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RESEARCH ARTICLE

Effects of habitat heterogeneity on epiedaphic Collembola (Arthropoda: Hexapoda) in a semiarid ecosystem in Northeast Brazil

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ABSTRACT. The spatial distribution of abiotic resources and environmental conditions can vary at small scales within terrestrial ecosystems, influencing the composition of soil fauna. Epiedaphic springtails (Collembola) of a semiarid Caatinga ecosystem were studied to determine if factors related to vegetation structure, such as species richness, aerial biomass, litterfall, and soil characteristics (pH, granulometry and soil organic matter), influence species richness and abundance of this group. A total of 5,513 individuals were collected of 15 species distributed in 13 genera and 9 families. The most abundant species were *Temeritas* sp., with 2,086 (38% of the total abundance) individuals, and *Neotropiella meridionalis* (Arlé, 1939), with 1,911 (35% of the total abundance) individuals. None of the variables in the regression model were significantly related to Collembola species richness, but abundance was significantly related to plant species richness, aerial biomass and soil pH. Thus, even at a small spatial scale, habitat heterogeneity influences the epiedaphic Collembola in the Caatinga ecosystem, especially their abundance.

KEY WORDS. Caatinga, diversity, soil dynamics, soil mesofauna, Neotropical Region.

INTRODUCTION

Habitat spatial heterogeneity plays a key role in species diversity, allowing populations to persist through the exploitation of a variety of resources and refuges (Cam et al. 2002, Tscharntke et al. 2002, Benton et al. 2003, Vanbergen et al. 2007). Although habitat heterogeneity is predictive of invertebrate population dynamics, more than 60% of the published articles on this topic focus on vertebrates, resulting in a scarcity of data on invertebrates, especially insects (Tews et al. 2004, Price et al. 2011).

In terrestrial ecosystems, studies on grasshoppers (Davidowitz and Rosenzweig 1998), beetles (Romero-Alcaraz and Ávila 2000), flies (Tanabe et al. 2001), and birds (Poulsen 2002) have shown that vegetation gradients influence the assemblages of these animals by affecting the physical structure of habitats and their potential for occupation. However, the relationship between species richness and habitat heterogeneity depends on the specificity of each taxonomic group and the spatial scale at which they are studied (Tews et al. 2004).

Collembola assemblages appear to be positively influenced by heterogeneity, habitat size, and resource availability (Sousa et al. 2006, Vanbergen et al. 2007, Salmon et al. 2014). These animals are among the most diverse and representative groups of soil fauna (Deharveng 1996, Cassagne et al. 2003) and play a critical role in nutrient cycling and organic matter decomposition dynamics (Hopkins 1997, Zeppelini and Bellini 2004). Despite their importance, most studies on springtails from Neotropical ecosystems employ solely a systematic or taxonomic approach (Abrantes et al. 2010, 2012, Bellini and Godeiro 2012, Bellini and Zeppelini 2008, 2011, Culik and Zeppelini 2003, Santos-Rocha et al. 2011, Zeppelini and Bellini 2004, Zeppelini and Lima 2012), yielding little information on variations in species richness and abundance of individuals in space and time (Vasconcellos et al. 2010, Ferreira et al. 2013).

Caatinga is a seasonally dry tropical forest that covers approximately 970,000 km² of a semiarid region almost entirely restricted to the Northeast Region of Brazil (Brasil 2007). It hosts a surprisingly large diversity of environments in the form of a mosaic of vegetation types, including dry forests and open formations (Tabarelli and Silva 2003). Caatinga soils are generally rich in minerals, but at the same time they are also stony, shallow, and well drained (Alves et al. 2009).

Currently, Caatinga is one of the South American phytogeographic domains most affected by anthropogenic disturbance, including desertification (Leal et al. 2003, MMA 2005), but there have been few studies on biodiversity and ecological processes of this region, especially on structure of its soil fauna. In this context, this study aims to identify which parameters of a selected set related to vegetation structure, such as species richness, aerial biomass, litterfall, and soil characteristics, such as pH, granulometry and soil organic matter, are related to and can predict the epiedaphic Collembola species richness and abundance in Caatinga, Northeast Brazil.

MATERIAL AND METHODS

Springtails were collected in Caatinga from Cauaçu Farm (05°32'15"S, 35°49'11"W), located at municipality of João Câmara, state of Rio Grande do Norte, Brazil. The study area covers 700 ha of a continuum of habitats composed of secondary forests with distinct disturbance histories and distinct levels of vegetation recovery, and has a strong decidual character, losing practically all leaves during the dry season. The climate of the region is semiarid with an average annual rainfall of 648.6 mm and a short rainy season from March to June. The average annual temperature is 24.7 °C with a minimum temperature of 21 °C and a maximum of 32 °C.

A grid of 2000 × 500 m that has been undisturbed for more than 50 years was delimited and, within this area, 30 plots (20 ×20 m) were randomly selected for sampling springtails and quantifying habitat variables. Two samplings were performed, one during the rainy season (July 2011) and another during the dry period (November 2011), using five pitfall traps in each plot, disposed in a cross-shaped design and distant 1m from each other. Traps were 20 cm high and 10 cm in diameter and each one contained 300 ml of 70% ethanol; they were left exposed for 48 hours in each plot.

All sampled specimens were counted under a stereomicroscope and posteriorly mounted on glass slides in Hoyer's medium, following the methodology described by Arlé and Mendonça (1982). Taxonomic identifications were performed under an optical microscope with specialized identification keys (Christiansen and Bellinger 1980, Zeppelini and Bellini 2004, Bellinger and Christiansen 1996–2017).

Species richness, density, and aerial biomass of the vegetation were obtained through a phytosociological study using the plots method (Mueller-Dombois and Ellenberg 1974); all living individual plants with a root collar diameter (RCD) equal to or greater than 3 cm and with a total height equal to or greater than 1m were sampled (Rodal 1992). The phytosociological evaluation was performed in a 10 × 10 m area at the centers of each plot. A general equation for Caatinga plants was used to estimate the aerial biomass of each plot (Sampaio and Silva 2005).

Litterfall was collected each month from November 2010 to October 2011 in a 1m × 1m collector net composed of a galvanized steel frame suspending a nylon mesh (1.0 mm) approximately 20 cm above the ground at the center of each plot. The nylon mesh enabled the falling litter to be collected without accumulating water (and thus avoided decomposition during the rainy season) (Costa et al. 2007). After 12 months, the litterfall dry mass was calculated for each of the 30 plots. Soil analyses to assess pH, organic matter content, and grain size were performed at the EMPARN (Empresa de Pesquisa Agropecuária do Rio Grande do Norte), using soil methods analysis described by Embrapa (1997).

To evaluate which of the studied habitat parameters best explain the species richness and abundance of epiedaphic Collembola in Caatinga, a multiple linear regression was performed between the assemblage and habitat parameters (plant species richness, plant density (ind./100 m^2), aerial biomass of the vegetation (kg) and litterfall, as well as the pH, organic matter ($g.dm^{-3}$) and sand ($g.kg^{-1}$)). Regression analyzes were also performed for the most abundant species. The parameters included in this model vary spatially and can create habitat heterogeneity on a local scale (Tscharntke et al. 2002, Vinatier et al. 2011). All analyses were performed in R (R core Team 2015).

RESULTS

A total of 5,513 springtails were collected, distributed in 15 species, 13 genera and 9 families (Table 1). Entomobryidae was the richest family with five species, three of them from *Seira* Lubbock, 1870. The most abundant species were *Temeritas* sp., with 2,086 individuals (38% of the total abundance) and *Neotropiella meridionalis* (Arlé, 1939), with 1,911 individuals (35% of the total abundance). The least abundant species was *Hemisotoma thermophila* (Axelson, 1900), with only one specimen collected.

Species richness and abundance were not correlated ($r = 0.42$) and, therefore, both were separately treated as dependent variables in the models. A correlogram between the environmental variables also showed a weak relation between them ($r < 0.5$); therefore, both were inserted in the regression model. The environmental variables included in the model did not significantly explain the epiedaphic Collembola species richness ($R^2 = 29\%$, $R^2_{adj} = 1.7\%$, P-value > 0.5), but the regression model explained approximately 59% ($R^2 = 59\%$, $R^2_{adj} = 43\%$, P-value < 0.01) of the variation in epiedaphic Collembola abundance (Table 2). From all the variables analyzed, plant richness, aerial biomass, and soil pH were significantly related to the epiedaphic Collembola abundance; aerial biomass was the only one negatively correlated (Table 2).

Based on the regressions among environmental variables and abundance of each species, only two of the sampled habitat variables significantly affected the number of individuals: *Seira* sp. 2 ($R^2 = 0.47$, $R^2_{adj} = 0.17$, P-value < 0.05) was positively correlated with litter production and *Sphaeridia* sp. ($R^2 = 0.48$, $R^2_{adj} = 0.27$, P-value < 0.05) was positively correlated with both plant density (P-value < 0.01) and litter production (P-value < 0.05).

Table 1. Epiedaphic Collembola taxa recorded from João Câmara, Rio Grande do Norte, Brazil, in July 2011 (rainy period) and November 2011 (dry period) and their respective abundances.

Taxa	Abundance
Poduromorpha	
Brachystomellidae	
Brachystomella aff. agrosa	596
Neanuridae	
Neotropiella meridionalis (Arlé, 1939)	1,911
Entomobryomorpha	
Entomobryidae	
Lepidocyrtus sp.	61
Rhynchocyrtus cf. klausi	3
Seira sp. 1	90
Seira sp. 2	336
Seira sp. 3	10
Isotomidae	
Desoria trispinata (Mac Gillivray, 1896)	20
Hemisotoma thermophila (Axelson, 1900)	1
Paronellidae	
Trogolaphysa sp.	6
Symphypleona	
Bourletiellidae	
Stenognathriopes sp.	22
Dicyrtomidae	
Calvatomina sp.	210
Sminthuridae	
Temeritas sp.	2,086
Sminthurididae	
Sminthurides sp.	11
Sphaeridia sp.	150
Total abundance	5,513
Total richness	15

Table 2. Results of multiple regressions between epiedaphic Collembola abundance (R^2: 59%, R^2_{adj}: 43%, P-value: 0.011) and richness (R^2: 29%, R^2_{adj}: 1.7%, P-value: 0.424) and environmental variables recorded in João Câmara, Rio Grande do Norte, Brazil, in 2011. SOM: soil organic matter.

	Abundance		Richness	
Environmental factors	T-value	P-value	T-value	P-value
Plant richness	3.549	0.002*	1.961	0.065
Plant density	-2.056	0.054	0.779	0.446
Aerial biomass	-3.237	0.004*	-1.260	0.223
Sand	-1.755	0.096	-0.653	0.521
SOM	-0.422	0.678	0.119	0.906
pH	3.094	0.006*	2.059	0.054
Litterfall	1.352	0.193	0.192	0.850

*Environmental variables that were significantly related to Collembola abundance.

DISCUSSION

Collembola species richness recorded in this study is in accordance with other studies performed in Caatinga, which range from 2 to 15 species (Santos-Rocha et al. 2011, Ferreira et al. 2013), and with *Seira* being dominant in terms of number of species. This genus is the most taxonomically rich in Brazil, with approximately 30 species, of which 17 have been recorded from Caatinga (Bellini and Zeppelini 2009, Santos-Rocha et al. 2011, Abrantes et al. 2010, 2012, Zeppelini et al. 2017). As suggested by Bellini and Zeppelini (2009), the Northeast Region of Brazil is possibly one of the areas with the highest *Seira* species richness in the world.

Epiedaphic Collembola abundance was explained by plant richness and aerial biomass, indicating that Caatinga plant assemblage influences habitat structure and, possibly, the availability of direct and indirect food resources for these hexapods. Although springtails are considered generalist consumers, intestinal content analysis has shown considerable amounts of plant organic matter in the digestive tracts of several Neotropical species (Castaño-Meneses et al. 2004). Therefore, the vegetation can apparently influence the Collembola fauna through changes in the habitat and the availability of food resources.

Epiedaphic Collembola assemblage only responded positively to spatial heterogeneity of the environment via plant richness, which potentially contributes to production of a more biochemically diverse litterfall that serves as a direct and/or indirect resource for different populations. A relationship between the composition of Collembola assemblages and vegetation structure and habitat quality has been previously suggested (Davidowitz and Rosenzweig 1998, Vegter et al. 1988, Romero-Alcaraz and Ávila 2000, Tanabe et al. 2001, Vanbergen et al. 2007, Nunes et al. 2008, Zeppelini et al. 2009), but our study indicated that the aerial biomass in the Caatinga was negatively related to epiedaphic Collembola abundance, suggesting that it is not favored by the high litterfall produced by a few large plant species. In other words, the environmental factors (i) plant species richness and (ii) aerial biomass were negatively related to each other in the study area. In this way, the model suggests that the epiedaphic Collembola has low species richness and abundance in sites where there is high litterfall produced by few plant species which hold abundant aerial biomass.

Variation in Collembola abundance was also explained by variation in soil pH, reflecting the expected adaptation of some species to subneutral soil pH as previously presented in the literature (Van Straalen and Verhoef 1997). Dynamics of soil pH is one of the most important edaphic biochemical factors, it differentially affects distribution and composition of Collembola soil assemblages, benefiting some taxa while eliminating more sensitive species (Pozo 1986, Cutz-Pool et al. 2003).

The small-scale spatial variations affected the epiedaphic Collembola fauna in the studied semiarid ecosystem, especially the abundance of individuals, which was influenced by changes in some vegetation parameters such as plant species richness, aerial biomass, and soil pH. In contrast, the measured variables did not explain the variation in species richness, suggesting that other unmeasured variables, such as soil moisture and temperature, plant litter height, and predation pressure may be more closely related to variation in Collembola species richness. It is possible that temperature and humidity, isolated or in synergism, represent important environmental factors that affect Collembola activity in semiarid ecosystems. This fauna can be active only during periods of lower temperature and higher humidity, such as night, early morning, and sunset. In this way, active methods (soil core samples or entomological aspiration) or passive (pitfall traps) can reveal different species richness and abundance, biasing the results.

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