hypothesis, these forests are remnants from one or various expansions of the Atlantic Forest, and perhaps even the Amazonian Forest, during one or more of the humid interglacial periods of the Quaternary. Support for this hypothesis stems mainly from comparative studies of the flora and of certain reptile and amphibian groups (Figueiredo and Barbosa 1990, Borges 1991, Hoogmoed *et al.* 1994, Figueiredo *et al.* 1995). However, the ensemble of data collected is still fragmentary and mainly limited to the Serra de Baturité. The biodiversity of the other moist, montane forests of Ceará remains poorly known. Furthermore, no studies have been carried out upon the invertebrate fauna of these mountains.

The purpose of the present study was to obtain a first description of the ground-dwelling myrmecofauna of the Serra de Baturité and to test the adequacy of a variation of the ALL protocol in the moist, montane forests of Ceará.

MATERIAL AND METHODS

Research was carried out from February to March 2001 in the Serra de Baturité (4°05'-4°40' S; 38°30'-39°10' W), a small mountain range located about 70 km from the Ceará coast (Brazil). The mountains have an average altitude of about 800 m and reach their highest elevation at 1114 m. Where higher than 600 to 700 m above sea level, the mountains are covered with a tropical moist, montane forest (with a total area of about 326 km^2) and protected by an APA (Área de Proteção Ambiental) (Fernandes 1998, Anonymous 1994), where human activities are theoretically strictly controlled.

The field site was located in a secondary forest located within the APA, in the municipality of Pacoti (4°15' S; 38°55' W), at an altitude of approximatively 850 m. The vegetation in the area was very dense: saplings and vines abounded and grew close together. The canopy was continuous except when interrupted by fields, paths, or power lines. Samples were taken only in areas where the canopy cover was complete. The canopy height varied but was generally relatively low. There were generally three strata easily distinguished: the

166

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canopy, a layer of small trees and bushes, and the undergrowth. The cover of the two lower strata varied considerably more than that of the canopy, as did the composition of the plant species found in them. The cover of litter was relatively continuous, becoming patchy only when the slope was extremely steep.

A variation of the ALL protocol commonly used in studies in the Atlantic Forest (Campiolo and Delabie 2000, Tavares 2002) was chosen for sampling in order to permit comparisons of the results obtained. Samples were taken every 50 m (the ALL protocol recommends a separation of 10 m between samples) along twelve 200 m transects, each separated from the others by at least 50 m and cut on either side of a recreational trail. Where possible, two transects were cut from the same starting point on the trail, one on either side. At each sample site two methods were used, as recommended in the ALL protocol: a pitfall trap and the treatment of 1 m² of leaf litter with the Winkler extractor, a system by which ants are forced down a bag connected to an alcohol-filled recipient after migrating out of a mesh bag containing the leaf-litter collected (Agosti and Alonso 2000). Both the pitfall traps and the Winkler extractors were operational for 48 hours. Ants were stored in a 70% alcohol solution.

Samples were sorted to separate ants from non-ants and then divided into morphospecies while in alcohol using a stereoscopic microscope. Examples of each morphospecies were then mounted and identified to the genus level using keys provided by Bolton (1994) and Hölldober and Wilson (1990). Mounted specimens of each morphospecies were sent to the Laboratório de Mirmecologia of the CEPEC-CEPLAC (Centro de Pesquisa do Cacau, Itabuna - Bahia-Brazil) for confirmation of the genus identification and, when possible, for identification to the species level.

Only records of worker ants were used in data analysis. To assess the completeness of the survey, a species accumulation curve was plotted using the means of 500 randomizations of sample accumulation order, provided by the program EstimateS 6.0b1 (Longino and Colwell 1997). For the analysis, each leaf litter sample was paired with the adjacent pitfall sample, collectively termed a sample point. EstimateS 6.0b1 was also used to plot first-order jackknife and Chao 2 estimates of the total number of species present at the research site for each succeeding sample point. The percentage of the fauna sampled was determined by dividing the observed number of species by the estimated number of species.

The voucher specimens were deposited in the reference collection of the Laboratório de Entomologia, CCS/UECE.

RESULTS

Taxonomic structure of the fauna: A total of 72 species, 23 genera, and six subfamillies of ants were collected (Table 1). The Myrmicinae

TABLE 1

Total number and percentage of species, genera and individuals collected per subfamily
(pitfall trap and Winkler extractor)

Subfamily	Genera		Species		Individuals	
	No.	%	No.	%	No.	%
Myrmicinae	14	60,9	42	58.3	11045	84.9
Formicinae	3	13	14	19.4	1229	9.4
Ponerinae	3	13	13	18.1	716	5.5
Dolichoderinae	1	4.3	1	1.4	20	0.15
Ecitoninae	1	4.3	1	1.4	2	0.02
Pseudomyrmicinae	1	4.3	1	1.4	2	0.02
TOTAL	23	100	72	100	13014	100

were the most common, with 14 genera and 42 species, followed by the Formicinae (3 genera and 14 species), the Ponerinae (3 genera and 13 species), and by the Dolichoderinae, the Ecitoninae, and the Pseudomyrmicinae (1 genus, 1 species). 87% of the genera, 96% of the species, and 99.8% of the individuals collected belonged to one of three subfamilies (Myrmicinae, Ponerinae, Formicinae).

The five most species-rich genera were *Pheidole* (16 spp.), *Camponotus* (9 spp.), *Hypoponera* (6 spp.), *Solenopsis* (5 spp.) and *Pachycondyla* (5 spp.) (Table 2). 19 species could be identified to the species level: *Acromyrmex subterraneus, Camponotus crassus, C. latangulus, C. renggeri, Cyphomyrmex peltatus, Hylomyrma balzani, Lachnomyrmex plaumanni, Leptothorax vicinus, Neivamyrmex orthonotus, Octostruma balzani, Odontomachus bauri, O. meinerti, Pachycondyla cavinodis, P. crenata, P. harpax, P. impressa, P. villosa inversa,* *Pseudomyrmex gracilis, Pyramica appretiatus.*

Patterns in species richness: The number of ant species found in each 1m² litter sample varied from eight to 14 in most samples, with an average of 11.1 (Fig. 1).

The species frequency of capture histogram (Fig. 2) demonstrates that a small number of very abundant species and a large number of rare species were captured: 45% of the species captured were only observed in one or two samples.

The accumulation curve for the species observed and the Chao 2 and jackknife estimates rise quickly initially and then gradually slow, without however, reaching a plateau (Fig. 3). Both estimators provided very similar species richness estimates for the studied area (jackknife: 92.65 sps, Chao 2: 89.57). They also indicate that the majority of the ground-dwelling ant species present at the research site were collected (80.4% and 77.7% of the number of

TABLE 2
Species richness of genera

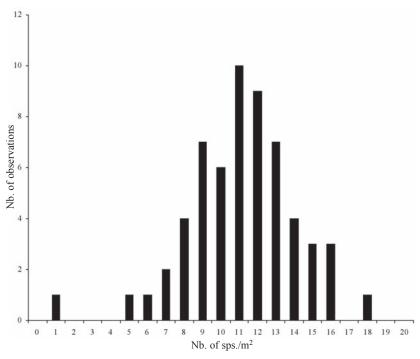| Subfamily	Genus	Species	
		No.	%
Dolichoderinae	*Linepithema*	1	1.4
Ecitoninae	*Neivamyrmex*	1	1.4
Formicinae	*Brachymyrmex*	3	4.2
	Camponotus	9	12.5
	Paratrechina	2	2.8
Myrmicinae	*Acromyrmex*	3	4.2
	Crematogaster	2	2.8
	Cyphomyrmex	2	2.8
	Hylomyrma	1	1.4
	Lachnomyrmex	1	1.4
	Leptothorax	1	1.4
	Octostruma	1	1.4
	Pheidole	16	22.2
	Pogonomyrmex	1	1.4
	Pyramica	3	4.2
	Sericomyrmex	1	1.4
	Solenopsis	5	6.9
	Strumigenys	2	2.8
	Wasmannia	3	4.2
Ponerinae	*Hypoponera*	6	8.3
	Odontomachus	2	2.8
	Pachycondyla	5	6.9
Pseudomyrmicinae	*Pseudomyrmex*	1	1.4
TOTAL		72	100

Fig. 1. Distribution of the number of ant species per 1 m² litter sample (Winkler).
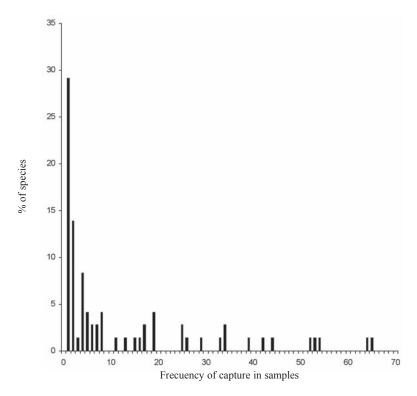

Fig. 2. Species frequency of capture histogramm. About 45% of the species were collected in only 1 or 2 samples.
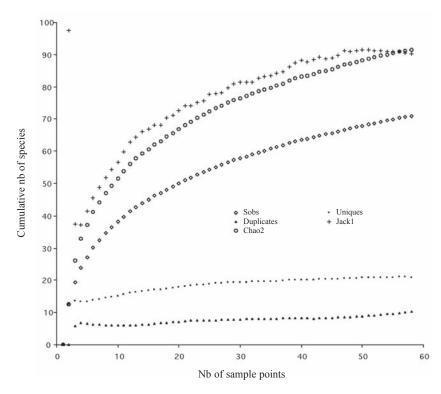
Fig. 3. Accumulation curves for observed and estimated number of species collected at 60 sample points (Winkler and pitfall). The estimations were calculated with the estimators Chao2 and the first-order jackknife (Jack1). Sobs = number of pecies observed s; Uniques = species collected in only 1 m²; Duplicates = species collected in only 2 m². All curves are plotted from the means of 500 randomizations of sample accumulation order.

species estimated with the Chao 2 and first-order jackknife estimators, respectively).

DISCUSSION

Our results indicate that the diversity of the ground-dwelling ant fauna of the moist forest of the Serra de Baturité is relatively high (72 species and 23 genera), and similar to that found in studies carried out in the Atlantic Forest with a comparable sampling effort and methodology (Campiolo and Delabie 2000, Delabie *et al.* 2000a, Tavares 2002).

Although the species accumulation curve is still increasing slowly at 60 sample points, it can be assumed that the majority (approximately 80%) of the ground-dwelling ant species in the area encompassed by the transects were

sampled. This is supported by various studies that have shown that a sample size of 50 m² allows reliable estimates to be calculated using estimators such as the first-order jackknife and Chao 2 (Delabie *et al.* 2000a, Fisher 2000).

The taxonomic structure of the myrmeco-fauna sampled resembles that of other tropical regions in two ways. First, many rare species and few abundant species were collected (Fig. 2) (Malsch 2000). Second, the subfamilies Myrmicinae, Ponerinae, and Formicinae are dominant. The Myrmicinae alone account for more than 50% of the genera, species, and individuals sampled (Ward 2000).

However, the relative importance of the Ponerinae and Formicinae subfamilies in the ants collected differs with that of ants collected in both the Atlantic Forest and the Amazonian Forest. In these two regions the

Ponerinae subfamily is significantly predominant (Majer and Delabie 1994, Delabie *et al.* 2000b, Vasconcelos and Delabie 2000, Tavares 2002), whereas the Formicinae subfamily is slightly predominant in the Serra de Baturité.

The present study represents the first effort to study the biodiversity of the ant fauna of the moist, montane forests of Ceará. The results indicate that the ground-dwelling myrmecofauna is quite diverse and comparable to other regions of Brazil that are considered to have high diversities. However, the difference observed in the relative importance of the subfamilies Ponerinae and Formicinae could indicate the existence of a distinctive feature of the moist, montane forests of the Brazilian "Nordeste" compared to other Neotropical moist forests. Should such a feature exist, it could possibly result from interactions existing between the ant fauna of the surrounding semi-arid "caatinga" and deciduous dry forests present on the lower slopes of the mountains with the myrmecofauna of the moist forests located higher up. A more complete and comparative study of the biodiversity of the ground-dwelling ant fauna of the principal moist, montane forests of the state of Ceará is presently being carried out.

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RESUMEN

Se presentan los resultados del primer inventario de la mirmecofauna del suelo en un parche de bosque montano húmedo del "Nordeste" semi-árido brasileño. Aunque estos parches o"islas verdes" son importantes económica, social, y ecológicamente, se conoce relativamente poco acerca de su biodiversidad. La investigación fue llevada a cabo en un bosque secundario en la Serra de Baturité, uno de los mayores del bosque montano húmedo del estado de Ceará, Brazil. La mirmecofauna de Serra de Baturité es muy diversa: encontramos individuos de 72 especies, 23 géneros y seis fsubfamilias. Los patrones de riqueza específica muestran las mismas tendencias de otras regiones tropicales, particularmente en la distribución de frecuencia de capturas, con muchas especies escasas y unas pocas especies abundantes. También hay diferencias con los bosques atlántico y amazónico, especialmente en cuanto a la importancia relativa de las subfamilias Ponerinae y Formicinae, lo que indica una posible influencia de la "caatinga" (ecosistema semejante a la sabana) cercana en la mirmecofauna del bosque montano húmedo.

Palabras clave: Biodiversidad, Hymenoptera, hormigas del suelo, bosque lluvioso, Nordeste, Ceará, Brasil.

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Rev. Biol. Trop. (Int. J. Trop. Biol. ISSN-0034-7744) Vol. 53 (1-2): 165-173, March-June 2005 (www.tropiweb.com)

171

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