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Litter Decomposition of Two Pioneer Tree Species and Associated Soil Fauna in Areas Reclaimed after Surface Coal Mining in Southern Brazil

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ABSTRACT: Decomposition of leaf litter from pioneer tree species and development of associated soil meso- and macrofauna are fundamental for rehabilitation processes in reclaimed coal mining areas. The aim of our study was to evaluate decomposition of *Schinus terebinthifolius* and *Senna multijuga* to answer three basic questions: (i) What type of leaf litter degrades faster in reclaimed coal min\ing areas? (ii) Is leaf decomposition correlated with the stage of regeneration and exposure time? and (iii) Does the type of leaf litter influence the diversity and abundance of the soil meso- and macrofauna species collected? Experiments were carried out in the state of Santa Catarina in three areas at different stages of regeneration. A total of 32 litter bags (16 per plant species) were used per study site, and they were divided into four blocks along a transect. Sampling was carried out at 15, 30, 60, and 120 days, when one litter bag per species/block was removed at random. We found no statistically significant difference between *S. terebinthifolius* and *S. multijuga* in regard to leaf-litter decomposition rate. However, the "area", "litter bag exposure time" and "fauna richness" factors were significant. Therefore, shading and time of reclamation of areas contribute to an increase in decomposition rate and in development of soil meso- and macrofauna communities.

Keywords: soil fauna, litter bags, leaf-litter decomposition, reclaimed areas.

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INTRODUCTION

Although coal extraction is important for the energy sector, activities related to it are a major source of pollution and environmental degradation (Costa and Zocche, 2009), and open-pit mining is a practice that has greatly affected the environment, especially the landscape in the southern region of the state of Santa Catarina, Brazil. During open-pit mining, layers are removed in a disorganized manner (Dias, 1998), which disrupts the characteristic soil horizons through inversion of layers, generating conic spoil heaps, with sedimentary rocks at the top of the pile and topsoil at the bottom (De Luca and Gastaldon, 1999). Consequently, there is loss of fertile soil, removal of vegetation, destruction of the seed bank, and decrease in the biodiversity of soil fauna, which directly affects soil functional characteristics (Sanchez and Formoso, 1990; Podgaiski et al., 2007; Citadini-Zanette et al., 2009; Klein et al., 2009).

After coal mining, companies are obliged to reclaim the land in the degraded areas. Initially, the landscape and topography are reclaimed by soil reconstruction. In this process, a compacted clay layer with limestone and nutrients is incorporated in the upper soil layers set aside and reserved during coal mining. Subsequently, plant cover is restored, which includes the use of native and/or exotic herbaceous plants and trees, to re-establish ecological integrity (Costa and Zocche, 2009; Campos et al., 2010).

With generation of the litter layer, provided by senescent materials that fall from the above ground parts of established plants, a substrate is provided for decomposer organisms to act. The decomposers, in turn, fragment and degrade plant material (Wardle et al., 2004), restoring organic matter in the upper soil layers and providing nutrients for biota (Andrade et al., 2003; Scheer, 2008). Such processes are critical for restoration of nutrient cycling processes and soil formation since they provide improved fertility conditions (Andrade et al., 2003; Lavelle et al., 2006; Scheer, 2008; Podgaiski et al., 2011).

Nutrient cycling in forest ecosystems, implemented or natural, has been widely studied in order to gain greater understanding of nutrient dynamics in these environments. This knowledge not only helps in understanding the functioning of the ecosystem, but also in seeking information to establish management practices for reclamation of degraded areas and maintenance of local productivity in the reclamation process (Souza and Davide, 2001; Selle, 2007). Several studies claim that decomposition rates are mainly influenced by three factors, namely: (a) environmental factors (temperature, humidity, seasonality, and pedological factors), (b) litter chemical composition (lignin rates, cellulose, phenolic compounds, mineral elements, and stimulating or allelopathic substances), which vary according to the plant species, and (c) the diversity and abundance of detritivores and decomposers (Swift et al., 1979; Aerts, 1997; Gonzalez and Seastedt, 2001; Andrade et al., 2003; Loureiro et al., 2006; Illig et al., 2008; Scheer, 2008; Souto et al., 2008).

In general, the invertebrate detritivores (soil meso- and macrofauna), such as isopods, millipedes, beetles, termites, springtails, and mites, aerate the soil and fragment litter, promoting the action of decomposing microorganisms (fungi and bacteria), which are responsible for mineralization processes and humification of organic matter in the soil, thus providing basic inorganic molecules (such as ammonia, nitrate, phosphate, CO_2, and water) for plant nutrition and other microorganisms (Aerts, 1997; Correia and Oliveira, 2005; Lima et al., 2010; Podgaiski et al., 2011).

There have been very few studies on litter decomposition and associated detritivorous fauna undertaken in Brazil, especially in areas degraded by coal mining activities. One such study conducted by Podgaiski and Rodrigues (2010) evaluated the decomposition of three pioneer plant species and the associated detritivore fauna in two areas influenced by coal ash deposition. There is a need to expand research efforts to improve our understanding of the dynamics of the decomposition process and allow verification of contributions of plant species to the nutrient cycling processes and restoration of areas after coal mining. Therefore, the aim of our study was to evaluate decomposition of leaf litter from two pioneer species, *Schinus terebinthifolius* Raddi (Anacardiaceae) and *Senna multijuga* (Rich.) Irwin & Barneby (Caesalpiniaceae) to answer three basic questions: (i) What type of leaf litter decomposes faster in areas reclaimed after coal mining?; (ii) Does the type of leaf litter influence the diversity and abundance of the soil meso- and macrofauna species collected? and (iii) Is leaf decomposition correlated with the stage of regeneration and exposure time?

MATERIALS AND METHODS

Study areas

This study was carried out in three areas located in the municipalities of Treviso (Areas A1 and A2 - 28° 32' S and 49° 28' W) and Lauro Müller (A3 - 28° 25' S and 49° 25' W) in the State of Santa Catarina, Brazil. Surface coal mining occurred during the period from 1982 to 1989 in areas A1 and A2, and from 1994 to 1997 in area A3. In areas A1 and A2, reclamation processes occurred in the year 2012 and in A3 in 2010 by removing coal waste and reconstructing the soil. In this process, a compacted clay layer with limestone and nutrients was incorporated in the upper soil layers set aside and reserved during coal mining, resulting in a 0.20 to 0.25 m thick clay layer. For restoration of vegetation, herbaceous and tree seedlings were planted in rows with 2 m between seedlings and rows, thus offering a density of 2,500 plants ha^{-1} (Santa Catarina, 2013).

Despite similarities in the reclamation process used in the three areas, there are differences in the establishment of pioneer species. In area A1, *Schinus terebinthifolius* Raddi is predominant, as well as *Eucalyptus* spp., several Asteraceae species (such as *Baccharis* spp.), and grass species (such as *Brachiaria* spp.). Area A2 has higher moisture due to a flat terrain and proximity to a swamp, with predominantly herbaceous species such as grasses and bushes (*Baccharis* spp.), as well as individual arboreal species such as *Pseudobombax grandiflorum* (Cav.) A.Robyns, *S. terebinthifolius*, *Senna multijuga* (Rich.) H.S.Irwin & Barneby, and *Mimosa scabrella* L. Area A3 has higher density and richness of plant species, due to a longer period for establishment of vegetation. This area included several species of grasses and bushes such as *Baccharis* spp. and *Solanum pseudocapsicum* L., exotic tree species such as *Eucalyptus* spp., and native tree species such as *Schinus terebinthifolius*, *Eugenia multicostata* D. Legrand, *Eugenia uniflora* L., and *Tabernaemontana catharinensis* A. DC., among others (Rocha-Nicoleite et al., 2013).

According to the Köppen classification system, the climate in the southern region of Santa Catarina is subtropical humid (Cfa) (Peel et al., 2007), with no established dry season and with hot summers, annual rainfall ranging from 1,400 to 1,800 mm, and mean annual temperature of 19 °C. During the winter there are thermal gradients below 10 °C, allowing frosts (IPAT, 2000).

Plant species

Leaves from two pioneer tree species, widely employed in the reclamation of degraded areas after surface coal mining in southern Santa Catarina were used (Bortoluzzi et al., 2011; Rocha-Nicoleite et al., 2013). They are:

(1) *Schinus terebinthifolius*, known as Brazilian peppertree, is a native species, occurring throughout Brazil's Atlantic Forest region, as well as areas belonging to the "Cerrado" (Brazilian tropical savanna) *latu sensu* and "Pampa" (Silva-Luz and Pirani, 2015). This species can reach 5-10 m in height, the trunk diameter is from 0.10-0.30 m. and leaves are compound (3-10 pairs of leaflets) (Lorenzi, 1992). It is considered a pioneer or early secondary species, and is commonly established in secondary vegetation and secondary forest. This species is frequently found on slopes, at the edge of rivers and fields, and as an invasive species in abandoned areas (Lorenzi,

1992; Carvalho, 2003). The Brazilian peppertree is recommended for recovery of low fertility soil (shallow, rocky, hydromorphic, or saline), due to its rustic character, pioneering nature, and aggressiveness (Carvalho, 2003). The species is easy to grow, due to its tolerance to poor and waterlogged soils, strong winds, and high luminosity. It is able to be established in very diverse habitats and is attractive to native fauna (pollinators and dispersers) (Mazza at al., 2001).

(2) *Senna multijuga*, known as false sicklepod, also has a wide geographic distribution in Brazil but is present mainly in the southeastern and southern regions of the country, where its occurrence seems to be more expressive (Carvalho, 2004; Souza and Bortoluzzi, 2015). This species reaches 2-10 m in height, with a trunk diameter from 0.20-0.30 m and compound leaves (18-44 pairs of leaflets) (Carvalho, 2004). It is a deciduous, heliophytic pioneer species, indifferent to soil physical conditions. It is characteristic of secondary forests of the Atlantic Rain Forest (Lorenzi, 1992) and is native to almost every area of Dense Ombrophilous Forest (Bortoluzzi et al., 2011). This species is widely used in the reclamation of areas degraded by surface coal mining since it possesses characteristics for the formation of complex food chains, with a high interactive value in animal-plant associations (Bortoluzzi et al., 2011).

Litter bag preparation

For testing leaf decomposition and colonization by meso- and macrofauna, we used litter bags with polyethylene mesh (mesh size = 0.2 × 1.0 cm) and measuring 0.30 × 0.20 m (Podgaiski and Rodrigues, 2010). This mesh allows meso- and macrofauna access to the leaf litter. Each litter bag was filled with 15±0.2 g of dried leaves (dried at 60 °C for 48 h or until constant weight was obtained) from one of the plants studied, which were collected within the study areas.

Experimental design

A randomized block design was used in order to reduce the effect of local environmental heterogeneity. The experiment began in January 2014 with 32 litter bags set out in each study area, for a total of 96 sample units. Average monthly rainfall during the evaluation period ranged from 3.1 to 8.4 mm, and mean temperature was 22.2 °C. The litter bags were separated into four experimental blocks (eight litter bags/block), with a distance of 10 m between each, along a 50 m transect. Each plant species was replicated in four litter bags for each block (Figure 1). Litter bags were placed on the surface of the soil and fixed with iron hooks to ensure contact with the soil and prevent shifting. Within each sampling period (15, 30, 60, and 120 days after setting out the litter bag) in each study area, one litter bag from each plant species was removed randomly from each block and placed in plastic bags for further processing.

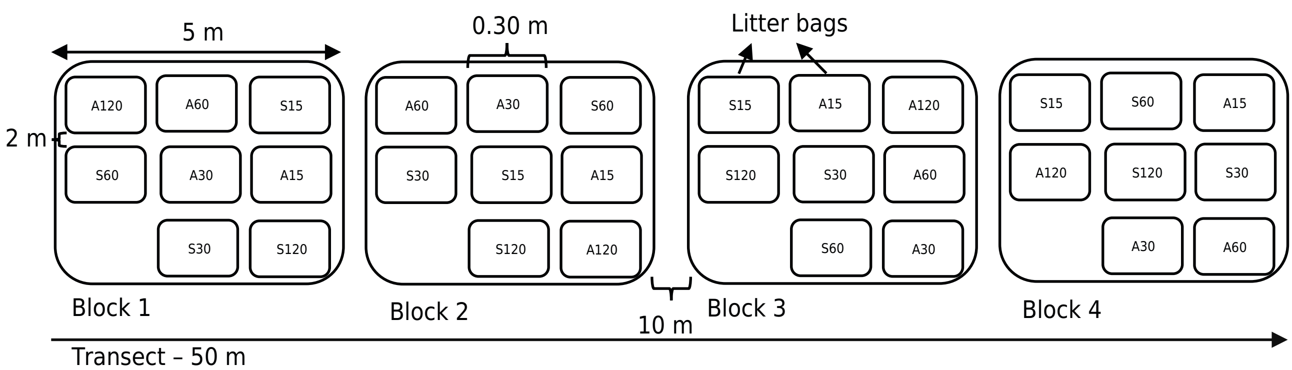

Figure 1. Experimental design showing the four blocks in each sampling site and the arrangement of the 32 litter bags of each leaf-litter species inside the blocks. The letters A and S inside the litter bags correspond to *Schinus terebinthifolius* and *Senna multijuga*, respectively. The numbers that follow indicate the number of days of exposure for sampling purposes (15, 30, 60, and 120).

In the laboratory, manual screening of the litter bags was conducted in order to collect soil mesofauna (invertebrates ≥0.1 mm and <2 mm) and macrofauna (≥2 mm) (Swift et al., 1979). Afterwards, the remaining plant material was dried (60 °C for 48 h or until obtaining constant weight) in order to determine the rate of leaf litter decomposition. During screening, the collected organisms were counted and placed in vials containing 70 % alcohol for subsequent identification of the relevant taxonomic level (class, order, and family).

Data analysis

Leaf-litter decomposition experiment

The rate of leaf-litter decomposition was evaluated by adjusting the model for simple exponential decay (SED) (Olson, 1963; Wieder and Lang, 1982), available on the software GraphPad Prims version 5.0 (Graphpad, 2007). The rate was expressed through a constant “K” and thus, parameters for half-life and leaf mass stabilization (Plateau) were estimated, in order to compare plants in each sample area consequently.

A nested (hierarchical) analysis of variance was conducted in order to evaluate the contribution of plant species, study area, and sampling period to the rate of leaf-litter decomposition. The experimental blocks were used as randomized factors to test local homogeneity. Adjustment to the model assumptions was evaluated using the Kolmogorov-Smirnov normality test and homogeneity of the Shapiro-Wilk variances. Observations with extreme values, identified by manual inspection for each sampling area and plant species, were replaced by the arithmetic mean of their respective group. Analysis was performed using Statistica 7 (Statsoft, 2004).

Soil meso- and macrofauna

The sum of taxa observations for each area and species was considered as abundance data for statistical analyses related to edaphic meso- and macrofauna. Invertebrate saprophages, fungivores, and invertebrates that feed on leaf litter were included in the detritivores functional group (Podgaiski and Rodrigues, 2010). Juvenile and adult forms were considered in different taxa only when it was possible to distinguish the form of resource exploitation, commonly represented by organisms with complete metamorphosis (ex: Coleoptera, Diptera, and Lepidoptera).

The sampling efficiency for edaphic meso- and macrofauna for each plant species was verified using Species Rarefaction Curves. Analysis was performed using the Vegan package with the *Specaccum* function and the rarefaction method (Oksanen et al., 2015) in the R statistical software (R. Development Core Team, 2015). In order to determine the strength of the relationship between leaf decomposition rate and fauna richness, a simple linear correlation analysis was conducted using the Statistica 7 software (Statsoft, 2004).

A non-metric multidimensional scaling analysis (NMDS) was applied to a Bray-Curtis dissimilarity index (9999 permutations) in order to perform the ordination of sampling units according to taxa composition. Analysis was conducted using the *metaMDS* function in the *Vegan* package. The STRESS (Standard Residual Sum of Squares) value calculated was 0.107, indicating the adequacy of the technique used on experimental data. The *envfit* function was used to adjust factors (sample areas, plant species, and litter exposure time) to the axes generated by the NMDS and to test the significance of the relationship.

RESULTS

Leaf-litter decomposition experiment

The rate of leaf litter decomposition did not vary significantly between plant species, but was considerably different between study areas (Table 1). The average values of leaf decomposition were more pronounced in the area at a more advanced stage of regeneration, both for *S. terebinthifolius* (A3 = 43.4 %; A2 = 36.2 %; A1 = 37.2 %) and for *S. multijuga* (A3 = 37.3 %; A2 = 34.0 %; A1 = 35.8). The time factor (nested in Area and Species) served as a major source of variation in the decomposition rate of leaf litter. The decomposition process occurred unevenly among the sample areas, mainly in areas A1 and A3 for *S. terebinthifolius*, in which approximately 40 % of the litter was decomposed 30 days after the beginning of the experiment

Based on the SED analysis (Table 2), the decomposition rate was significantly different between the areas only for the species *S. terebinthifolius*, especially in relation to area A3, which had the highest rate. Regarding the decomposition rate of leaf-litter over time (K), no variation was observed between areas for either plant species studied. Comparison of the parameters Plateau and K also showed no significant variation among plant species ($F_{(1;113)}$ = 1.224 and p=0.271; and $F_{(1;113)}$ = 0.835 and p=0.363, respectively). However, the average decomposition rate for *S. terebinthifolius* was 2.31 g g^{-1} yr^{-1}, while *S. multijuga* had a rate of 1.95 g g^{-1} yr^{-1} (Table 2).

Soil meso- and macrofauna

Correlation analysis revealed that the observed decomposition rate for *S. terebinthifolius* was significantly associated with an increase in the richness of the three areas sampled (r^2 = 0.70 and p=0.002 for A1, r^2 = 0.66 and p=0.005 for A2, and r^2 = 0.84 and p<0.001 for A3). However, for the species *S. multijuga*, this correlation was only significant in A2 (r^2 = 0.54 and p=0.03).

This study sampled 6,725 individuals present in litter bags, representing 21 morphological groups identified at different taxonomic levels (Table 3). Of these, 87 % of the organisms were detritivores. Collembola was the most abundant group, constituting 45 % of the collected organisms, followed by Acari (15 %) and Isopoda (7 %). Among the invertebrates

Table 1. Summary of general linear model results for leaf litter decomposition rate

	Effect	SQ	DF	MS	F	p
Area	**Fixed**	**471.57**	**2**	**235.79**	**5.37**	**0.007**
Species (Area)	Fixed	359.31	3	119.77	2.73	0.051
Time (Area × Species)	**Fixed**	**10522.32**	**18**	**584.57**	**13.31**	**0.000**
Block	Random	256.95	3	85.65	1.95	0.130
Error		3030.48	69	43.92		

Values highlighted in bold represent statistically significant effects (p<0.05). SQ: sum of squares; DF: degrees of freedom; MS: mean square.

Table 2. Simple Exponential Decay summary for areas and plant species in the litter bags

	Area 1	Area 2	Area 3	$F_{(2,51)}$	p
		Shinus terebinthifolius			
Plateau	54.43	50.36	44.06	3.88	0.027
K (g g^{-1} yr^{-1})	18.40 (2.76)	12.72 (1.90)	15.26 (2.28)	0.92	0.404
Half-life (year)	0.04	0.05	0.05		
Span (%)	45.90	49.60	55.50		
		Senna multijuga			
Plateau	46.63	54.61	54.41	1.64	0.205
K (g g^{-1} yr^{-1})	9.48 (1.42)	13.59 (2.03)	15.95 (2.39)	1.64	0.204
Half-life (year)	0.07	0.05	0.04		
Span (%)	51.75	44.97	45.39		

Plateau: material at the end of the experiment; K: decomposition rate of leaf-litter in percentage per year (in g $g^{-1}$$year^{-1}$); Half-life: time it takes material to lose half its mass; Span: percentage of what was decomposed up to 120 days.

belonging to the Insecta class, Formicidae (33 %), Diptera larvae (27 %), and Coleoptera (15 %) were the most abundant groups. Coleoptera was the group with the largest number of families collected (n = 16), followed by Diptera (n = 10), Hemiptera (n = 9), Hymenoptera and Lepidoptera (n = 4 each), Blattaria (n = 2), and Dermaptera, Orthoptera, Psocoptera, and Thysanoptera (n=1 each).

S. multijuga was more attractive to soil fauna present in the study areas, harboring richer taxa (S_{obs} = 59 compared to S_{obs} = 50 for *S. terebinthifolius*) (Figure 2), as well as a greater abundance of individuals (63 % of total collected organisms) (Table 3).

The NMDS analysis showed significant differences in soil meso- and macrofauna in relation to the sample sites (*Bray-Curtis*, r^2 = 0.22, p=0.02) and litter exposure times (r^2 = 0.39, p=0.002) (Figure 3). It can be seen from the graph that there was an overlap between the species gathered from areas A1 and A2, and greater similarities between the litter bags exposed for 15 and 30 days, and those for 60 and 120 days, respectively, within the three areas sampled.

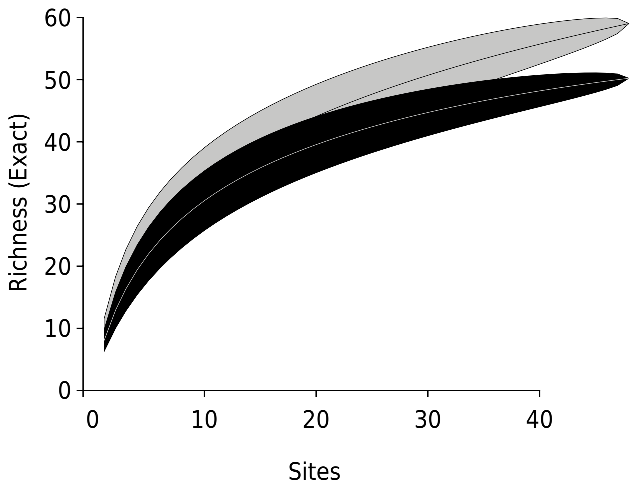

Figure 2. Rarefaction curves of soil meso- and macrofauna in response to litter from plant species tested (black curve - *Schinus terebinthifolius*; gray curve - *Senna multijuga*).

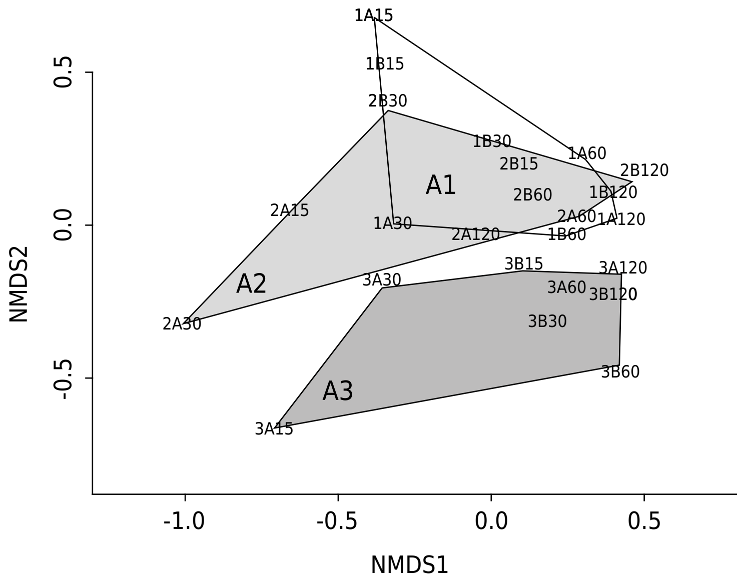

Figure 3. Non-metric multidimensional scaling analysis (NMDS) ordination in two dimensions of the sample units showing the collection structure of edaphic meso- and macrofauna in response to sampling location. First numbers correspond to areas 1, 2, and 3; the letters A and B represent the plant species tested (A = *Schinus terebinthifolius*, B = *Senna multijuga*); and the numbers 15, 30, 60, and 120 are number of days of litter bag exposure.

Table 3. Total abundance of groups of meso- and macroinvertebrates in descending order collected from litter bags of *Schinus terebinthifolius* and *Senna multijuga* for the three study areas. The juvenile forms were recorded individually only for cases in which it was possible to distinguish the form of resource exploitation

Taxa	*Shinus terebinthifolius*			*Senna multijuga*			Total
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	
Collembola	396	417	79	742	1,218	212	3,064
Acari	102	115	286	107	112	346	1,068
Isopoda	88	29	18	145	146	39	465
Formicidae	65	58	13	149	56	98	439
Diptera (Larval form)	51	29	93	97	23	67	360
Araneae	187	19	20	36	45	26	333
Gastropoda	8	4	37	2	5	152	208
Coleoptera	35	15	32	32	37	46	197
Diplopoda	77	0	7	54	2	12	152
Oligochaeta	6	0	32	17	19	18	92
Diptera	18	0	12	15	4	36	85
Hemiptera	15	4	8	5	16	25	73
Coleoptera (Larval form)	10	7	7	8	11	12	55
Lepidoptera	5	0	1	2	0	3	11
Amphipoda	0	3	4	0	6	12	25
Lepidoptera (Larval form)	5	2	4	1	0	11	23
Blattaria	3	6	5	0	3	1	18
Hymenoptera	3	2	2	1	2	5	15
Thysanoptera	3	6	2	0	3	0	14
Chilopoda	0	0	1	7	0	2	10
Dermaptera	3	1	0	2	0	1	7
Orthoptera	0	3	0	0	1	2	6
Psocoptera	4	0	0	0	0	0	4
Symphyla	0	0	0	1	0	0	1
Subtotal	1,084	720	663	1,423	1,709	1,126	
Total per plant species			2,467			4,258	6,725

DISCUSSION

Leaf-litter decomposition experiment

The observed patterns of response in relation to decomposition in the three study areas allows us to affirm that shading or reclamation time between areas contribute to different decompositon rates. This is supported by the observation that for both plant species that we studied, the leaf decomposition value was more pronounced in area A3, which was at a more advanced stage of regeneration due to a longer period of the reclamation process. In relation to time, the longer the leaf-litter exposure period in the field, the greater the decomposition, due to the colonization and action of detritivores and decomposers (Aerts, 1997; Scheer, 2008). This was shown in our study, as an increase in edaphic invertebrate richness was correlated with an increase in decomposition rate.

Most leaf-litter decomposition observed within the first 30 days of the experiment may be related to the hypothesis formulated by Scheer (2008), which was based on the observation of a sharp loss in material in the first quarter in that study. According to the author, in the initial decomposition phases, fragmentation of particles by physical agents and biota may occur, resulting in more soluble compounds (sugars, starch, and protein) being released and quickly being used by decomposing organisms. After this period, most of the resistant structures, such as nerves and petioles that are rich in lignin, cellulose, fats, waxes, and tannins, remain, reducing the decomposition rate. For example, Podgaiski and Rodrigues (2010) verified that leaves of *Ricinus communis* L. (considered more palatable than *Cynodon dactylon* (L.) Persoon and *S. terebinthifolius*) had more than 90 % of its mass decomposed in the first 35 days of the experiment. For *Ficus yoponensis,* Desvaux, Barajas-Gusmán and Alvarez-Sánchez (2003) observed losses of 70 % of litter weight in 20 days, probably due to leaching of soluble compounds, such as K and Na.

The mean decomposition rate obtained in our study for *S. terebinthifolius* (2.3 g g^{-1} yr^{-1}) was less than that observed by Podgaiski and Rodrigues (2010) (3.2 g g^{-1} yr^{-1}), who found that almost 70 % of the material had been decomposed in 140 days, while in the present study, we observed that only about 50 % of the material was decomposed in 120 days. However, decomposition rates obtained in our study were similar to those observed by Aerts (1997) in tropical climate areas (K = 2.33 g g^{-1} yr^{-1}) and greater than rates observed in that study in temperate climates (K = 0.36 g g^{-1} yr^{-1}). This large difference between tropical and temperate areas reported by Aerts (1997) is attributed to the fact that a region's climatic condition indirectly influences the chemical parameters of litter. Furthermore, according to the same author, litters from tropical regions, in general, have larger concentrations of N and smaller proportions of lignin/N than litters from other regions. In addition, low values of K (between 0.06 and 0.95) in litter have been reported from regeneration plots in Dense Ombrophilous Forest in Paraná (Scheer, 2008). Our study shows that it would take 3.2 to 4.4 years for 95 % of the litter to decompose. A large set of leaf decomposition data from 110 research locations was compiled by Zhang et al. (2008), who verified that K values tend to decrease with latitude and with increased lignin content in the litter, but increase with temperature, precipitation, and nutrient concentrations in large spatial scales. According to the authors, a combination of total nutrients and the C/N ratio are responsible for 70.2 % of taxa variation in decomposing litter.

On a local scale, chemical parameters, such as lignin, cellulose, phenolic compounds, etc. are the best predictors of decay rates (Aerts, 1997). For example, Podgaiski and Rodriques (2010) attributed the high concentration of N and low C/N ratio to a higher density of detritivores at the beginning of the experiment and to the faster decomposition rate in *R. communis*. According to Ricklefs (2010), the differences obtained in loss of leaf mass in different tree species in a forest in eastern Tennessee, USA, was due to the uneven lignin content in the leaves, providing different degrees of rigidity, which directly interferes in the access of shredder and decomposer organisms to the litter. In the case of *Nectandra ambigens*, Barajas-Gusmán and Alvarez-Sánchez (2003) also suggested that slower decomposition in *Ficus yoponensis* is possibly due to higher concentrations of lignins and tannins. Therefore, the lack of differences in relation to decomposition rates between the two plant species in the present study is possibly due to their similar chemical composition, which affects the decomposition process in a similar way. However, to our knowledge, there is no information available on the chemical composition of the species studied.

Soil meso- and macrofauna

The prevalence of Collembola found in our study, especially in A1 and A2, reinforces the importance of these detritivores, common and abundant in leaf litter, and their contribution to the decomposition of organic matter and control of microorganisms, especially fungi (Baretta et al., 2006; Mello et al., 2009). Evaluating the effect of different types of crop soils on the diversity of soil fauna in the Southern Plateau of Santa Catarina, Baretta et al. (2006) also found that Collembola was the most frequent group (35 % total occurrence), and in treatments without cultivation and with conventional practices, this frequency was even greater (75 %). Collembola together with Acari and Hymenoptera totaled over 90 % of the occurrences in all the management practices studied by these authors.

The frequency of mites also stood out in our study, particularly in area A3. Mites live in almost all habitats, they are diverse and very abundant in the soil and in organic residues, and they demonstrate a great variety of habits, being able to act as parasites, predators, herbivores, and leaf-litter detritivores (Triplehorn and Jonnson, 2011). The greater abundance of mites in litter bags in A3 for both plants species tested may reflect a greater diversity of niches and/or better conditions, both for food and shelter, as well as better microclimatic conditions for maintaining these organisms. The presence of a greater abundance of gastropods in A3 further reinforces this finding since these organisms live in very wet environments and feed mainly on organic matter (Pereira et al., 2013).

The conspicuous presence of isopods in the litter bags can be explained by the fact that they are organisms that mainly break down plant material, promoting their fragmentation (Irmler, 2000). They are considered primary shredders, and some species can be coprophagous, eating their own feces and those of other soil organisms (Correia and Andrade, 2008). According to Loureiro et al. (2006), isopods play an important role in the decomposition process by fragmenting the leaf litter, and stimulating and/or ingesting bacteria and fungi, which are fundamental to the process of nutrient cycling. In a study conducted by Podgaiski and Rodrigues (2010), Isopoda was the most abundant group (38 %), followed by Oligochaeta (19 %) and Hymenoptera (16 %).

Among the invertebrates in the Insecta class, Formicidae stood out as the most abundant group due to the social habit of these organisms, which in general, exploit and seek food collectively (Fernández, 2003). However, it is also essential to highlight the importance of these organisms because of their capacity to colonize anthropogenic environments that offer few resources (Mello et al., 2009). This is because ants are an extremely abundant and diverse group in local communities; they show considerable behavioral plasticity and occupy higher trophic levels. They are also important because of the contribution of their ecological characteristics, playing an important role in the energy flow and biomass of terrestrial ecosystems, intervening particularly in nutrient cycling, the physical and chemical structure of soil, seed dispersion, plant protection against herbivores, herbivory, and control of other invertebrate populations (Majer, 1983; Hölldobler and Wilson, 1990; Mello et al., 2009).

Dipterans are among four megadiverse insect orders, with abundance in terms of individuals and species in almost all environments (Carvalho et al., 2012). In this group, soil larvae represent a significant portion of the soil community in a variety of ecosystems, from preserved forests to agricultural ecosystems (Correia, 2002). During their larval stage, many Dipteran species participate in important biological processes, such as leaf-litter decomposition and nutrient cycling (Frouz, 1999). Soil Dipterans show great functional diversity in ecosystems, especially as phytosaprophagous organisms, microphages, scrapers, mycophagous organisms, and predators (Frouz, 1999).

Coleoptera is a widely distributed and diverse group, constituting the largest order of insects. Many Coleopterans play an important role in nutrient cycling as detritivores, especially during the larval stage, but may also act as phytophagous organisms, predators, parasites, or fungivorous organisms (Triplehorn and Jonnson, 2011; Casari and Ide, 2012).

Although the species *S. multijuga* had a richer and more abundant colonization of soil meso- and macrofauna, there was no noticeable influence on the decomposition process of leaf litter when compared to *S. terebinthifolius*. According to Podgaiski and Rodrigues (2010), detritivores use leaf litter as shelter and food and prefer to use leaves of plants that have a low C/N ratio and a high amount of N, which tend to make these leaves more palatable to these organisms. Although this condition should explain the higher abundance and richness of organisms in *S. multijuga*, it does not explain the lack of influence on leaf decomposition rate for the species tested.

The great similarity between the species collected in areas A1 and A2 is presumably due to the proximity between these areas (approximately 100 m). However, the differentiated development of vegetation in area A3, which has higher richness and density of tree species, may be another factor contributing to greater distinction of the communities in these environments. The greater similarity between the communities sampled in the initial stages (15 and 30 days) and those sampled in the second half of the experiment (60 and 120 days) is due to the larger colonization of soil invertebrates in the final periods of study.

Our results indicate that both species tested are suitable for use in reclamation of degraded areas after open-pit coal mining, since they have the potential to contribute to leaf-litter addition and to restructure nutrient cycling. To our knowledge, this is the first study in Brazil that shows the relationship of leaf-litter decomposition processes with soil meso- and macrofauna in areas reclaimed after open-pit coal mining. Nevertheless, more studies should be conducted in other locations, using more plant species of interest for reclamation and taking into account soil type, climatic conditions, and the chemical composition of leaves. These studies will provide deeper insights into decomposition processes and will help monitor the recovery dynamics of these areas during the restructuring of nutrient cycling processes.

CONCLUSIONS

Leaf-litter decomposition did not vary significantly between *S. terebinthifolius* and *S. multijuga*, and both had about 50 % of their leaves degraded after 120 days. Therefore, these two pioneer species are suitable for use in reclaimed areas after coal mining, contributing to litter addition and restructuring of nutrient cycling processes.

Differences in the reclamation period between areas contribute to different decomposition rates and soil meso- and macrofauna composition. This is supported by the observation that for both plant species we studied, the leaf litter decomposition rate and invertebrate richness and abundance were more pronounced in areas that were in a more advanced stage of regeneration due to a longer time in the reclamation process.

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