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Soil macrofauna in areas with different successional vegetation stages after *Eucalyptus grandis* harvest in Brazil

Macrofauna do solo em áreas com diferentes estágios de vegetação sucessional após a colheita de *Eucalyptus grandis* no Brasil

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Highlights

There was a substitution in the faunistic composition between plant formations.
The occurrence of predators indicated good structure of the trophic community.
Spiders were important indicators of environmental quality.
Macrofauna differentiated between litter and soil layers.

Abstract

The objective of this study was to evaluate the composition of soil macrofauna over different periods after the harvest of *Eucalyptus grandis* to understand the ecological restoration process. Data collection was carried out in each climatic season by the "Tropical Soil Biology and Fertility" Program. In general, 25,789 individuals were collected from the soil macrofauna and distributed in 26 taxonomic groups, with the Formicidae family being the most abundant. Of the individuals found, 7,418 were collected during autumn, 7,320 in summer, 5,553 in winter, and 5,498 in spring. The soil macrofauna was influenced by seasonality, with a higher density of individuals in autumn and summer. Regarding functional groups, social groups were dominant in all areas and seasons, comprising 74.50% of the total number of individuals. The detritivores group comprised 17.98% of the total individuals. Herbivores, snails, and slugs accounted for 3.98% of the total individuals. The functional groups detritivores, herbivores, and predators were more abundant in the litter, while the social groups were predominant in the soil depths of 0 to 30 cm. As the forest progressed, the richness of the macrofauna groups increased, demonstrating the influence of successional dynamics on the composition of the soil macrofauna.

Key words: Composition of soil macrofauna. Taxonomic groups. Seasons. Successional dynamics.

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Resumo

O objetivo deste estudo foi avaliar o processo de restauração ecológica por meio da composição da macrofauna do solo em diferentes períodos após a colheita de *Eucalyptus grandis.* As coletas de dados foram realizadas em cada estação climática usando o método recomendado pelo Programa “Tropical Soil Biology and Fertility”. No geral, foram coletados 25.789 indivíduos da macrofauna do solo, distribuídos em 26 grupos taxonômicos, destacando-se a família Formicidae com maior abundância. Dos indivíduos encontrados, 7.418 foram coletados no outono, 7.320 no verão, 5.553 no inverno e 5.498 na primavera. A macrofauna do solo foi influenciada pela sazonalidade, com maior densidade de indivíduos no outono e no verão. Em relação aos grupos funcionais, os sociais foram dominantes em todas as áreas e estações do ano, compreendendo 74,50% do total de indivíduos. O grupo dos detritívoros representou 17,98%. Herbívoros, caracóis e lesmas representaram 3,98% do total de indivíduos. Os grupos funcionais detritívoros, herbívoros e predadores foram mais abundantes na serapilheira, enquanto os grupos sociais predominaram nas profundidades do solo de 0 a 30 cm. À medida que o estágio sucessional da floresta progrediu, a riqueza dos grupos da macrofauna aumentou, evidenciando a influência da dinâmica sucessional na composição da macrofauna do solo.

Palavras-chave: Composição da macrofauna do solo. Grupos taxonômicos. Estações do ano. Dinâmica sucessional.

Introduction

Soil macroinvertebrates are sensitive to biological, physical, and chemical changes in the environment due to soil management and the crop used. Depending on the method and its impact on the environment, such management can affect certain populations; therefore, the sensitivity of soil macrofauna plays an important role in the assessment of anthropic activities and can be utilized an indicator of soil quality (Baretta et al., 2011; Góes, Freitas, Lorentz, Vieira, & Weber, 2021).

Bioindicators are organisms that promote litter fragmentation, improve the distribution of organic matter and nutrients, and build galleries that facilitate root penetration, aeration, and the capacity of water infiltration. They also improve the structure of the soil by turning and depositing its excrement, digesting cellulose, lignin, and hemicellulose allowing biological control, and degrading toxic substances in the soil (Baretta et al., 2011). Therefore, macrofauna respond to soil environmental changes and can provide valuable information on the impacts of soil management (Rousseau, Fonte, Téllez, Hoek, & Lavelle, 2013).

Ecological restoration has been implemented with increasing intensity in Brazil, and although soil macroinvertebrates have an important impact on the soil restoration process, these organisms do not receive attention as agents in most ecological restoration projects (Snyder & Hendrix, 2008). The assessment of the restoration efficiency of an area must consider the presence of biodiversity and the degree of recovery through parameters that evaluate the reestablishment of the various forms of organisms, including both flora and fauna (Kageyama, 2001). Therefore, the recovery of populations and faunal composition during succession are strongly associated with the renewal of vegetation, as regenerating forests provide different types and amounts of resources for fauna at various stages (Chazdon, 2012).

In this context, monitoring of soil macrofauna is a method of assessing the functioning of the forest system since it is closely associated with the processes of decomposition and nutrient cycling at the soil-plant interface (Correia & Oliveira, 2000; Mello et al., 2009). Several studies have focused on macrofauna as indicators of soil quality, with the aim of understanding how soil uses interfere with their distribution (Oliveira, Zeppelini, Sousa, Baretta, & Klauberg, 2020; Pompeo, Oliveira, Klauberg, Mafra, & Baretta, 2020; Pereira et al., 2021). In the Vale do Itajaí Region in Santa Catarina State, Brazil, few studies have evaluated the populations of terrestrial invertebrates as indicators of soil quality (M. A. B. Santos et al., 2018), but knowledge of the soil macrofauna in areas with different stages of abandonment after Eucalyptus cultivation are not found in the literature. Therefore, the objective of this study was to evaluate the soil macrofauna in areas characterized by different ages of abandonment of previously managed *Eucalyptus grandis* Hill ex Maiden plantations to understand the ecological restoration process.

Materials and Methods

Study area

The study was carried out in the Vale do Itajaí Region of Santa Catarina State, in the municipality of Brusque, Brazil, in the phytoecological region of the dense submontane rainforest in the Atlantic Forest biome (Klein, 1978). The experimental area is located on the property of the Buettner Company which has a total of 330 ha with *Eucalyptus grandis* plantations and 320 ha with a permanent preservation area (27°02'07"S, 48°54'0"W, 206 masl), in areas that were previously managed with *Eucalyptus grandis* stands and were abandoned at different periods in order to incorporate them into permanent preservation areas.

The climate of the region is characterized as humid subtropical (Cfa), according to the Köppen climate classification, with an average annual temperature of 19.8 °C and average annual precipitation of 1,785 mm (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). The relief varies from undulating to strongly undulating on the slopes and gently undulating on the depressions at the bottom of the valleys. The predominant soil is red-yellow ultisol with a medium clayey texture (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2004).

Data collection

Soil collection was conducted in 2014, one month after the beginning of each climatic season, in areas characterized by different ages of abandonment after the harvesting of *Eucalyptus grandis* stands as follows: a) no forest cover (tree/shrub) and no litter (27°1′59″ S, 48°54′53″ O) (Control1-C1); b) natural regeneration for 5.5 years (27°2′11″ S e 48°54′54″ O) (NR5); c) natural regeneration for 7 years (27°2′3″ S e 48°54′53″ O) (NR7); d) natural regeneration for 9 years (27°2′5″ S e 48°54′40″ O) (NR9); and e) climax forest, with low anthropic interference (27°1′51″ S e 48°54′49″ O) (Control2-C2).

Sampling was performed by the Tropical Soil Biology and Fertility Program, as described by Anderson & Ingram (1993). The sampling points in each area were 10 m apart along the transect. The transects were allocated in a south-north direction, with the exception of NR5, which had an east-west direction due to the shape of this regenerating area.

In each season, eight soil monoliths (25 × 25 cm in area and 30 cm deep) were allocated and extracted per experimental area. The monoliths were subdivided at depths of 0-10, 10-20, and 20-30 cm, totaling eight samples per level of depth and area, with 40 samples and 120 sub-samples in each season. The litter was collected from the same monolith before removal from the soil. New collection transects were defined each season, in the same hydrographic basin and in forests with the same characteristics and successional stages as the first sampling. The transects were located at distances greater than 50 m from each other.

Sample screening was performed manually by separating all individuals with a body diameter greater than 2 mm and storing in 70% alcohol solution (Aquino, 2001). Identification and counting were performed with a binocular magnifying glass, and the individuals were classified to class and order and stage of development as adult and immature. Taxonomic identification was performed according to the specialized literature (Borror & Delong, 1969; Triplehorn & Johnson, 2011) and expert opinions. Subsequently, classes and orders were organized into functional groups (Table 1), according to the predominant feeding and behavioral habits (Borror & Delong, 1969; Triplehorn & Johnson, 2011; Ruppert & Barnes, 1996). With the exception of the social group, represented by the family Formicidae and the Order Isoptera, the class Insecta was not included in this division.

Table 1
Composition of the functional groups selected for the study

Detritivore	Predator	Social	Herbivore
Oligochaeta	Chilopoda	Formicidae	Gastropoda
Diplopoda	Araneae	Isoptera	
Symphyla	Scorpiones		
Amphipoda	Pseudoscorpionida		
Isopoda	Opiliones		
Collembola	Diplura		

Adapted by the author according (Borror & Delong, 1969; Triplehorn & Johnson, 2011; Ruppert & Barnes, 1996).

Data analysis

Comparisons were made between the macrofauna taxonomic groups in the different vegetation stages by the abundance and density of individuals, based on Mueller-Dombois & Ellenberg (1974), the richness of the groups determined by Shannon's diversity index, and the equability of Pielou as described by Magurran (2011). For functional groups, density was assessed at different successional stages of vegetation and litter, and at different soil depths.

The density and richness of the taxonomic and functional groups were tested for normality and homogeneity using the PAST® and SISVAR® software. Two-way ANOVA was performed to verify the differences between the average density of the taxonomic groups and the vertical distribution of the macrofauna, Shannon's diversity index, the Pielou equability index, and richness between areas and between seasons. All ANOVA analyses were complemented by Tukey's test at a 5% probability of error.

Results and Discussion

Composition of the soil macrofauna community

Overall, 25,789 individuals were collected, of which 9,112 were found in NR7, 6,645 in NR5, 4,399 in NR9, 3,763 in C2, and 1,870 in C1 (Table 2). These individuals were distributed in 22, 23, 22, 25, and 17 taxonomic groups, respectively. Areas with low anthropic interference (C2) showed a higher number of taxonomic groups due to the presence of greater plant diversity and favorable microclimates. These areas showed the highest numbers of Amphipoda, Araneae, Blattodea, Chilopoda, Coleoptera, Diptera, Lepidoptera, Neuroptera, Opiliones, Pseudoescorpionida, and Scorpiones. Changes in the composition of macrofauna depending on land use has been previously reported, where areas with low anthropogenic interference showed more stability in terms of soil macrofauna biodiversity when compared with areas with greater interference (Rosa et al., 2015; Silva et al., 2020; Góes et al., 2021).

The soil fauna was influenced by seasonality. Of the 25,789 individuals found during the study, 7,418 were collected during autumn, 7,320 in summer, 5,553 in winter, and 5,498 in spring (Table 3). Several studies have also found that the distribution of soil fauna is influenced by the sampling period (Pompeo et al., 2020; Góes et al., 2021). The largest number of individuals in all seasons occurred in NR7 and NR5, differing statistically from C1, which had the lowest number of individuals. The number of individuals in the NR7 area differed significantly in all seasons from NR9 and C2.

Table 2
Absolute abundance of taxonomic groups present in the study areas after the harvest of *Eucalyptus grandis* in Brazil

Taxonomic groups	C1	NR5	NR7	NR9	C2	ind groups
Acari		1				1
Amphipoda		74	54	66	133	327
Araneae	22	74	104	56	212	468
Blattodea		20	10	14	42	86
Chilopoda	19	52	53	47	88	259
Coleoptera	36	143	184	241	249	853
Collembola	40	410	544	171	275	1,440
Dermaptera		7	19	10	7	43
Diplopoda	3	54	107	57	103	324
Diplura	1	1	4	1	4	11
Diptera	4	36	41	43	68	192
Ephemeroptera	13	1	5		2	21
Formicidae	1,172	4,737	6,435	2,641	1,613	16,598
Gastropoda	4	121	326	352	143	946
Hemiptera	14	95	49	90	47	295
Hymenoptera (not-F)*	26	95	42	106	35	304
Isopoda	26	83	273	96	158	636
Isoptera	127	336	452	66	255	1,236
Lepidoptera		4	7	12	18	41
Neuroptera (larvae)					6	6
Oligochaeta	344	290	388	291	192	1,505
Opiliones		3	1	7	15	26
Orthoptera	1	3	5	14	2	25
Pseudoscorpionida				4	72	76
Scorpiones					6	6
Symphyla	18	5	9	14	18	64
Ind. area	1,870	6,645	9,112	4,399	3,763	25,789

C1: without forest cover; NR5: natural regeneration after 5.5 years; NR7: natural regeneration after 7 years; NR9: natural regeneration after 9 years; C2: climax forest with little anthropic interference.
* (not-F): except Formicidae.

In all seasons, the highest densities of macrofauna were found in areas NR7 and NR5 (Table 3). The density of NR7 differed statistically from C1, NR9, and C2. In contrast, with the exception of the summer season, area C1 displayed the lowest density values, showing a statistically significant difference with areas NR5 and NR7.

In general, the Formicidae family showed the highest abundance in all environments (64.36%), overshadowing the other groups of macrofauna (Table 4). Ants play an important role in the flow of materials in the ecosystem (Baretta et al., 2011) and are generally dominant in tropical soils (approximately 50% of the total abundance). The other groups of invertebrate organisms had little representation when compared to this group.

Table 3
Number of individuals and density (ind m^{-2}) of macrofauna in litter and soil after harvesting of *Eucalyptus grandis* in Brazil

Season	C1	NR5	NR7	NR9	C2	Total
			Individuals numbers*			
Summer	584.0 A	2,207.0 BC	3,161.0 B	947.0 AC	421.0 AC	7,320.0
Autumn	619.0 A	1,861.0 BC	2,060.0 B	1,512.0 AC	1,366.0 AC	7,418.0
Winter	155.0 A	1,430.0 BC	2,209.0 B	838.0 AC	921.0 AC	5,553.0
Spring	512.0 A	1,147.0 BC	1,682.0 B	1,102.0 AC	1,055.0 AC	5,498.0
			Density*			
Summer	389.3 A	1,109.5 BC	1,580.5 B	473.5 AC	210.5 AC	3,763.0
Autumn	418.7 A	930.5 BC	1030.0 B	766.5 AC	683.0 AC	3,829.0
Winter	103.3 A	715.0 BC	1,110.5 B	419.0 AC	461.5 AC	2,809.0
Spring	341.3 A	573.5 BC	841.0 B	551.0 AC	527.5 AC	2,834.0

C1: without forest cover; NR5: natural regeneration after 5.5 years; NR7: natural regeneration after 7 years; NR9: natural regeneration after 9 years; C2: climax forest with little anthropic interference.
*Not significant ($p < 0.05$) between collection periods. The same letters in the same column do not differ significantly according to Tukey's test at the 5% error level.

Table 4
Abundance and percentage of the Formicidae taxonomic group and other groups in the study areas after harvest of *Eucalyptus grandis* in Brazil

Area	Formicidae	%	Other Groups	%	Total
C1	1,172	62.67	698	37.33	1,870
NR5	4,737	71.29	1,908	28.71	6,645
NR7	6,435	70.62	2,677	29.38	9,112
NR9	2,641	60.04	1,758	39.96	4,399
C2	1,613	42.86	2,150	57.14	3,763
Total	16,598	64.36	9,191	35.64	25,789

C1: without forest cover; NR5: natural regeneration after 5.5 years; NR7: natural regeneration after 7 years; NR9: natural regeneration after 9 years; C2: climax forest with little anthropic interference.

Diversity and richness

In all areas studied, the lowest values of the Shannon diversity index were found in summer, with statistically significant differences with winter and spring. Shannon's diversity index ranged from: 1.05 to 1.35 (summer and spring) in C1, 0.93 to 1.71 (summer and winter) in NR5, 0.87 to 1.45 (summer and autumn) in NR7, 1.21 to 2.00 (summer and winter) in NR9, and 1.89 to 2.37 (autumn and winter) in C2 (Table 5). The greatest diversity was found in C2, followed by NR9. C2 showed a statistically significant difference with the other areas and, due to the lower number of dominant groups, it obtained high equability and higher values of diversity, since this area is more structured, providing better trophic conditions and a microclimate favorable to soil macrofauna. This result supports the theory that the permanent vegetation cover of the soil in forests contributes to the conservation of edaphic biodiversity (Silva et al., 2020; Pereira, Baretta, Oliveira, Baretta, & Cardoso, 2020; Góes et al., 2021). It was also found that having a high abundance in the system did not necessarily reflect higher values of diversity, corroborating the results of Ortiz et al. (2019). Therefore, the increase in faunal diversity and the reestablishment of the trophic chain can be an indication that the ecosystem is in balance and self-sustaining (Baretta et al., 2011).

Table 5
Shannon's diversity index, macrofauna uniformity and richness in the litter layer and the soil in the study areas after the harvest of *Eucalyptus grandis* in Brazil

Season/ Area	C1	NR5	NR7	NR9	C2
			Shannon		
Summer	1.05±0.11 (A a)	0.93±0.06 (AB a)	0.87±0.05 (AB a)	1.21±0.10 (B a)	2.05±0.12 (C a)
Autumn	1.30±0.10 (A ab)	1.25±0.07 (AB ab)	1.45±0.06 (AB ab)	1.67±0.07 (B ab)	1.89±0.08 (C ab)
Winter	1.20±0.21 (A b)	1.71±0.07 (AB b)	1.41±0.06 (AB b)	2.00±0.08 (B b)	2.37±0.07 (C b)
Spring	1.35±0.12 (A b)	1.21±0.09 (AB b)	1.35±0.07 (AB b)	1.56±0.09 (B b)	2.27±0.07 (C b)
			Pielou		
Summer	0.41±0.05 (AB a)	0.33±0.02 (A a)	0.30±0.02 (A a)	0.41±0.03 (B a)	0.70±0.04 (C a)
Autumn	0.49±0.04 (AB a)	0.41±0.02 (A a)	0.49±0.02 (A a)	0.56±0.03 (B a)	0.61±0.03 (C a)
Winter	0.52±0.08 (AB b)	0.59±0.03 (A b)	0.48±0.02 (A b)	0.67±0.03 (B b)	0.77±0.03 (C b)
Spring	0.51±0.04 (AB ab)	0.41±0.03 (A ab)	0.44±0.03 (A ab)	0.52±0.03 (B ab)	0.70±0.03 (C ab)
			Richness		
Summer	13±1.0 (A a)	17±1.0 (B a)	18±1.0 (B a)	19±1.0 (B a)	19±1.0 (B a)
Autumn	14±1.0 (A ab)	21±1.0 (B ab)	19±1.0 (B ab)	20±1.0 (B ab)	22±1.0 (B ab)
Winter	10±1.0 (A ab)	18±1.0 (B ab)	19±1.0 (B ab)	20±1.0 (B ab)	22±1.0 (B ab)
Spring	14±1.0 (A b)	19±1.0 (B b)	22±1.0 (B b)	20±1.0 (B b)	25 ±1.0 (B b)

C1: without forest cover; NR5: natural regeneration after 5.5 years; NR7: natural regeneration after 7 years; NR9: natural regeneration after 9 years; C2: climax forest with little anthropic interference.
Capital letters in the same row or lowercase letters in the same column do not differ significantly by Tukey's test at the 5% error level.

The Pielou equability index showed a statistically significant difference between the winter season, which in general obtained the highest index values, and the summer and autumn seasons, where the lowest values were found (Table 5). Pielou's equability index ranged from 0.41 to 0.52 (summer and winter) in C1, 0.33 to 0.59 (summer and winter) in NR5, 0.30 to 0.49 (summer and autumn) in NR7, 0.41 to 0.67 (summer and winter) in NR9, and 0.61 to 0.77 (autumn and winter) in C2. In the NR5 and NR7 areas, the equability values were influenced by the dominance of the Formicidae family (Table 4). The NR7 area had a discontinuous canopy, whereas the NR5 area had a negligible canopy. Therefore, it is possible that the higher incidence of solar irradiation in the areas with a lower density of vegetation likely caused a large evaporation of water from the soil, causing greater temperature variation and a strong impact of rain on the soil, which allowed only certain groups to survive under these conditions.

In general, the richness was lower in the summer season, differing statistically from the spring, which had the highest values. Richness varied from 10 to 14 in C1 (winter and autumn, spring), 17 to 21 in NR5 (winter and autumn), 18 to 22 in NR7 (summer and spring), 19 to 20 in NR9 (summer and autumn, winter, spring), and 19 to 25 in C2 (summer and spring) (Table 5). Area C1 had the lowest wealth values, differing statistically from the other areas.

In addition, there was a clear difference in the composition of fauna between plant formations, that is, the orders Neuroptera, Pseudoscorpionida, and Scorpiones occurred frequently in the litter in area C2 (Table 2), along with Araneae. In general, the survival of these predators also depends on the diversity of prey that is usually most abundant in more balanced environments (Rosa, Santos, Brescovit, Mafra, & Baretta, 2018), which justifies the low occurrence or absence of these groups in recently abandoned areas (Ruppert & Barnes, 1996). Therefore, changes in the physical soil properties and the food supply could affect different groups of organisms (Kladivko, 2001).

Vertical distribution

In general, the highest densities of individuals were found at a depth of 0-10 cm (Table 6). This layer has more intense biological activity and the material that makes up the litter influences the number of individuals present (Baretta et al., 2011).

Table 6

Average density (ind m^{-2}) of the taxonomic groups of the soil macrofauna in the litter and soil layers in the study areas after the harvest of *Eucalyptus grandis* in Brazil

Season/Area		C1	NR5	NR7	NR9	C2
Summer	Litter	--	1,086 AB ab	1,286 A ab	618 AB ab	514 B ab
	0-10 cm	888 AB a	2,162 AB a	3,484 A a	1,116 AB a	284 B a
	10-20 cm	266 AB ab	906 AB ab	1,360 A ab	160 AB ab	38 B ab
	20-30 cm	14 AB b	284 AB b	192 A b	0 AB b	6 B b
Autumn*	Litter	--	1,180 a	1,752 a	1,786 a	862 a
	0-10 cm	1,068 a	1,160 a	2,096 a	994 a	1,756 a
	10-20 cm	82 b	1,120 b	258 b	278 b	102 b
	20-30 cm	106 b	264 b	18 b	6 b	8 b
Winter*	Litter	--	1,802 a	3,510 a	658 a	790 a
	0-10 cm	230 ab	944 ab	792 ab	942 ab	946 ab
	10-20 cm	60 b	72 b	114 b	70 b	96 b
	20-30 cm	20 b	44 b	26 b	6 b	12 b
Spring*	Litter	--	610 ab	902 ab	1,374 ab	806 ab
	0-10 cm	838 a	1,396 a	2,350 a	644 a	1,126 a
	10-20 cm	168 bc	258 bc	104 bc	160 bc	156 bc
	20-30 cm	18 c	30 c	26 c	26 c	22 c

C1: without forest cover; NR5: natural regeneration after 5.5 years; NR7: natural regeneration after 7 years; NR9: natural regeneration after 9 years; C2: climax forest with little anthropic interference.
* Not significant ($p < 0.05$) between the study areas.
Matching capital letters in the same line or lower case letters in the same column do not differ significantly by Tukey's test at the 5% error level.

In the summer, NR7 presented the highest densities of macrofauna, differing statistically from C2 , where the lowest values were found. This relates to the high number of Formicidae present in the NR7 area. In general, the highest densities of individuals were observed at a depth of 0-10 cm and the lowest at a depth of 20-30 cm, with a statistically significant difference between these depths.

In autumn and spring, the highest density of macrofauna in litter occurred in the NR9 area. At a depth of 0-10 cm, a higher density of individuals was detected in NR7, whereas in NR5 the densities were greater at depths of 10-20 and 20-30 cm. In winter, the highest density of individuals occurred in NR7, with the exception of the 20-30 cm layer, where the greatest density was observed in NR5.

Regarding the depths, in the summer and spring, the depth of 0-10 cm differed statistically from 20-30 cm, with the lowest densities of individuals at the greatest depths. In autumn, the density of individuals in the litter layer and at a depth of 0-10 cm differed significantly from the depths of 10-20 and 20-30 cm. In spring, the depth of 0-10 cm with the highest density of soil individuals differed significantly from the layer of 20-30 cm, with the lowest density. From these results, it can be inferred that, with an increase in depth, there is a decrease in biological activity. The highest concentration of biological activity in the topsoil was also found by Baretta, Santos, Ribeiro, & Klauberg (2005).

Functional groups

The social group, where ants prevailed, was dominant in all areas studied, comprising 74.50% of the total number of individuals and differing statistically in relation to the other areas (Table 7). This group dominated NR5 and NR7, with the highest number of individuals, and the lowest number in C2. It should be noted that ants are dominant animals in most terrestrial ecosystems, including tropical forests (Korasaki, Morais & Braga, 2013). Therefore, the specificity and fidelity of ant species to a habitat suggests that these species can be used as environmental indicators in the recovery of forest areas (Schmidt, Ribas, & Schoereder, 2013).

Table 7
Mean density (ind m^{-2}) of taxonomic groups of soil macrofauna in litter and soil layers after harvesting *Eucalyptus grandis* in Brazil

Group/Area	C1	NR5	NR7	NR9	C2
			Functional Groups *		
Detritivore	54 A	115 A	172 A	87 A	110 a
Predator	5 A	16 A	21 A	14 A	50 a
Social	162 B	634 B	861 B	338 B	234 b
Herbivore	1 A	15 A	41 A	44 A	18 a

C1: without forest cover; NR5: natural regeneration after 5.5 years; NR7: natural regeneration after 7 years; NR9: natural regeneration after 9 years; C2: climax forest with little anthropic interference.
* Not significant (p <0.05) between the study areas.
The same letters in the same column do not differ significantly according to Tukey's test at the 5% error level.

The detritivores group comprised 17.98% of the total number of individuals, predominating NR7 and NR5 with the highest density of individuals. This value was highlighted by the presence and action of Collembola, which are soil organisms with wide morphological diversity and sensitivity to changes in the soil; therefore, they are good indicators of soil quality (M. A. B. Santos et al., 2018; Oliveira et al., 2020). Collembola are in a constant process of formation and fragmentation of litter; they feed on debris and microorganisms and are fundamental in the decomposition of organic matter (Hopkin, 1997). Therefore, detritivores play a fundamental role in such areas as litter decomposition, and microbial population regulation (Giller, 1996).

Herbivores, snails, and slugs accounted for 3.98% of the total number of individuals and obtained the highest density values in the NR9 area. This area has several watercourses, which consequently provide greater humidity to the region compared to the other areas studied. This may explain the high density of herbivores in the environment, as these individuals survive in humid places and avoid the sun and/or excess heat, which cause dehydration (E. Santos, 1982). Predators constituted 3.54% of the total number of individuals in the area. The highest density was found in area C2 and lowest in area C1 (Table 7). The significant occurrence of predators may indicate a good structuring of the trophic community (Cunha, Correia, Pereira, Pereira, & Leles, 2012).

The functional groups detritivores, herbivores, and predators (mainly spiders) were more abundant in the litter, while the social groups were predominant in the soil depths of 0 to 30 cm (Fig. 1). The ability of spiders to proliferate across contiguous areas is directly related to soil management conditions, as the type of vegetation acts as a filter for their families (Rosa et al., 2019). The spiders inhabiting the litter represent greater than 43% of the species of spiders in a forest, representing the largest biomass of this guild (Uetz, 1979). Ecological stability in natural vegetation favors the accumulation of quantity and quality of litter. In addition, various soil organisms that are attracted by the diversity of plant residues are potential prey for spiders. Thus, the content of organic matter becomes an indirect determinant for a greater abundance of spider families (Rosa et al., 2018). These individuals are considered fundamental to the hierarchy of the food chain and directly and indirectly influence various factors in agricultural and forest ecosystems (Pereira et al., 2021). Social insects such as ants, termites, and earthworms, are considered "soil engineers" and can modify the availability and accessibility of resources to other organisms by excavating the soil and unearthing a wide variety of organic mineral structures (Lavelle, 1996). These invertebrates are important in nutrient cycling and the decomposition of plant material (Baretta et al., 2011), and they are commonly related to fertile soils and widely used as indicators of environmental quality (Nadolny et al., 2020).

Conclusions

As the successional stage of the forest advance, the richness and diversity of the macrofaunal groups increase, demonstrating the influence of successional dynamics on the composition of the soil fauna.

Seasonality influence macrofaunal density, with the greatest reduction in winter.

The distribution of macrofauna in the vertical profile of the soil decrease with depth.

Thus, soil macrofauna is a good indicator of the quality of the environment, since there is greater richness of groups and the presence of predators in the control area with advanced forest.

References

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift, 22*(6), 1-18. doi: 10.1127/0941-2948/2013/0507

Anderson, J. M., & Ingram, J. S. I. (1993). *Tropical soil biology and fertility: a handbook of methods.* Wallingford: CAB International.

Aquino, A. M. (2001). *Manual para a coleta da macrofauna do solo.* Seropédica: EMBRAPA Agrobiologia.

Baretta, D., Santos, J. C. P., Ribeiro, S. F., & Klauberg, O., Fº. (2005). Efeito do monocultivo de pinus e da queima do campo nativo em atributos biológicos do solo no Planalto Sul. *Revista Brasileira de Ciência do Solo, 29*(5), 715-724. doi: 10.1590/S0100-06832005000500007

Baretta, D., Santos, J. C. P., Segat, J. C., Geremia, E. V., Oliveira, L. C. I., Fº., & Alves, M. V. (2011). Fauna edáfica e qualidade do solo. *Tópicos em Ciência do Solo, 7*, 119-170.

Borror, D. J., & Delong, D. M. (1969). *Introdução ao estudo dos insetos.* São Paulo: EDUSP.

Chazdon, R. L. (2012). Regeneração de florestas tropicais. *Boletim do Museu Paraense Emílio Goeldi, 7*(3), 195-218.

Correia, M. E. F., & Oliveira, L. C. M. de. (2000). *Fauna de solo: aspectos gerais e metodológicos.* Seropédica: EMBRAPA Agrobiologia.

Cunha, F. V., Neto, Correia, M. E. F., Pereira, G. H. A., Pereira, M. G., & Leles, P. S. S. (2012). Soil fauna as an indicator of soil quality in forest stands, pasture and secondary forest. *Brazilian Journal of Soil Science, 36*(5), 1407-1417. doi: 10.1590/S0100-06832012000500004

Empresa Brasileira de Pesquisa Agropecuária (2004). *Solos do Estado de Santa Catarina.* (Boletim de Pesquisa e Desenvolvimento, n. 46). Rio de Janeiro: EMBRAPA Solos.

Giller, P. (1996). The diversity of soil communites, the "poor man's tropical rain forest". *Bioversity and Conservation, 5,* 135-168.

Góes, Q. R., Freitas, L. R., Lorentz, L. H., Vieira, F. C. B., & Weber, M. A. (2021). Análise da fauna edáfica em diferentes usos do solo no Bioma Pampa. *Ciência Florestal, 31*(1), 123-144. doi: 10.5902/1980509832130

Hopkin, S. P. (1997). *Biology of the Springtails (Insecta: Collembola).* Oxford: Oxford University Press.

Kageyama, P. Y. (2001). *Restauração da mata ciliar: manual para recuperação de áreas ciliares e microbacias.* Rio de Janeiro: SEMADS.

Kladivko, E. J. (2001). Tillage systems and soil ecology. *Soil and Tillage Research, 61*(1-2), 61-76. doi: 10.1016/S0167-1987(01)00179-9

Klein, R. M. (1978). *Mapa fitogeográfico do estado de Santa Catarina.* Itajaí: Herbário Barbosa Rodrigues.

Korasaki, V., Morais, J. W. de, & Braga, R. F. (2013). Macrofauna. In F. M. S. Moreira, J. E. Cares, R. Zanetti, & S. L Stürmer (Eds.), *O ecossistema solo: componentes, relações ecológicas e efeitos na produção vegetal* (pp. 183-200). Lavras: UFLA.

Lavelle, P. (1996). Diversity of soil fauna and ecosystem function. *Biology International,* (33), 3-16.

Magurran, A. E. (2011). *Medindo a diversidade biológica.* Curitiba: UFPR.

Mello, Z. V., Brown, G. G., Constantino, R., Louzada, J. N. C., Luizão, F. J., Morais, J. W., & Zanetti, R. (2009). A importância da meso e macrofauna do solo na fertilidade e como bioindicadores. *Boletim Informativo da Sociedade Brasileira do Solo, 34*(1), 39-43.

Mueller-Dombois, D., & Ellenberg, M. (1974). *Aims and methods of vegetation ecology.* New York: Wiley e Sons.

Nadolny, H., Santos, A., Demetrio, W., Ferreira, T., Maia, L. S., Conrado, A. C.,... Brown, G. (2020). Recommendations for assessing earthworm populations in Brazilian ecosystems. *Pesquisa Agropecuária Brasileira, 55,* e01006. doi: 10.1590/s1678-3921.pab2020.v55.01006

Oliveira, L. C. I., Fº., Zeppelini, D., Sousa, J. P., Baretta, D., & Klauberg, O., Fº. (2020). Collembola community structure under different land management in subtropical Brazil. *Annals of Applied Biology, 177*(3), 294-307. doi: 10.1111/aab.12622

Ortiz, D. C., Santos, M. A. B., Oliveira, L. C. I., Fº., Pompeo, P. N., Niemeyer, J. C., Klauberg, O., Fº.,... Baretta, D. (2019). Diversity of springtails (Collembola) in agricultural and forest systems in Southern Santa Catarina. *Biota Neotropica, 19*(3), e20180720. doi: 10.1590/1676-0611-BN-2018-0720

Pereira, J. M., Baretta, D., Oliveira, L. C. I., Fº., Baretta, C. R. D. M., & Cardoso, E. J. B. N. (2020). Fauna edáfica e suas relações com atributos químicos, físicos e microbiológicos em Floresta de Araucária. *Ciência Florestal, 30*(1), 242-257 doi: 10.5902/1980509831377

Pereira, J. M., Cardoso, E. J. B. N., Brescovit, A. D., Oliveira, L. C. I., Fº., Segat, J. C., Baretta, C. R. D. M., & Baretta, D. (2021). Soil spiders (Arachnida: Araneae) in native and reforested Araucaria forests. *Scientia Agricola, 78*(3), e20190198. doi: 10.1590/1678-992X-2019-0198

Pompeo, P. N., Oliveira, L. C. I., Fº., Klauberg, O., Fº., Mafra, A. L., & Baretta, D. (2020). Coleoptera diversity and soil properties in land use systems. *Floresta e Ambiente, 27*(3), e20180068. doi: 10.1590/2179-8087.006818

Rosa, M. G., Brescovit, A. D., Baretta, C. R. D. M., Santos, J. C. P., Oliveira, L. C. I., Fº., & Baretta, D. (2019). Diversity of soil spiders in land use and management systems in Santa Catarina, Brazil. *Biota Neotropica, 19*(2), e20180619. doi: 10.1590/1676-0611-BN-2018-0619

Rosa, M. G., Klauberg, O., Fº., Bartz, M. L. C., Mafra, A. L., Sousa, J. P. F. A., & Barreta, D. (2015). Macrofauna edáfica e atributos físicos e químicos em sistemas de uso do solo no Planalto Catarinense. *Revista Brasileira de Ciência do Solo, 39*(6), 1544-1553. doi: 10.1590/01000683rbcs20150033

Rosa, M. G., Santos, J. C. P., Brescovit, A. D., Mafra, A. L., & Baretta, D. (2018). Spiders (Arachnida: Araneae) in Agricultural Land Use Systems in Subtropical Environments. *Revista Brasileira de Ciência do Solo, 42*(6), e0160576. doi: 10.1590/18069657rbcs20160576

Rousseau, L., Fonte, S. J., Téllez, O., Hoek, R. van der, & Lavelle, P. (2013). Soil macrofauna as indicators of soil quality and land use impacts in smallholder agroecosystems of western Nicaragua. *Ecological Indicators, 27,* 71-82. doi: 10.1016/j.ecolind.2012.11.020

Ruppert, E. E., & Barnes, R. D. (1996). *Zoologia dos invertebrados.* São Paulo: Roca.

Santos, E. (1982). *Moluscos do Brasil: vida e costumes.* Belo Horizonte: Itatiaia.

Santos, M. A. B., Oliveira, L. C. I., Fº., Pompeo, P. N., Ortiz, D. C., Mafra, A. L., Klauberg, O., Fº., & Baretta, D. (2018). Morphological diversity of springtails in land use systems. *Revista Brasileira de Ciência do Solo, 42,* e0170277. doi: 10.1590/18069657rbcs20170277

Schmidt, F. A., Ribas, C. R., & Schoereder, J. H. (2013). How predictable is the response of ant assemblages to natural forest recovery? Implications for their use as bioindicators. *Ecological Indicators, 24,* 158-166. doi: 10.1016/j.ecolind.2012.05.031

Silva, D. C., Pereira, J. M., Ortiz, D. C., Oliveira, L. C. I., Fº., Pinto, L. V. A., & Baretta, D. (2020). Fauna edáfica como indicadora de qualidade do solo em fragmentos florestais e área sob cultivo do cafeeiro. *Brazilian Journal of Development, 6,* 14795-14816. doi: 10.1016/j.ecolind.2012.05.031

Snyder, B. A., & Hendrix, P. F. (2008). Current and potential roles of soil macroinvertebrates (Earthworms, Millipedes, and Isopods) in ecological restoration. *Restoration Ecology, 16*(4), 629-636. doi: 10.1111/j.1526-100X.2008.00484.x

Triplehorn, C. A., & Johnson, N. F. (2011). *Estudo dos insetos.* São Paulo: Cengage Learning.

Uetz, G. W. (1979). The influence of variation in litter habitat on spider communities. *Oecologia, 40,* 29-42.