

Full Length Research Paper

Diversity of Collembola (Arthropoda: Hexapoda) across different types of vegetation in Brazil

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The diversity of Collembola across three forest types was compared on the basis of species richness, abundance and species turnover. The goal of this study was to identify patterns of diversity at local scale in each forest type sample and to compare it at the regional scale. Our results showed that samples taken from the Atlantic Forest had higher α , β and γ diversity than those from Amazon Campinarana Forest and Caatinga Forest, as a result of soil humidity/moisture and environmental complexity. Samples from Amazon Campinarana Forest shared four species with those from Atlantic Forest, whereas the Caatinga Forest, the driest studied environment, showed the lowest richness, diversity and abundance. The Caatinga Forest was more dissimilar when compared with the other two, with the highest δ diversity, due to the extreme environmental conditions and specialized fauna. These results may have important impact on management and conservation efforts, and highlight the importance of the spatial scale as a parameter for defining conservation units and conservation policies.

Key words: Amazon Campinarana, Atlantic Forest, Brazilian Collembola, Caatinga Forest, species turnover.

INTRODUCTION

The grouping of diversity into categories has been used to compare and describe communities across distinct areas (Gotelli and Colwell, 2001). This grouping results

from the fact that different spatial scales can share similar environmental characteristics and therefore the population is considered to represent these natural limits (Wilson and Shmida, 1984; Whittaker et al., 2001).

In this sense, the description of species composition distributed in single spots is named point diversity or “ α diversity”. That illustrates a local natural community. At larger spatial scales, landscape community is described

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as “ γ diversity”, and a larger geographic region is represented by “ ϵ diversity” (Sepkoski, 1988; Stoms and Estes, 1993; Whittaker et al., 2001). These parameters can describe the biodiversity and may be used to assess community richness across different spatial scales. Three aspects emerge when species diversity is compared across multiple scales: “pattern diversity” deals with the comparison within single spots, “ β diversity” compares the biotic structure of natural communities across spots and “ δ diversity” is used to compare landscapes and larger regions (Stoms and Estes, 1993; Whittaker et al., 2001).

Six main phytogeographic domains could be distinguished in Brazil: The Amazon Rainforest, the Atlantic Forest, the Cerrado, the Caatinga Forest, the Pantanal and the Pampa (Velooso and Goés-Filho, 1982). Each of these units have special characteristics of vegetation, climate and soil that affect the fauna (Joly et al. 1999). Nevertheless, it is important to note that none of these domains is homogeneous. Even though, areas within each domain share overall similarities, there are areas with specific biotic and abiotic characteristics that determine the distribution of animal taxa. Some of these environments can play an important role as “corridors”, promoting the maintenance of biodiversity by connecting different domains and providing the dispersion of species (Velooso and Goés-Filho, 1982).

This study compares Collembola species richness and composition through the sampling of three different forest types (Amazon Campinarana, Caatinga Forest and Atlantic Forest) characterized by different climatic and edaphic conditions. In order to determine the Collembola species diversity among different conditions in Brazil and to establish their role in promoting regional diversity (γ), we investigated the patterns of biodiversity by comparing species richness (α diversity) and turnover in species composition between transects (β diversity) and between forest type samples (δ diversity).

MATERIALS AND METHODS

Study area

This study was performed on three forests sites in Brazil: Caatinga Forest, Amazon Campinarana Forest and Atlantic Forest, each with different climatic and edaphic conditions. The Caatinga spans an area of 800 000 km² and covers most of Brazil's Northeast (Andrade-Lima, 1981; Prado, 2003). The landscape of Caatinga is dominated by a mosaic of physiognomic forms such as arboreal, shrubby and thorny caatinga, all adapted to drought (Coimbra-Filho and Câmara, 1996) with different types of soil, climates and vegetation. It may include patches of Cerrado, evergreen forests with influence of Atlantic and/or Amazon Rainforest, but is most commonly represented by hypo to hyperxerophytic woodlands (Zanella, 2003; Vasconcellos et al., 2010). The rainfall in the Caatinga is commonly lower than 750 mm per year and 50 to 70% of the annual precipitation is concentrated within three to six consecutive months. Climate is seasonal semi-arid (Vasconcellos et

al., 2010).

The Amazon Forest covers 58% of the Brazilian territory and it is distributed mostly on Northern Brazil. Climate is mainly tropical with low thermal amplitude. The annual average temperature is 27°C with a range of about 2°C. The annual average rainfall is about 1.600 mm. There are two general types of forest in the Brazilian Amazon: Terra Firme forests and flooded forests (Kirby et al., 2006). Even though the Terra Firme forests may appear homogeneous, with dense populations of tall trees, there are many patches of savannah vegetation within the typical Amazonian landscapes. These vegetal formations can occur as savannah shrubby forests (Campinarana and Cerrado) or savannah grasslands (Kirby et al., 2006). The vegetation in Campinarana ranges from open herbaceous savannas to closed canopy forests and some patches can cover thousands of square kilometers (Barbosa and Ferreira, 2004; Barreto et al., 2006). Due to the distribution of the Campinarana throughout the Amazon Rainforest, many areas of this vegetation are isolated from each other, and have the potential to hold portions of the overall Campinarana biodiversity (Kirby et al., 2006).

The Atlantic Forest is the second largest pluvial forest in the Neotropical Region. Before European colonization, it covered almost 1.5 million square kilometers, approximately 90% distributed along the Brazilian coast (Tabarelli et al., 2005). Due to intense human activities, it has lost about 93% of the original distribution, with remnants encompassing approximately 100,000 square kilometers (Tabarelli et al., 2005; SOS Mata Atlântica and INPE, 2011). Despite that, the Atlantic Forest is one of the 25 world's biodiversity hotspots and includes at least 8,000 endemic species of vascular plants and terrestrial vertebrates (Myers et al., 2000). The Atlantic Forest includes two major formations: the Atlantic Rainforest located on the coastal region, within low to medium altitudes; and the tropical seasonal forest or Atlantic Semi-deciduous forest extending across higher altitudes in South-Eastern Brazil (Morellato, 2000). The climate is distinct in each area, where the Atlantic Rainforest has warm and wet climate without a defined dry season, the Atlantic Semi-deciduous forest shows a seasonal climate marked by a relatively severe dry winter (Morellato, 2000; Oliveira-Filho and Fontes, 2000).

Sampling design

Three different regions were surveyed on May 2011: the Amazon Campinarana (AC) in North-Western Brazil (02° 35' 25"S, 60° 01' 45"W), the North-Eastern Caatinga Forest (CF) (07° 29' 46"S, 36° 43' 53"W) and the Atlantic Forest (AF) in the South-East of the country (22° 27' 15.11"S, 43° 0' 10.62"W). At each site, two 100 m long transects were established 20 m apart from each other and within each transect 10 soil samples, 10 m apart along the transect, consisting of the humus and up to 5 cm of the soil layers, were taken in 2 L plastic containers. Soil Collembola were extracted using Berlese-Tulgren funnels for 3 days at room temperature and 4 days with 20 W bulbs over each funnel. Specimens collected from the samples were fixed in 90°GL ethanol. All Collembola were bleached and mounted on slides using Hoyer's medium for identification under optic microscope (Christiansen and Bellinger, 1998). Main specialized bibliography used for identification were Bellinger et al. (2006-2012), Betsch (1980), Bretfeld (1999), Christiansen and Bellinger (1998), Massoud (1967) and Potapov (2001).

Additional abiotic data were taken, comprising of soil humidity (%), soil type and precipitation (mm). For soil humidity, samples were collected 5 cm deep and oven dried at 105°C for 48 h. Wet and dry weights were used to determine percentage of soil water. Soil type and precipitation were obtained from Joly et al. (1999).

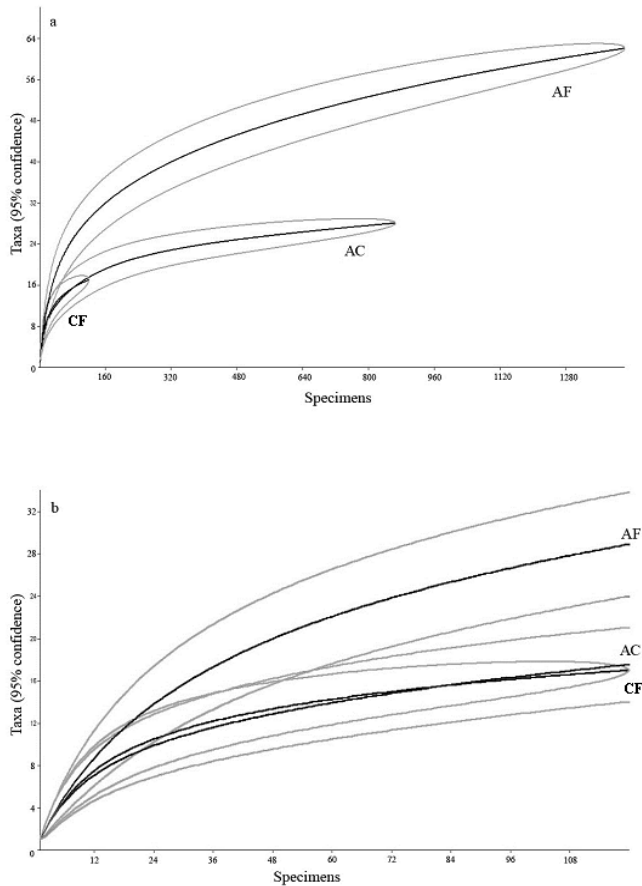


Figure 1. Species accumulation curves for the three forest types studied (a) and for the first 100 specimens (b) of each forest type. AF, Atlantic Forest samples, AC, Amazon Campinarana Forest samples and CF, Catinga Forest samples.

Climate type was determined according to the classification of Köppen (1936).

Data analysis

Collembola diversity was estimated using species richness (S), defined as the total number of species at each sampled transect. Species accumulation curves (and their 95% confidence interval curves) were calculated on EstimateS (Colwell, 2005) to evaluate the adequacy of sample size. None of the accumulation curves plateaued for the three forest type samples. For the Atlantic Forest samples, for instance, where excess of 1200 individuals were caught, new species were still being found. The same was observed for samples taken from the Caatinga and Campinarana forests, whose species accumulation curves were still increasing (Figure 1).

Since species richness is commonly affected by sample size, a rarefaction was applied to the richness in order to standardize S for sample size (Gotelli and Colwell, 2001). At each transect sample, richness was rarefied to the expected number of species (ES) for a theoretical sample of 45 individuals (which was the overall average number of individuals collected per transect) and the average ES for each transect was then calculated. Species diversity was measured using Shannon-Wiener index (H^2) and equitability was

measured using Pielou's index (J'). To test for differences in number of individuals (N), richness (S and ES) and diversity indices of Collembola across the three investigated forests and transects, a factorial ANOVA was carried out, where each sample measurement of the response variables (N, S, ES and diversity indices) was classified according to two factors (transect and forest type), where transect had two factor levels and forest type had three. A $\log_{10}(x+1)$ transformation was applied to the response variables to enhance normality of the data set and the equality of variances (Sokal and Rohlf, 1969). *Post-hoc* pairwise comparisons were performed using Tukey's HSD test ($\alpha < 0.05$).

Local or within transect (α) and regional or within forest type (γ) diversity measures were used to provide information on species richness at different spatial scales. Turnover diversity between transects (β diversity) and turnover diversity between forest types (δ diversity) were measured to provide indications of the change in species composition among transects (β diversity) and regions (δ diversity). β and δ diversity were measured using similarity percentage (SIMPER) analysis and expressed as percentage of dissimilarity, based on a Bray-Curtis similarity matrix (Danovaro et al., 2009). SIMPER analyses were performed to estimate the β and δ diversity, estimated as % Bray-Curtis dissimilarity (Danovaro et al., 2009) in Collembola composition between transects within the same forest type and among forest types. Analysis of similarities (ANOSIM) was performed to test for significance of differences in Collembola species composition between transects within the same forest type and among forest types (Clarke, 1993). All indices and multivariate statistics were calculated based on presence/absence data using Bray-Curtis similarity on PRIMER v5 (Clarke and Gorley, 2001).

A 2-dimensional non-metric multidimensional scaling (NMDS) plot was obtained based on the Bray-Curtis similarity between all samples (McCune and Grace, 2002) to evaluate composition of Collembola across forest types. Indicator Species Analysis (Dufrene and Legendre, 1997) was used to determine which species discriminated the different forest types. The significance ($\alpha < 0.05$) of the discriminating power (IV) was determined by the Monte-Carlo test (1000 permutations). These analyses were performed on PC-ORD 4.27 (McCune and Mefford, 1999). To assess how well the environmental constraints across forest types were correlated with the community variables (N, S, ES and diversity indices) standard and hierarchical multiple regressions were performed between these variables and soil humidity. All variables were log-transformed ($\log_{10}(x+1)$) and the significance of correlations ($\alpha < 0.05$) between variables were tested using the Pearson's coefficient, comprising soil humidity (%), soil type and precipitation (mm).

RESULTS

A total of 2408 Collembola specimens were collected, distributed among 103 species. The regional species richness in AF was 62 species, 28 species in AC and 17 species in CF. The number of individuals (N) collected varied significantly among forest types (two-way ANOVA, $F_N = 33.2$; d.f. = 2,48; $p < 0.001$), being lower in the CF (Tukey $p_N < 0.01$) and not different between AF and AC (Tukey $p_N = 0.334$). Differences in N between transects across forest types were not significant (two-way ANOVA, $F_N = 0.9$; d.f. = 1.48; $p = 0.333$). Collembola richness (S) was higher in the AF, whereas CF showed the lowest values (two-way ANOVA, $F_S = 63.2$; d.f. =

Table 1. Richness and diversity indices at each studied forest. N, number of individuals; S, species richness; ES (45), rarefaction species richness; H', Shannon diversity index and J', species evenness.

Parameter	N	S	ES(45)	H' ²	J'
Amazon Campinarana					
Transect 1	421	21	9.3	3.53	0.80
Transect 2	444	23	9.6	3.42	0.75
Caatinga Forest					
Transect 1	75	12	2.9	3.08	0.86
Transect 2	45	13	2.7	3.18	0.86
Atlantic Forest					
Transect 1	881	49	14.8	4.58	0.81
Transect 2	542	44	9.5	3.79	0.69

Table 2. Average dissimilarities (%), SIMPER (% dissimilarity) and ANOSIM (R and p value) to test for differences in Collembola composition across transects and forest type. SIMPER results are presented below the diagonal and ANOSIM above the diagonal.

							ANOSIM	
AV Similarity (%)	59.76		20.49		39.05			
AV Similarity (%)	58.94	61.52	25.22	9.46	52.68	29.05		
	Amazon Campinarana		Caatinga Forest		Atlantic Forest			
AV Dissimilarity (%)	Transect 1	Transect 2	Transect 1	Transect 2	Transect 1	Transect 2		
Amazon Campinarana								
Transect 1	0	0.033 (p=0.283)	0.836 (p=0.001)	0.800 (p=0.001)	1.000 (p=0.001)	0.925 (p=0.001)		
Transect 2	40.67	0	0.836 (p=0.001)	0.800 (p=0.001)	1.000 (p=0.001)	0.908 (p=0.001)		
Caatinga Forest								
Transect 1	100	100	0	-0.038 (p=0.611)	0.836 (p=0.001)	0.781 (p=0.001)		
Transect 2	100	100	78.82	0	0.800 (p=0.001)	0.733 (p=0.002)		
Atlantic Forest								
Transect 1	89.59	87.01	100	100	0	0.190 (p=0.007)		
Transect 2	94.87	93.26	100	100	62.59	0		
SIMPER								

2.48; $p < 0.001$). CF also showed significantly lower ES and H'^2 diversity (two-way ANOVA, $F_{ES} = 63.4$; $F_{H'^2} = 37.2$; d.f. = 2.48; $p < 0.001$). Even though AF showed a higher S than the AC (Tukey $p_S = 0.013$), differences in ES and H'^2 between AF and AC were not significant (Tukey $p_{ES} = 0.121$ and $p_{H'^2} = 0.462$). Differences in richness (S and ES) and H'^2 diversity between transects across study areas were not significant (two-way ANOVA, $F_S = 3.9$; $F_{ES} = 3.1$; $F_{H'^2} = 1.5$; d.f. = 1.48; $p > 0.05$). Two-way ANOVA also showed that J' evenness was not significantly different between forest types (two-way ANOVA, $F_J = 2.2$; d.f. = 2.45; $p = 0.119$) or transects (two-way ANOVA, $F_J = 1.4$; d.f. = 1,45; $p = 0.240$) (Table 1).

SIMPER analysis carried out for each transect across forest types showed that the dissimilarity in Collembola species (δ diversity) across study forest types ranged

from 40.7 to 100%. CF in particular did not share any species with the other forest types, whereas AC and AF showed similarities between 12.99 and 5.13% in Collembola composition. The ANOSIM on transects across forest types revealed significant differences in Collembola composition across different forest types ($p < 0.05$) and no difference between transects within each forest type (Table 2). Even though the p value for the comparison between both transects in the AF is significant, the pairwise R value indicates that these transects are barely separable in terms of Collembola composition. It must be kept in mind that a p value denoting a significant difference may be accompanied by an inconsequentially small R (Clarke, 1993).

The two-dimensional solution by the NMDS based on these results explained 82.9% of the variation in the data

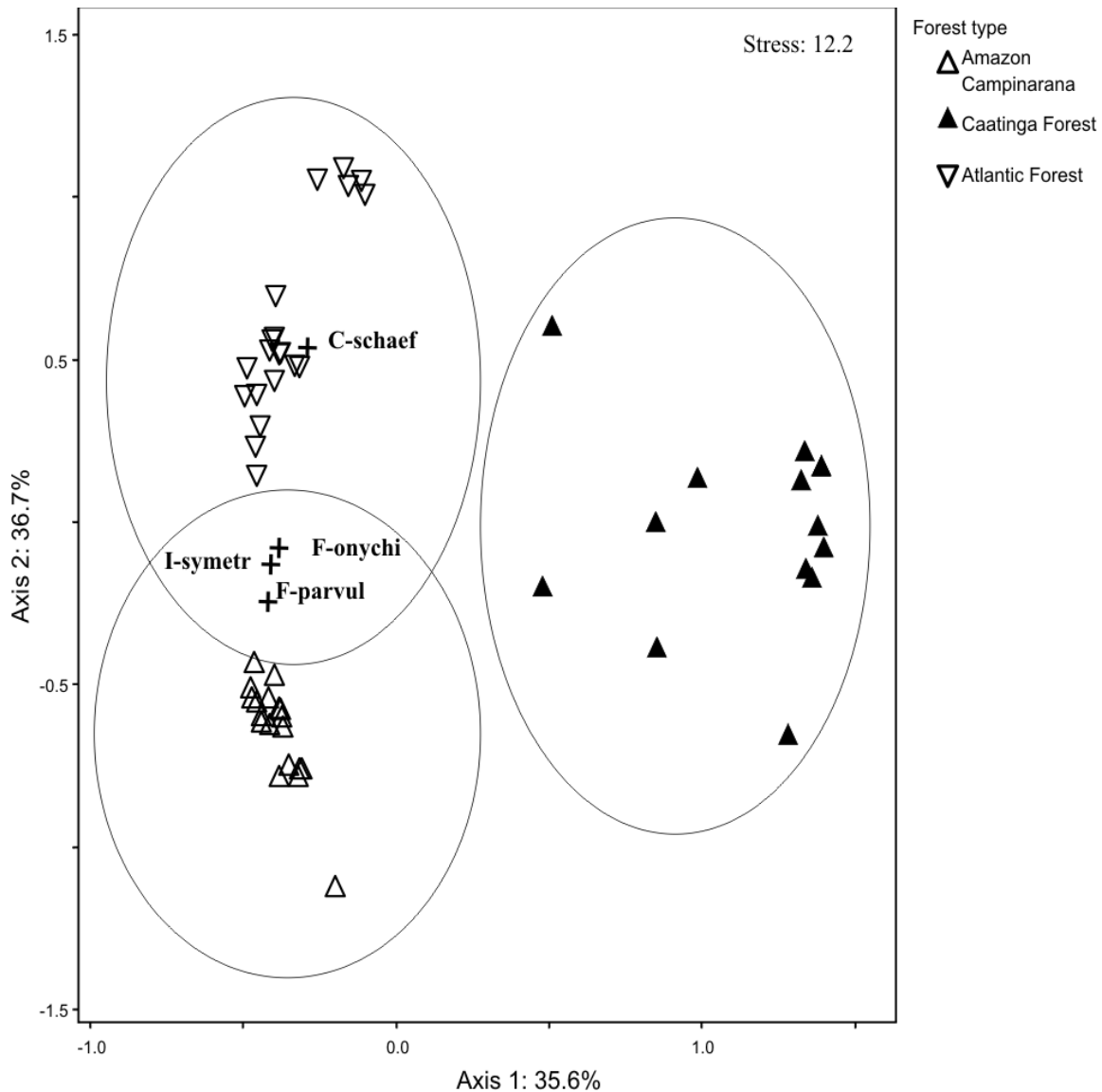


Figure 2. Two-dimensional solution of the NMDS showing similarity in species composition (presence/absence data) of Collembola across three different forest types. “+” indicates shared species between forest types: C-schaef, *Campylothorax schaefferi*; F-parvul, *Folsomides parvulus*; F-onychi, *Folsomina onychiurina*; I-symetr, *Isotomiella symetrimucronata*.

set, 72.3% being explained by the first two axes. The ordination plot shows clear segregation between CF and the other forest types. Less segregation is observed between AC and AF which share four species (Figure 2). Indicator species analysis showed that, among the 103 species of Collembola registered in the present study, 15 were indicator species for the AC, 5 for the CF and 24 for the AF. The highest IV's were observed for *Cyphoderus arlei* Cassagnau 1963 (95%) and *Isotomiella similis* Deharveng & Oliveira 1990 (90%), indicator species for the AC, and for *Lepidonella* sp. 1 (85%), indicator species for the AF. *Pseudosinella dubia* Christiansen 1960 was

the indicator species with greater IV for the CF (57.1%) (Table 3). Patterns of Collembola species richness across all study scales (transect and forest type) are shown in Figure 3. As indicated by ANOSIM, the local diversity (α diversity) was similar in the AC and CF, but not in the AF. Regional diversity (γ diversity) was higher in the AF than in CF and AC.

Standard multiple regression revealed that soil humidity (Table 4) was significantly correlated with the number of individuals collected (N), richness (S and ES) and diversity ($r > 0.544$; $p < 0.001$), but no correlation was observed between this environmental variable and

Table 3. Significant indicator species and their respective indicator values for the studied forests.

Forest type	Indicator Species	Indicator Value	P
Amazon Campinarana	<i>Cyphoderus arlei</i> Cassagnau, 1963	95.0	0.001
	<i>Isotomiella similis</i> Deharveng & Oliveira, 1990	90.0	0.001
	<i>Paronella</i> sp. 2	80.0	0.001
	<i>Sphaeridia</i> sp. 2	80.0	0.001
	<i>Isotomiella nummulifer</i> Deharveng & Oliveira, 1990	65.0	0.001
	<i>Neelus</i> sp. 2	65.0	0.001
	<i>Isotomiella symetrimucronata</i> Najt & Thibaud, 1987	46.6	0.005
	<i>Folsomina onychiurina</i> Denis, 1931	44.1	0.002
	<i>Neotropiella</i> sp. 1	40.0	0.002
	<i>Pseudosinella brevicornis</i> Handschin, 1924	35.0	0.002
	<i>Mesaphorura</i> sp. 1	35.0	0.004
	<i>Entomo brya</i> sp. 2	35.0	0.005
	<i>Pseudachorutes</i> sp. 1	30.0	0.008
	<i>Proisotoma oliveirae</i> Deharveng, 1984	25.0	0.009
	<i>Lepidosira tapuia</i> Arlé & Guimarães, 1981	25.0	0.010
Caatinga Forest	<i>Pseudosinella dubia</i> Christiansen, 1960	57.1	0.001
	<i>Brachystomella agrosa</i> Wray, 1953	28.6	0.003
	<i>Proisotoma</i> sp 3	28.6	0.005
	<i>Cyphoderus similis</i> Folsom, 1927	21.4	0.017
	<i>Neotropiella vanderdrifti</i> Massoud, 1963	21.4	0.020
Atlantic Forest	<i>Lepidonella</i> sp. 1	85.0	0.001
	<i>Arlea lucifuga</i> (Arlé, 1939)	70.0	0.001
	<i>Desoria trispinata</i> (MacGillivray, 1896)	65.0	0.001
	<i>Neelides</i> sp. 1	65.0	0.001
	<i>Dicranocentrus silvestrii</i> Absolon, 1903	60.0	0.001
	<i>Trogolaphysa tijucana</i> (Arlé & Guimarães, 1979)	60.0	0.001
	<i>Neelus</i> sp. 1	55.0	0.001
	<i>Folsomiella trisetosa</i> Mendonça <i>et al.</i> , 2005	55.0	0.001
	<i>Cinctocyrtus</i> sp. 1	50.0	0.001
	<i>Thalassaphorura</i> sp. 1	50.0	0.001
	<i>Paracerura</i> sp. 1	45.0	0.001
	<i>Campylothorax schaefferi</i> Börner, 1906	40.5	0.001
	<i>Brachystomella septemocolata</i> Denis, 1931	40.0	0.001
	<i>Neotropiella pentocolata</i> (Denis, 1931)	40.0	0.001
	<i>Mucrosomia</i> sp. 1	40.0	0.002
	<i>Folsomiella albida</i> (Arlé, 1960)	35.0	0.001
	<i>Folsomia similis</i> Bagnall, 1939	35.0	0.002
	<i>Isotomiella barrana</i> Mendonça & Abrantes, 2007	35.0	0.004
	<i>Proisotoma ramosi</i> Arlé, 1960	30.0	0.004
	<i>Isotomiella canina</i> Mendonça & Fernandes, 2003	25.0	0.008
<i>Pseudosinella</i> sp. 1	25.0	0.009	
<i>Dicranocentrus heloisae</i> Arlé & Mendonça, 1982	20.0	0.032	
<i>Cyphoderus agnotus</i> Börner, 1906	20.0	0.034	
<i>Brachystomellides compositus</i> Arlé, 1959	20.0	0.036	

species evenness ($r = -0.171$; $p = 0.114$). Furthermore, hierarchical multiple regression showed that only the

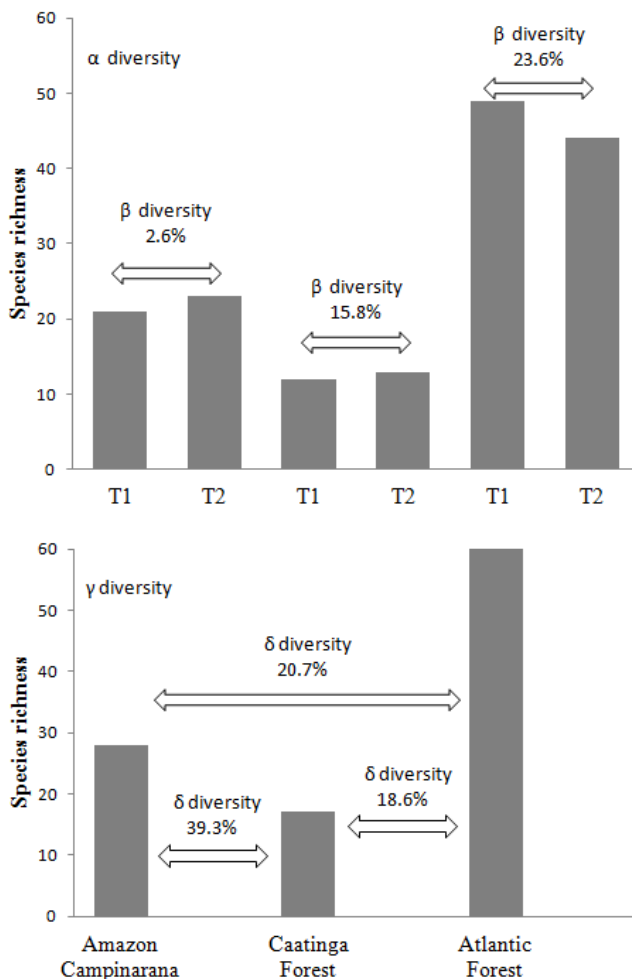


Figure 3. Species richness of Collembola at different spatial scales: transect diversity (α diversity) and forest type diversity (γ diversity). α Diversity was given by values of species richness at each transect, β diversity was given by percentage of dissimilarity between transects, γ diversity was given by species richness at regional scale, δ diversity was given by the percentage of similarity of species richness between forests at biogeographical scale.

model incorporating N and S was significant (Fchange=10.1; $p=0.003$), explaining 41.9% of the correlations between soil humidity and the community parameters.

DISCUSSION

The results of the present study showed that differences between transects within each forest type were lower than the differences among forest types. The Atlantic Forest showed higher β diversity with about 23% dissimilarity between transects and the greatest γ

diversity. It shows that this highly threatened forest is more heterogeneous and richer, in number of species, than the other studied sites. This may be an effect of the complexity of the humid multi-stratified Atlantic Forest, which offers a wide variety of micro-habitats, therefore enhancing local scale diversity.

The fact that the differences between transects across forest types were low (except for AF; Table 2) and that the differences among forest types were high, indicates that the grouping of diversity in the present study resulted from different spatial scales which share similar environmental characteristics at the α diversity level with different environmental components at larger scales (γ diversity). Such results strengthen the importance of understanding whether population samples can represent the natural limits of forest types (Wilson and Shmida, 1984; Whittaker et al., 2001).

Despite lower α and γ diversity of Amazon Campinarana and Caatinga Forest, as compared to Atlantic Forest, species composition of the study forest types shows that each forest has a particular assemblage at regional scale.

The (dis)similarity among study sites reveals that samples taken from the Amazon Campinarana are more similar to those from the Atlantic Forest than the ones from the Caatinga Forest, regarding the springtail fauna. Samples from AF are the richest in Collembolan species across the three studied sites, followed by AC and CF, respectively. The Caatinga Forest is the driest sampled environment and presents the lowest number of species (either α and γ diversity). Furthermore, it is the more dissimilar of the study forest types, since samples from this forest type had no species shared with the other sites.

The Brazilian North-Eastern Caatinga is located in a semi-arid region with elevated endemism rates (Vanzolini, 1981; Vasconcellos et al., 2010), which can explain the high dissimilarity to the other study areas. Lower δ diversity values were observed between AF and AC, reflecting the four shared species in their diversity composition. These findings are corroborated by the indicator species analysis, where AF presents a proportionally higher number of indicator species than AC and CF, reflecting the species richness, abundance and diversity. However, the highest IV's were observed for species in AC, *C. arlei* (95%) and *I. similis* (90%).

The similarity analysis based on richness shows a different scenario. When richness values are compared, the AC is more similar to CF than to AF. This is likely to be the effect of the elevated number of species in AF (62 species), which is more than the double of AC (28 species), while CF (17 species) has approximately 60% as many species as AC. The variation in the number of species must be as result of water content in soil. Soil humidity strongly affects abundance (N), richness (S, ES) and, to a lower degree, diversity (H'). Water is a limiting

Table 4. Soil humidity, precipitation, soil type and climate according to Köppen's system. T, transect; AC, Amazon Campinarana; CF, Caatinga Forest; AF, Atlantic Forest.

Vegetation	Soil humidity (%)	Precipitation (mm)	Soil type	Climate Köppen
T1 AC	52.39	165	Podzol hydromorphic	Amw
T2 AC	62.02			
T1 CF	9.23	232	Regosol dystrophic	Asw
T2 CF	6.75			
T1 AF	72.00	170	Latosol yellow dystrophic	Cwb
T2 AF	51.22			

factor for Collembola (Verhoef and Witteveen, 1980), playing an important role, regardless of the environment type. Furthermore, the fact that AC presents low β diversity, similar to that of CF, while AF presents over 23% of dissimilarity among transects, indicates that the structure of the vegetation in each type of forest may affect species richness and composition. Both AC and CF are composed by sparsely distributed, medium to small sized bushes and low trees, which largely expose the soil to weathering. The Atlantic Forest, on the other hand, is mostly shaded by high trees and dense vegetation, minimizing such effects.

The abundance and diversity of Collembola have been found to be positively correlated to the diameter of the crown of trees and depth of leaf litter (Zeppelini et al., 2009), variables that are associated with the shading over the soil and evaporation rates. Therefore, higher γ diversity in AC and AF is likely to be the result of the water content of the soil (57 and 61%, respectively). It is important to note that, despite the elevated volume of rain fall in the CF (above 230 mm during May 2011 as compared to 165 mm in AC and 170 mm in AF in the same period), the water content of the soil is less than 8%. This is the result of the shallow and sandy crystalline composition of CF's soil combined with high evaporation rates, due to high solar radiation at a low altitude and latitude, preventing soil water to accumulate.

Even though this study represents small areas in three extensive phytogeographic domains, some final conclusions can be drawn from its results. The Caatinga Forest is much drier and presents less stratified vegetation than any of the other domains studied. These environmental conditions lead to lower number of species of Collembola and consequently, lower α , β and (possibly) γ diversity. Caatinga is known to contain endemic species of several biological groups (Vanzolini, 1981; Andrade-Lima, 1982), however there are only five described species of springtails endemic for this domain, but this group of species comprises an insulated genus known to be distributed only in Caatinga Forest. The collembolan fauna in such an extreme environment must be highly specialized or resistant to subsist in dry conditions, resulting in elevated indices of dissimilarity,

therefore a high δ diversity when compared with more complexes and less drastic environments. These findings imply that conservation policies and decision-makers should consider the different aspects of species diversity and the distributions of species at varied scales in order to optimize the efficiency of conservation plans. They should take into account the scale of diversity (local and regional) and the environmental characteristics of each phytogeographic domain. Finally, in a scenario of climatic global warming, the strong correlation between soil humidity and collembolan abundance, richness, α and γ diversity, indicate that the Amazon Campinarana and Atlantic Forest will be subject to greater loss of local and regional diversity, as temperature increases and soil moisture and habitat complexity reduce. Even though such losses may be less intense in the Caatinga Forest, given that species have been naturally subjected to high hydrological deficit, this loss of diversity may be irreversible, because those species are more restricted in their distribution and cannot be found elsewhere in a biogeographical scale.

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