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Effects of Understory Structure on the Abundance, Richness and Diversity of Collembola (Arthropoda) in Southern Brazil

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Efeitos da Estrutura do Sub-Bosque na Abundância, Riqueza e Diversidade de Collembola (Arthropoda) no Sul do Brasil

RESUMO - O propósito deste estudo foi investigar os efeitos da estrutura do sub-bosque na comunidade de colêmbolos. Foram comparados quatro ambientes florestais distintos: plantações de *Pinus* spp., plantações de *Eucalyptus* spp., plantações de *Araucaria angustifolia* e áreas de floresta ombrófila nativa remanescente. Para cada fisionomia vegetal houve três áreas com duas unidades amostrais de 25 m × 2 m cada. As coletas foram realizadas com guarda-chuva entomológico, medindo 1 m × 1 m, no período de setembro de 2003 a agosto de 2004. Investigou-se se a abundância, a riqueza e a diversidade da comunidade de colêmbolos foram influenciadas pelas fisionomias vegetais. Também verificou-se se a estrutura do habitat de cada tipo de floresta teve associação com a composição da comunidade de colêmbolos. Foram coletados 4111 indivíduos, pertencentes às famílias Entomobryidae, Tomoceridae e Sminthuridae, divididos em 12 morfoespécies. A plantação de *Pinus* spp. apresentou maior riqueza, abundância e diversidade de colêmbolos, devido à maior quantidade de vegetação disponível no sub-bosque. A composição de colêmbolos esteve associada aos tipos vegetacionais, com Entomobryidae e Sminthuridae associados aos arbustos, e Tomoceridade às árvores. A estrutura do habitat, medida através da densidade e composição da vegetação do sub-bosque mostrou-se um fator importante na determinação da estrutura e composição da comunidade de Collembola.

PALAVRAS-CHAVE: Ação antrópica, estrutura de paisagem, floresta de araucária, comunidade de artrópodes

ABSTRACT - The purpose of this study was to investigate the effects of different landscape structures on the understory Collembola community. Four different forest physiognomies were compared: *Pinus* spp. plantation, *Eucalyptus* spp. plantation, *Araucaria angustifolia* plantation, and a remaining native *Araucaria* forest. Three areas containing two sampling units (25 m x 2 m each) were selected in each forest physiognomy. Understory Collembola collection was done with a 1 x 1m canvas sheet held horizontally below the vegetation, which was beaten with a 1m long stick, seasonally from September 2003 to August 2004. We evaluated the influence of forest physiognomies on the abundance, richness and diversity of Collembola communities. It was also verified if the habitat structure of each physiognomy was associated with the composition of the Collembola community. A total number of 4,111 individuals were collected belonging to the families Entomobrydae and Tomocerida (Entomobryomorpha), and Sminthuridae (Symphypleona), and divided in 12 morphospecies. *Pinus* plantation presented the highest richness, abundance and diversity of Collembola and it was associated to diverse understory vegetation. The abundance of Entomobrydae and Sminthuridae was associated to the presence of bushes, while Tomoceridae abundance was associated to the presence of trees. The habitat structure, measured through understory vegetation density and composition, plays an important role on the determination of the structure and composition of the Collembola community.

KEY WORDS: Human action, landscape structure, *Araucaria* Forest, arthropod community

Landscape patterns are key elements for understanding biodiversity. Nonetheless, the tools for prediction and evaluation of landscape effects on biodiversity are still scarce (Ernoult *et al* 2003). Human-made disturbances play an important role in the formation of many landscapes, comparable to natural disturbance agents. In landscapes influenced by human activities, knowledge of the influence of environmental factors on the structure and composition of animal community is crucial for biodiversity maintenance. The alteration of natural habitats modifies patterns of resource availability and biotic interactions in local communities (Baker 1995, Schweiger *et al* 2005). Both the spatial arrangement of the habitat elements and the spatial heterogeneity of the landscape are fundamental for species diversity.

Springtails are small hexapod arthropods, apterous and ametabolous, with small antennae and body size ranging from 0.2 to 9 mm (Eisenbeis & Wichard 1987). They are ubiquitous, world widely distributed arthropods, and are one of the most well succeeded and abundant arthropod lineage in terrestrial ecosystems (Bellinger *et al* 1996, Vázquez & Palacios-Vargas 2004). Springtails are found over the vegetation frequently consuming pollen grains and fungi spores (Rosello *et al* 1986). Nonetheless, springtails are predominantly associated with the soil fauna, particularly abundant in the litter, humus and even in deep soil layers (Janssens & Dethier 2005). These little hexapods diet consists of fungi spores and mycelia, yeasts, decomposing plant material and bacteria, since its role as fragmenters and decomposers of organic materials is fundamental for energy cycling (Vázquez & Palacios-Vargas 2004), and significantly influence the soil microbial ecology and fertility. Springtails act as fungi dispersers, and are consumed by other invertebrates, mostly spiders (Sanders & Platner 2007); furthermore, they are bioindicators of environmental changes (Chauvat *et al* 2007, Lins & Gonçalves 2007).

A total of 199 springtail species are known to Brazil, distributed into 19 families and 80 genera. Most species (93.7%) for which information on habitat is available live in forests (Zeppelini Filho & Bellini 2004). Additionally, there are seven species classified as vulnerable according to Brazilian Threatened Fauna Species List (MMA 2003).

In southern Brazil the alteration of vegetation physiognomies is mostly generated by human actions. Among all, silviculture is of particular importance, since plantations of *Pinus* spp. (Gimnosperma, Pinaceae) and *Eucalyptus* spp. (Myrtales, Myrtaceae) are very common in the region, leading to vegetation physiognomy structures characterized by a mosaic of forest formations and grassy fields, composed by patches of different environments. These environmental mosaics might influence both regionally and locally the distribution and occurrence of animal communities, as different environmental structures are developed (Rambo 1956, Tews *et al* 2004).

Araucaria forest, also called mixed ombrophyllous forest, is composed by species from tropical and temperate floras, being *Araucaria angustifolia* a key species, which defines its physiognomic characteristics (Rambo 1956, Fontoura *et al* 2006). The *Araucaria* forests present an understory composed mostly by specimens of Lauraceae, Myrtaceae and Aquifoliaceae (Zanini & Ganade 2005). *Araucaria* forests formerly occupied ca. 20 million of hectares, distributed in the States of Paraná (40%), Santa Catarina (31%) and Rio Grande do Sul (25%), with sparse patches in southern São Paulo (3%), extending to the south of Minas Gerais and Rio de Janeiro, in high elevation areas (1%) (IBGE 1992). That formation is considered one of the 178 terrestrial eco-regions of Latin America and Caribbean pointed as in critical state of environmental conservation. Nowadays, the *Araucaria* forest is limited to less than 5% of the original distribution (Dobrovolski *et al* 2006).

Studies on understory springtail are scarce in the literature, particularly those focusing on springtail ecological aspects (Andre & Lebrun 1994). Results from a study performed by Culik & Zeppelini Filho (2003) indicated that many aspects of the Brazilian Collembola fauna remain to be learned, especially in North-East, Center-West and South regions. The potential value of Collembola as biological indicators of soil quality and ecosystem health has been widely recognized; thus, knowledge on Collembola can be useful for the development of conservation and monitoring strategies for natural areas disturbed by human activities.

The purpose of this study was to verify if different vegetation physiognomies and habitat structures influenced the abundance, richness and diversity of understory springtails. According to the Spatial Heterogeneity Theory (Simpson 1949, MacArthur & Wilson 1967, Lack 1969), a higher springtail diversity is expected in indigenous areas in detriment of planted areas, due to a higher structural heterogeneity in the understory.

Material and Methods

Study area. This study was performed at the Floresta Nacional São Francisco de Paula – FLONA-SFP, a conservation unit of sustainable use administered by the Instituto Chico Mendes de Conservação da Biodiversidade - MMA. FLONA - SFP is situated at the Northeast region of Rio Grande do Sul State (29^{o}25'22,4"S; 50^{o}23'11,2"W), in São Francisco de Paula. It was funded in 1945, and covers an area of 1,606 ha, with elevations up to 900 m. The conservation unit is within the area corresponding to the Reserva da Biosfera da Mata Atlântica, and is composed mainly by a mosaic of natural areas (mixed ombrophyllous forest) and reforested areas with *Araucaria angustifolia, Pinus* spp. and *Eucalyptus* spp., and some wetlands and natural grasslands (Schneider *et al* 1989).

Data collection. Collembola sample collection was performed in four different forest physiognomies: *Pinus* spp. plantations (PP), *Eucalyptus* spp. plantations (EP), *A. angustifolia* plantations (AP) and remaining native ombrophyllous forests (Araucaria Forest - NF). Each physiognomy had three replicates, totaling 12 sampling areas. In each sampling area, two sampling units (25 m × 2 m quadrats) were randomly plotted, one rightwards and other leftwards from the main 100 m long transects previously delimited. Understory springtails were collected between 1 m and 2.5 m height with an entomological umbrella (1 m × 1 m). Within each sampling unit all plant structures were beaten.

Therefore, sampling effort was defined by the area sampled (50 m^2). The sampling procedure was performed every three months from September 2003 to August 2004, covering all seasons. After the collection, the material was stored in pots containing ethanol 85%, classified into morphospecies and taxonomically identified following Zeppelini Filho & Bellini (2004).

The vegetation structure analysis was performed following Baldissera *et al* (2008). The frequency with which plants reached a pole at 1 m and 2.5 m height interval was measured in summer and winter within each quadrant. Fifty vegetation touch measurements inside each sampling unit were taken, which were classified into trees, shrubs, lianas, ferns and grasses. Temperature and humidity measurements were obtained for all sampling units using a thermohygrometer (Instrutherm Digital Thermohygrometer Model HT-156).

Data analyses. The total and relative abundance, the number of morphospecies (richness) and the Shannon diversity index were calculated for each sampling area. Mean temperature and mean humidity did not vary among the physiognomies along the year (Repeated Measures ANOVA $F_{9,24} = 0.566$; $P = 0.811$; and $F_{9,24} = 1.561$; $P = 0.184$, respectively). Therefore, we eliminated the effects of these two variables by performing a regression analysis with each Collembola diversity parameters as dependent variables and temperature and humidity as independent variables. Residuals resulted from the multiple linear regression analysis were used as community diversity parameters. We used an ANOVA with randomized tests (Manly 1997) to verify if the Collembola found in different vegetation physiognomies varied in terms of richness, relative abundance and Shannon diversity (Q statistics, Pillar & Orlóci 1996). We calculated the Euclidean distance matrix between sampling areas taking the year seasons as blocks to remove its effects. In cases when the ANOVA indicated significant differences between groups ($\alpha < 0,05$), we performed an analysis of contrasts between the groups (Pillar & Orlóci 1996), in a similar way as performed for the ANOVA.

We also used a Correspondence Analysis (Manly 1997) to verify if the composition of springtail morphotypes was influenced by the vegetation type reaching the central pole. We generated a matrix A containing sampling areas described by morphospecies and a matrix B containing sampling areas described by habitat variables. By multiplication, A'B = C, which contained springtail morphospecies described by habitat variables. From matrix C we verified the relationship among the 12 Collembola morphopecies and the five habitat variables using a Principal Coordinates Analysis (PCoA). Ordination was based on chord distances between sampling units. Stability of ordination axes was evaluated by bootstrap auto-resampling (Pillar 1999). All analyses were performed using the statistical software MULTIV 2.3.10 (Pillar 2004).

Additionally, we performed a cluster analysis to characterize the physiognomies in relation to morphspecies composition. We generated a matrix of chord distances based on morphspecies abundance matrix and utilized UPGMA grouping criterion to draw the dendrogram.

Results

A total of 4,111 individuals were collected, which were associated with the four different forest physiognomies, and distributed into two orders (Entomobryomorpha and Symphypleona) and three families (Entomobryidae, Tomoceridae and Sminthuridae). The family Entomobryidae was the most abundant (92%) and presented eight morphospecies, followed by Tomoceridae (5.5%) with one morphospecies, and Sminthuridae (2.5%) with three morphospecies. The relative abundance of morphospecies significantly varied between different vegetation physiognomies (P = 0.0001). The mixed ombrophyllous forest differed from the *A. angustifolia* plantation (P = 0.0002), *Pinus* spp. plantation (P = 0.0009) and from the *Eucalyptus* spp. plantation (P = 0.001). The *Pinus* spp. plantation differed from the *A. angustifolia* plantation (P = 0.0002) and from the *Eucalyptus* spp. plantation (P = 0.0138) (Fig 1).

Richness also significantly differed between the forest physiognomies (P = 0.0034). The mixed ombrophyllous forest differed from the *Pinus* spp. plantation (P = 0.0362). The *Eucalyptus* spp. plantation differed from the *A. angustifolia* plantation (P = 0.0067) and from the *Pinus* spp. plantation (P = 0.0001) (Fig 2).

Taxa diversity also significantly varied in different forest physiognomies (P = 0.0025). The *Pinus* spp. plantation (mean H'= 1.80) differed from the mixed ombrophyllous forest (mean H' = 1.69) (P = 0.0117) and from the *Eucalyptus* spp. plantation (mean H' = 1.37) (P = 0.0008). The *A. angustifolia* plantation (mean H' = 1.63) differed from the *Eucalyptus* spp. plantation (P = 0.0085).

The composition of the understory Collembola morphospecies was summarized through the PCoA into two principal axes which explained 80% of the total variation

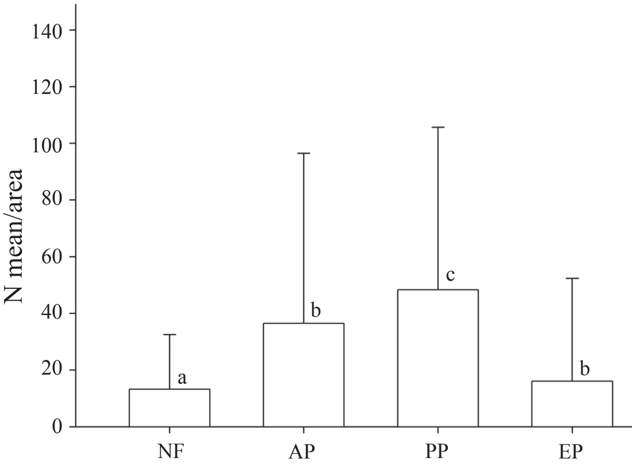

Fig 1 Average abundance of Collembola specimens collected from the understory in 12 sampling areas in the FLONA-SFP, from September 2003 to August 2004. Vegetation physiognomies: (NF = mixed ombrophyllous forest; AP = *Araucaria* spp. plantation; PP = *Pinus* spp. plantation; EP = *Eucalyptus* spp. plantation). Different letters indicate significant differences. Bars indicate the standard error.

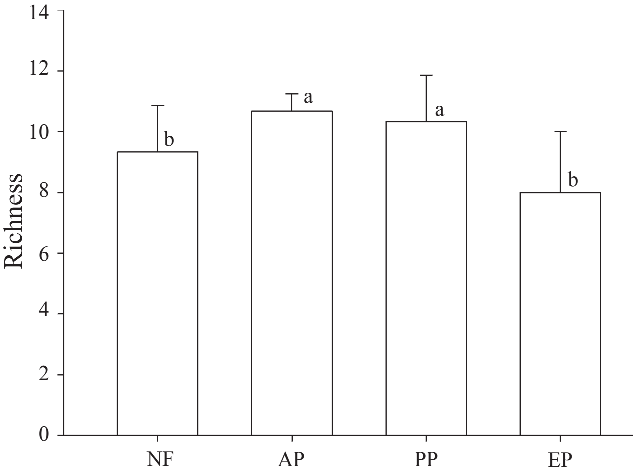

Fig 2 Average richness of Collembola morphospecies collected from the understory in 12 sampling areas in the FLONA-SFP, from September 2003 to August 2004. Vegetation physiognomies: (NF = mixed ombrophyllous forest; AP = *Araucaria* spp. plantation; PP = *Pinus* spp. plantation; EP = *Eucalyptus* spp. plantation). Different letters indicate significant differences. Bars indicate the standard error.

(axis 1 = 48% and axis 2 = 32%). Along the first axis the environmental variables associated were shrub (r = -0.86) and fern (r = 0.85), while along the second axis the associated variables were liana (r = -0.98) and tree (r = 0.79) (Fig 3). The grass variable was eliminated from the analysis as it showed collinearity with the fern variable.

The resulting cluster dendrogram showed that *A. angustifolia* and *Pinus* spp. plantations exhibited higher similarities based on morphospecies composition, whilst mixed ombrophyllous forest exhibited the most dissimilar community composition (Fig 4).

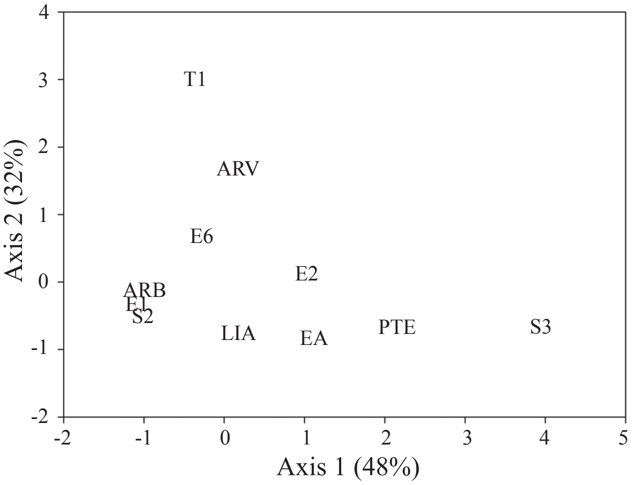

Fig 3 Correspondence Analysis between Collembola morphospecies described by habitat types (ARV = tree; ARB = shrub; LIA = liana; PTE = fern). Only morphspecies correlated to ordination axes are shown (T1 = Tomoceridae; E1, E2, E4 and E6 = Entomobryidae sp.1, sp.2, sp. 4 and sp.6; S2 and S3 = Sminthuridaesp.2 and sp.3).

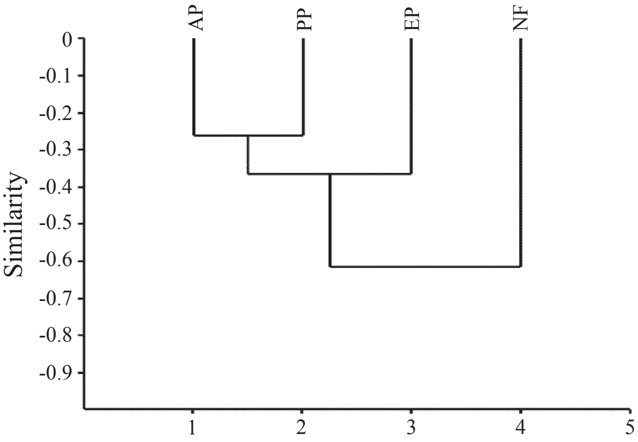

Fig 4 Cluster analysis dendrogram of four physiognomies in southern Brazil mixed ombrophyllous forest based on understory springtail abundances. The analysis was based on chord distance between vegetation physiognomies and UPGMA grouping criterion. Indicated resulting groups were significant after bootstrap resampling (1,000 iteractions). NF = mixed ombrophyllous forest; AP = *Araucaria* spp. plantation; PP = *Pinus* spp. plantation; EP = *Eucalyptus* spp. plantation.

Discussion

Our hypothesis that higher springtail diversity should be found in the native forest was not entirely corroborated. The higher abundance of collembolans in the *Pinus* spp. plantation areas in relation to the other forest physiognomies might result from differences in the understory density. Baldissera *et al* (2008) found the highest number of vegetation touches (which confers higher understory density) in *Pinus* spp. plantation areas. Selective logging and long woodcutting cycle are usual practices in the study area, particularly in *Pinus* spp. plantations. The characteristic canopy openness contributes to the development of an understory vegetation, which might affect the springtails abundance in cultivated areas. In the same way, the difference in richness found among the *Eucalyptus* spp., *Pinus* spp. and *A. angustifolia* plantations might be generated by the understory density, since it was much less developed in *Eucalyptus* spp. plantations, which were younger than other areas and dominated by grasses.

Understory density highlights the importance of these sites as foraging, mating and sheltering sites for springtails. Microhabitat patches can input remarkable physical and biological complexity to the understory environment. These microhabitats presumably increase species richness of arboreal arthropods by means of the increment in the diversity of available niches. The heterogeneity hypothesis (Simpson 1949, MacArthur & Wilson 1967, Lack 1969) supposes that structurally complex habitats can provide more niches and diverse modes of environmental resources for exploitation, increasing species diversity. The diversity difference among the forest physiognomies was probably related to the fact that *Pinus* spp. and *A. angustifolia* plantations present more resources, expressed as vegetation quantity, available for sustaining higher springtail abundance and richness. Further, according to Yoshida & Hijii (2005), several detritivorous and fungivorous arthropods, including Collembola, occur not only in dead leaves, but also in functional leaves, justifying its abundance in the denser understory of those plantations.

The remarkable dominance of the Entomobryomorpha found in the present study might result from its morphological and behavioral characteristics. Entomobryomorpha presents advantage against predators, like the presence of inedible substances on the body, as well as bristles and scales that prevent water loss (Bellinger *et al* 1996). Furthermore, Bellinger *et al* (1996) stressed that in very humid environments, species typically found in the soil, as those from the Entomobryomorpha, can move to more elevated vegetation strata, inhabiting even tree crowns and epiphytes, which may also influence their higher abundance in this stratum, since in the shade of closed, several layered canopy, the moist microclimate and light conditions remain fairly constant and favor the growth of fungi and other decomposers (Nummelin & Zilihona 2004). Joner F (unpublished data), in the same study area, found a dominance of springtails in the soil invertebrate fauna, although the taxa were not identified. Noteworthy, the same author did not found differences in springtail abundance between native and cultivated areas, indicating a possible difference in the resource availability for the investigated species when comparing soil and understory.

The result we found in terms of the composition of Collembola morphospecies related to the habitat variables shrub, fern, liana and tree shows that in many habitats the plant community structure determines the environmental physical structure, influencing the distribution and interactions of animal species (Lawton 1983). Identifying the structural key of the vegetation has important implications for biodiversity management and conservation. For understory springtails, the presence of Entomobryidae morphospecies and Sminthuridae sp.2 were more associated with shrubs and lianas and Sminthuridae sp.3 was related to ferns. These vegetation forms were related to *Pinus* spp. and *A. angustifolia* plantations and we could infer that this higher amount of resources in the form of decomposed plants, which stimulates fungi and bacteria growth, could be shared by more springtail populations. Additionally, the presence of two morphospecies that belong to different families strongly related to bushes (Entomobryidae sp. 1 and Sminthuridae sp.2) indicate there is a separation of resources exploited by them. This statement is further supported by the separation of habitat preference exhibited by the other Entomobrydae morphospecies (lianas and ferns), indicating the possible dominance of Entomobrydae sp. 1 over the other morphospecies of this family. The Tomoceridade morphospecies was related to trees, which are the highest structures. It is possible that this morphotype was able to climb higher than the others. Further studies in this system must emphasize the study of individual springtails morphospecies habitat and resource preferences to shed light on the mechanisms underlying the patterns we reported here.

We conclude that, despite of the potential negative effects, some long-term human disturbance regimes act on community parameters of understory promoting Collembola biological diversity.

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