Natureza on line
ISSN 1806–7409

Decomposition of leaves of *Myrcia lineata* (O. Berg) Nied. in reaches with different levels of riparian canopy cover of an Atlantic Forest stream in southeast Brazil

Decomposição de *Myrcia lineata* (O. Berg) Nied. em trechos com diferentes níveis de cobertura do dossel ripário de um riacho de Mata Atlântica no Sudeste do Brasil

Jéssika F Marques[1], Flávio Mendes[1], Walace P Kiffer[1], Cinthia G Casotti[1], Larissa C Costa[1], Juliana V Rangel[1] and Marcelo S Moretti[1,2]*

1. Laboratório de Ecologia de Insetos Aquáticos, Universidade Vila Velha. Av. Comissário José Dantas de Melo 21, CEP 29.102-920, Vila Velha, Espírito Santo, Brasil; 2. Professor Titular.
*Corresponding author: marcelo.moretti@uvv.br

Abstract Leaf litter decomposition can be used as a tool to assess the integrity of lotic ecosystems, given that decomposition rates may vary in response to environmental changes. This study determined the decomposition rates of leaves of *Myrcia lineata* (O. Berg) Nied. in two reaches of Norte Stream (Espírito Santo State) that have different levels of riparian canopy cover. We hypothesized that, due to differences in luminosity, water temperature and nutrient availability, the effect of microbial and invertebrate organisms on the decomposition process would differ between the reaches. Leaves of *M. lineata* were placed in fine (0.5 mm) and coarse (10 mm) mesh bags, and incubated in both reaches. After intervals of 0, 3, 7, 15, 30, 45, 60 and 90 days, 4 replicates per treatment were collected from each reach. The observed coefficients of decomposition (k) ranged from 0.0015 to 0.0021 day^{-1} and did not differ between the reaches in both treatments. In total, 288 organisms belonging to 20 taxa were found associated with leaves in the preserved reach, and 705 organisms belonging to 28 taxa in the altered reach. The taxa composition of the invertebrate assemblages was similar, consisting mainly of Chironomidae (Diptera), Baetidae (Ephemeroptera) and Hydroptilidae (Trichoptera). Levels of invertebrate abundance and richness were higher in the altered reach, but did not differ over the incubation periods. Gathering-collectors were dominant in both reaches (67.79% and 64.60%), and the taxonomic composition of invertebrate assemblages varied more widely in the preserved reach. Gripopterygidae (Plecoptera) was the indicator taxon of the assemblages in the preserved reach (IV: 62.8) and Hydroptilidae in the altered reach (IV: 71.8). The results indicate that the removal of the riparian vegetation did not change the decomposition of *M. lineata* leaves in the stream. The observed differences in the invertebrate assemblages from the two reaches support the notion of the importance of riparian vegetation for the maintenance of aquatic organisms in streams.

Keywords: leaf decomposition, ecological integrity, anthropic impacts, aquatic invertebrates, functional feeding groups.

Resumo A decomposição de detritos foliares pode ser utilizada como ferramenta na avaliação da integridade de ecossistemas lóticos, dado que as taxas de decomposição podem variar em resposta a alterações ambientais. Este estudo determinou as taxas decomposição dos detritos foliares de *Myrcia lineata* (O. Berg) Nied. em dois trechos do córrego do Norte (Espírito Santo) que apresentam diferentes níveis de cobertura do dossel ripário. Foi hipotetizado que, devido a diferenças na luminosidade, temperatura e disponibilidade de nutrientes na água, o efeito dos microorganismos e invertebrados no processo de decomposição iria diferir entre os trechos. Os detritos foliares de *M. lineata* foram colocados em *litter bags* de malha fina (0.5 mm) e grossa (10 mm) e incubados nos dois trechos. Após os intervalos de 0, 3, 7, 15, 30, 45, 60 e 90 dias, 4 réplicas por tratamento foram coletadas em cada trecho. Os coeficientes de decomposição (k) observados variaram de 0,0015 a 0,0021 dia^{-1} e não diferiram entre os trechos estudados em ambos os tratamentos. No total, 288 organismos pertencentes a 20 táxons foram encontrados associados aos detritos no trecho preservado e 705 organismos pertencentes a 28 táxons no trecho alterado. A composição das assembleias de invertebrados foi similar, consistindo principalmente por Chironomidae (Diptera), Baetidae (Ephemeroptera) e Hydroptilidae (Trichoptera). Os valores de abundância e riqueza de invertebrados foram maiores no trecho alterado, mas não diferiram ao longo dos tempos de incubação. Os coletores-catadores foram dominantes em ambos os trechos

(67,79% e 64,60%) e a composição taxonômica das assembleias de invertebrados apresentou maior variação no trecho preservado. Gripopterygidae (Plecoptera) foi o táxon indicador das assembleias no trecho preservado (IV: 62,8) e Hydroptilidae no trecho alterado (IV: 71,8). Os resultados indicam que a remoção da vegetação ripária não alterou a decomposição dos detritos foliares de *M. lineata* no riacho. As diferenças observadas nas assembleias de invertebrados dos dois trechos reforçam a importância da vegetação ripária para a manutenção dos organismos aquáticos em riachos.

Palavras-chaves: decomposição de detritos foliares, integridade ecológica, impactos antrópicos, invertebrados aquáticos, grupos tróficos funcionais.

Introduction

Streams are dynamic ecosystems whose characteristics are influenced by anthropogenic activities in the drainage basin (Allan 2004). Several studies have shown that human population growth is mainly responsible for the pressure of these activities on aquatic ecosystems (Hepp and Santos 2009, Yule *et al.* 2010). The deforestation of surrounding areas, the introduction of exotic species, and pollution have impaired the ecological integrity of streams, since these activities change the concentrations of dissolved nutrients in the water and reduce habitat diversity on the substrate, affecting local biodiversity (Silva-Junior and Moulton 2011, Jinggut *et al.* 2012).

The preservation of riparian vegetation is critical to maintaining the ecological characteristics of small streams, since the vegetation acts as a filter, reducing the input of soil particles and excess of nutrients leached from the surroundings (Greenwood *et al.* 2012). The riparian vegetation, in addition to providing resources for a wide variety of organisms, also contributes to the stability of streambanks by preventing sedimentation and changes in water chemistry (Kominoski and Rosemond 2012). In forest streams, the canopy limits the incidence of solar radiation on the streambed, resulting in low primary productivity of aquatic flora (Webster and Benfield 1986). Thus, most of the energy that sustains food chains in these environments is allochthonous in origin, resulting in a heterotrophic metabolism (Cummins *et al.* 1973). The input of organic material derived from riparian zones, such as leaves, branches, flowers and fruits, is essential for the maintenance of consumer organisms in these ecosystems (Tank *et al.* 2010).

Leafpacks are often formed on the substrate of streams, offering habitat and food resources to various species of decomposers (Kobayashi and Kagaya 2004), and leaf decomposition is an important process for cycles of matter and energy transfer in these environments (Graça 2001). This process usually occurs in three major stages: (i) leaching of water-soluble compounds, which occurs after the leaf litter enters the aquatic environment; (ii) microbial conditioning, where leaf litter is colonized and mineralized by aquatic microorganisms, resulting in significant changes in leaf chemistry; and (iii) biological and physical fragmentation, where leaf litter is converted to smaller particles by the activity of decomposer invertebrates and water abrasion (Webster and Benfield 1986). Both the intrinsic characteristics of leaf litter (e.g., toughness and contents of nutrients and secondary metabolites) and aquatic environments (e.g., water flow, temperature, pH and dissolved nutrients) may influence leaf decomposition rates, since these characteristics are closely related to the activity of decomposers (Moretti *et al.* 2007, Li and Dudgeon 2008).

Leaf litter decomposition in aquatic ecosystems can be used as a tool to assess the functioning and integrity of these environments (Medeiros *et al.* 2008). Leaf decomposition rates vary in response to environmental changes, affecting the composition and nutritional quality of leaf litter and the abundance of decomposers (Gessner and Chauvet 2002). Sridhar *et al.* (2001), studying leaf decomposition in two polluted streams in Germany, observed an absence of invertebrates associated with decomposing leaves. According to these authors, the high concentration of heavy metals in leaf tissues, probably due to the high affinity of fungal mycelia to divalent ions, decreased the leaf quality for detritivores. Changes that directly affect the activity and biomass of decomposers may also alter the functioning of food webs and decomposition processes in lotic ecosystems (Jinggut *et al.* 2012).

This study determined the decomposition rates of leaves of *Myrcia lineata* (O. Berg) Nied. in two reaches of the same stream that have different levels of riparian canopy cover. A preserved reach, located inside an Atlantic Forest fragment, and an altered reach, where the native vegetation was removed due to the presence of small rural properties, were chosen as study sites. Assuming that removal of riparian vegetation alters the luminosity, water temperature and nutrient availability (Allan 2004, Greenwood *et al.* 2012), we hypothesized that the effect of microbial and invertebrate organisms on leaf decomposition would differ between the two reaches.

Methods

Study Area

The reaches of Norte Stream studied here (preserved: 20° 01' 23.5" S – 40° 33' 00.5" W; altered: 20° 01' 43.9" S – 40° 32' 00.8" W) are located in the municipality of Santa Leopoldina (Espírito Santo State), and are 637 m distant from each other, at altitudes of 571 and 490 m a.s.l. respectively. The preserved reach is located inside an Atlantic Forest fragment and has a heterogeneous substrate composed of submerged pebbles, gravel, branches and leafpacks. The riparian vegetation is well developed and there are no signs of bank erosion or sedimentation. In the altered reach, riparian vegetation has been removed and the streambanks are occupied by monocultures (eucalyptus and banana) and small rural properties. The substrate is homogeneous, predominantly sandy with moderate deposition of mud.

Leaf decomposition experiments were conducted concurrently

Table 1 Water physical and chemical properties (mean, maximum and minimum values) of the two reaches in Norte Stream (Santa Leopoldina, Espírito Santo) during the decomposition experiments on leaves of *Myrcia lineata*.

	Preserved reach		Altered reach	
	Mean	**Range**	**Mean**	**Range**
Width (m)	3.42	4.1 - 2.4	6.59	6.84 - 6.40
Depth (cm)	14	26 - 4	27	60 - 3
Discharge (m^3/s)	1.30	2.22 - 0.49	1.02	1.57 - 0.43
Conductivity (μS/cm)	21.38	26.39 - 19.40	26.22	29.90 - 23.70
Temperature (°C)	18.6	20.50 - 17.30	19.6	21.5 - 18.4
Dissolved O_2 (mg/L)	7.62	10.46 - 6.40	7.15	10.25 - 6.64
pH	6.46	7.25 - 6.11	6.82	7.72 - 6.11
N (mg/L)*	2.84	-	2.49	-
P (mg/L) *	0.010	-	0.015	-
Fe (mg/L) *	0.189	-	0.263	-
Mn (mg/L) *	0.004	-	0.009	-
Zn (mg/L) *	0.063	-	0.047	-

‒ 8 measurements; * ‒ single measurement.

in both reaches from June to September 2012. During this period, mean air temperatures ranged from 21.6 to 23.5 °C and monthly cumulative rainfall ranged from 50 to 279 mm (INMET 2012). Water physical and chemical properties of the two reaches were measured *in situ* during each sampling interval, and are presented in Table 1. A 500 ml water sample from each reach was taken to the laboratory at the beginning of the experiments for analysis of dissolved nutrients (total N and P) and heavy metals (total Fe, Mn and Zn). These analyses were done according to Standard Methods for the Examination of Water and Wastewater (APHA 2012).

Leaves

Leaves of *M. lineata* were used in the experiments because they are abundant in the riparian zone of the stream. The contribution of these leaves to the vertical input of organic matter in the preserved reach is high and constant throughout the year (W. Kiffer *unpublished data*). Prior to the experiments, leaves were collected with the use of four litter traps (1 m^2, 10 mm mesh) that were set on the streambanks, close to individuals of *M. lineata*, at approximately 1.5 m above the ground. The litter traps were monitored regularly, and senescent leaves were placed in plastic bags. In the laboratory, leaves were air-dried and stored until the beginning of the experiments.

Experimental design

Portions of 2.0 ± 0.5 g of *M. lineata* leaves were placed in fine (0.5 mm) and coarse mesh (10 mm) litter bags (10 x 15 cm) and incubated on the substrate of the two reaches, under similar conditions of depth and water flow. In total, 64 litter bags were incubated in 4 different pools (blocks) of each reach. After sampling intervals of 0, 3, 7, 15, 30, 45, 60 and 90 days, 4 litter bags (replicates) of each mesh size (treatment) were removed from

the preserved and altered reaches, placed in individual plastic bags and transported on ice in an insulated container. Time 0 samples of each treatment were used to correct for any weight losses that occurred during handling and transport of litter bags.

In the laboratory, leaves were washed with tap water over a 250-µm mesh, oven-dried (60 °C, 72 h) and weighed (0.01 g). Additional portions of leaves were used to determine an oven-dry mass / air-dry mass correction factor, which was used to correct the initial weight of all samples. The invertebrates found associated with each sample were preserved in 70% ethanol for later identification. These organisms were identified to genus or family level in a stereoscopic microscope (32x) and classified into functional feeding groups, according to Merritt and Cummins (1996), Cummins *et al.* (2005), Mugnai *et al.* (2010) and Trivinho-Strixino (2011). After identification, specimens of each taxon were dried (60 °C, 72 h) and weighed on an analytical balance (0.1 mg).

Leaf characteristics

Leaves that were not used in the experiments were dried (60°C) to constant weight, ground in an electric mill, and homogenized for the determination of initial nitrogen, phosphorus and potassium contents. The chemical analyses of the leaves were done according to Tedesco *et al.* (1995). The toughness of leaves incubated in coarse-mesh bags in both reaches was estimated using a device that measures the force needed to tear apart a leaf (Graça and Zimmer 2005).

Data analysis

The decomposition process in each treatment was determined from the leaf dry mass, using the exponential decay model $W_t = W_o e^{-kt}$, where W_t is the remaining mass at time t (days), W_o is the initial mass, and *k* is the coefficient of decomposition (Webster and Benfield

1986). The coefficients of decomposition were compared by Analysis of Covariance (ANCOVA), using time as a cofactor. These analyses were performed to test for possible differences in the decomposition of *M. lineata* leaves in each treatment in both reaches.

Data for invertebrate abundance, taxonomic richness and biomass, and for leaf toughness were compared by Analysis of Variance (ANOVA), using the reaches and sampling intervals as factors (Zar 2010). A non-metric multidimensional scaling analysis (NMDS), using Bray-Curtis distances and data for total abundance (log-transformed), was used to explore the variation in taxa composition of invertebrate assemblages found in each reach during the experiments. An Analysis of Similarities (ANOSIM) was used to test for significant differences between assemblages found in each reach. The Analysis of Indicator Species (Dufrêne and Legendre 1997) was used to determine if any taxon was characteristic of one group of samples. This method combines the information on the abundance and relative frequency of one taxon in a particular group. This analysis classifies each taxon with an indicator value (IV), which ranges from 0 to 100, according to the taxon's abundance and relative frequency in each previously defined group (reaches, in this study). These values were statistically tested using the Monte Carlo technique. If significant differences in the IVs of the same taxon are found in different groups ($p < 0.05$), this taxon can be considered as an indicator for one or more groups.

All statistical analyses were performed using *SPSS* (version 16.0 for Macintosh, SPSS, Chicago, Illinois), *Primer 6 Beta* (Primer-E Ltd.) and *R* (R Development Core Team), according to Zar (2010).

Results

The decomposition of *M. lineata* was slow in both reaches, and almost 80% of the initial leaf mass remained after 90 days of incubation (Figure 1). Consequently, the observed coefficients of decomposition were low, ranging from 0.0015 to 0.0021 day^{-1}. Although the coefficients were higher in the altered reach, the mass loss of *M. lineata* in fine- and coarse-mesh bags did not differ between the reaches (Table 2).

The leaves showed initially low nutrient content (N: 9.83 ± 0.06 mg.g^{-1}, P: 0.10 ± 0.01 mg.g^{-1}, and K: 4.64 ± 0.10 mg.g^{-1}). Leaf toughness values were initially high and decreased over the incubation period (Figure 2). These values were lower in the preserved reach throughout the experiments, and ranged from 632.3 ± 87.6 to 415.9 ± 62.8 g (0 and 90 days, respectively). However, leaf toughness values did not differ between reaches (F = 1.496, p = 0.227) or among sampling intervals (preserved: F = 1.751, p = 0.167; altered: F = 0.653, p = 0.707).

Leaves were little attractive to the invertebrate assemblages. In total, 288 organisms belonging to 20 taxa were found in the preserved reach, and 705 organisms belonging to 28 taxa in the altered reach. Chironomidae (Diptera), Baetidae (Ephemeroptera) and Hydroptilidae (Trichoptera) were the most abundant taxa in
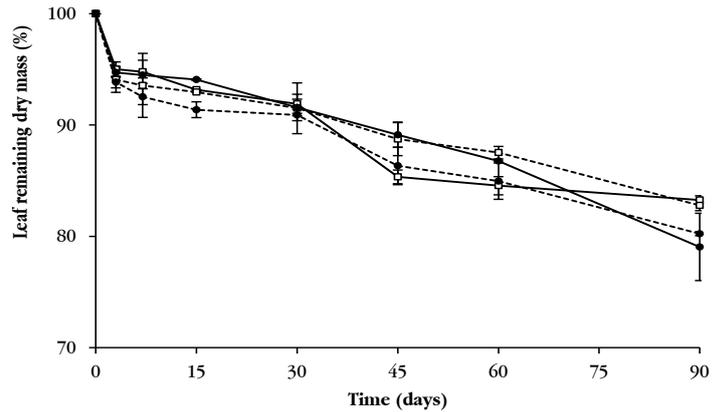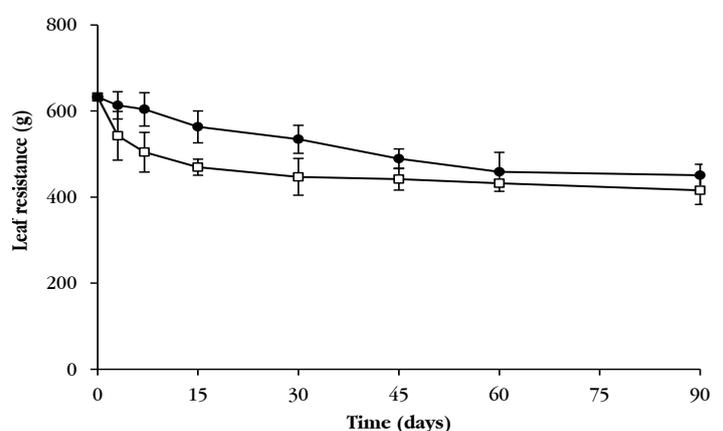

Figure 1 Mass loss (mean ± SE) of leaves of *Myrcia lineata* in fine (solid lines) and coarse (dashed lines) mesh litter bags incubated in a preserved (□) and an altered (●) reach of Norte Stream, Santa Leopoldina, Espírito Santo.

Table 2 Coefficients of decomposition (mean ± SE) of leaves of *Myrcia lineata* in fine- and coarse-mesh bags incubated in a preserved and an altered reach of Norte Stream (Santa Leopoldina, Espírito Santo). F and p are results from ANCOVA.

	Coefficient of Decomposition (-k day^{-1})		ANCOVA	
	Preserved	Altered	F	p
Fine mesh	0.0017 ± 0.0001	0.0020 ± 0.0003	2.23	0.14
Coarse mesh	0.0015 ± 0.0002	0.0021 ± 0.0005	0.48	0.49

the invertebrate assemblages of both reaches. These taxa comprised more than 70% of all organisms, and the relative abundance of Chironomidae ranged from 34 to 43% (Table 3). During the experiments, values of invertebrate abundance and taxa richness increased as sampling progressed in the altered reach, while the highest values were observed after 7 days of incubation in the preserved reach (Figure 3A, 3B). These values were significantly higher in the altered reach, and no differences were found among sampling intervals in both reaches (Table 4). The biomass of invertebrates was low in both reaches and did not differ between reaches or among sampling intervals (Figure 3C, Table 4).

Gathering-collectors were the dominant functional feeding group in the invertebrate assemblages associated with *M. lineata* leaves in both reaches (67.79% and 64.60%), while filtering-collectors
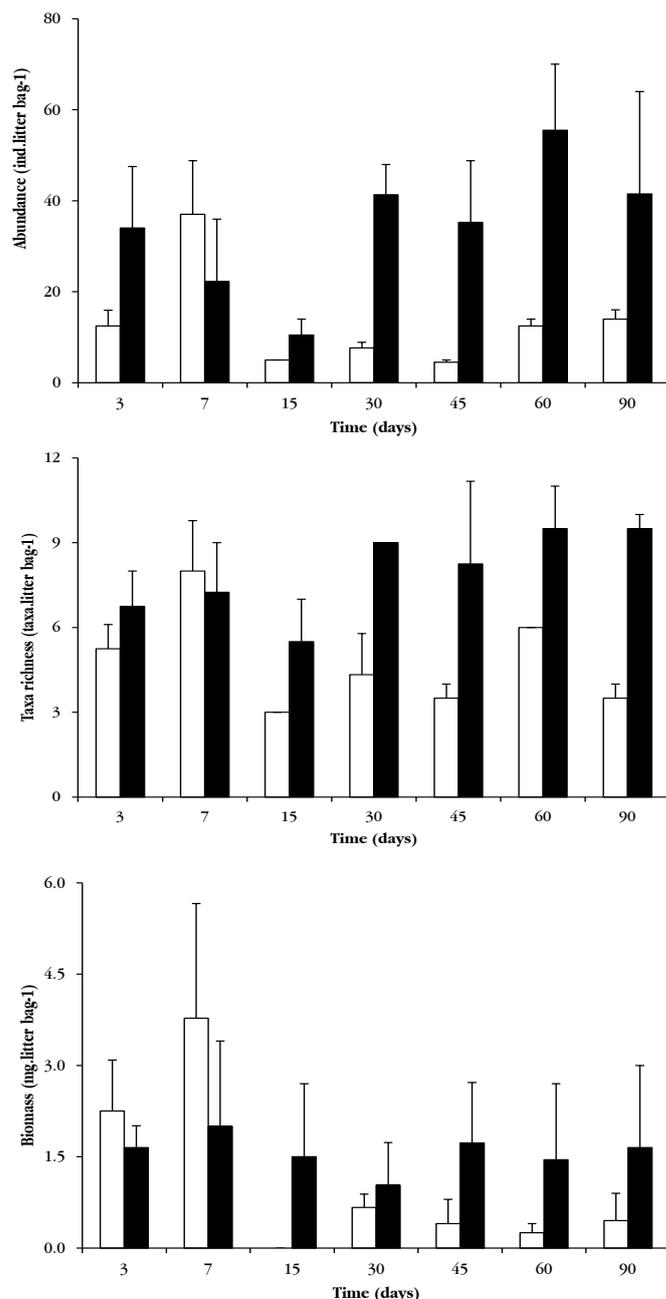

Figure 2 Resistance (mean ± SE) of leaves of *Myrcia lineata* in coarse-mesh litter bags incubated in a preserved (□) and an altered (●) reach of Norte Stream, Santa Leopoldina, Espírito Santo.
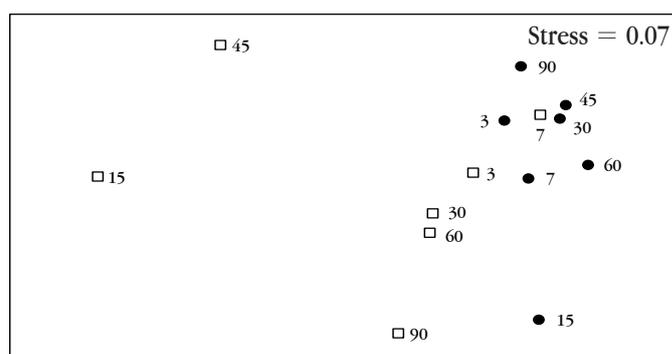
Table 3 Relative abundance (%) and functional feeding groups of invertebrate taxa found associated with leaves of *Myrcia lineata* incubated in a preserved and an altered reach of Norte Stream (Santa Leopoldina, Espírito Santo).

Taxon	FFG	Relative Abundance	
		Preserved	Altered
OLIGOCHAETA	Ga-Co	2.43	3.97
EPHEMEROPTERA			
Leptohyphidae	Ga-Co	2.43	4.11
Baetidae	Ga-Co/Scr	32.29	21.13
Leptophlebiidae	Ga-Co	-	0.14
ODONATA			
Anisoptera			
Libellulidae	Pr	0.69	0.43
Zygoptera			
Megapodagrionidae	Pr	0.69	1.28
Calopterygidae	Pr	2.43	2.55
PLECOPTERA			
Gripopterygidae			
Tupiperla sp.	Shr	5.56	0.71
Perlidae	Pr	-	0.57
COLEOPTERA			
Elmidae (Larva)	Ga-Co	1.39	1.56
Dytiscidae (Adult)	Pr	0.35	0.28
Gyrinidae (Larva)	Pr	-	0.28
TRICHOPTERA			
Hydropsychidae	Fil-Co/Pr	3.82	3.55
Hydroptilidae	Scr	9.38	8.23
Philopotamidae	Fil-Co	-	0.57
Odontoceridae	Scr	0.69	1.56
Polycentropodidae			
Polycentropus sp.	Fil-Co	-	0.71
Calamoceratidae			
Phylloicus sp.	Shr	0.35	0.28
Leptoceridae	Shr/Fil-Co	2.08	3.26
Triplectides sp.	Shr	0.35	0.14
DIPTERA			
Chironomidae			
Chironominae	Ga-Co	23.61	31.63
Tanypodinae	Pr	10.42	9.79
Orthocladiinae	Ga-Co	0.69	2.27
Ceratopogonidae	Ga-Co/Pr	0.35	0.14
Tipulidae	Pr	-	0.14
Muscidae	Pr	-	0.57
COLLEMBOLA	Ga-Co	-	0.14

Figure 3 Values (mean ± SE) of abundance (A), taxa richness (B) and biomass (C) of the invertebrate assemblages associated with leaves of *Myrcia lineata* incubated in a preserved (white columns) and an altered (black columns) reach of Norte Stream, Santa Leopoldina, Espírito Santo.

Figure 4 Non-metric multidimensional scaling (NMDS) analysis of the invertebrate assemblages associated with leaves of *Myrcia lineata* incubated in a preserved (□) and an altered (●) reach of Norte Stream, Santa Leopoldina, Espírito Santo.

(3.38%) and shredders (2.78%) were the least abundant groups in the preserved and altered reaches, respectively. Predators were the second most abundant group, comprising 17.08% and 16.95% of the relative abundance in the preserved and altered reaches. Invertebrate assemblages differed between the reaches (ANOSIM: R = 0.25, p = 0.02). The spatial ordination generated by the NMDS

Table 4 Results from ANOVAs comparing the values of abundance, taxa richness and biomass of invertebrates found associated with leaves of *Myrcia lineata* incubated in a preserved and an altered reach of Norte Stream. Reaches and sampling intervals were used as factors.

	d.f.	F	*p*
Reaches			
Abundance	1	4.706	0.037
Richness	1	7.643	0.009
Biomass	1	0.228	0.636
Sampling intervals			
Preserved reach			
Abundance	6	2.858	0.063
Richness	6	1.553	0.249
Biomass	6	1.667	0.219
Altered reach			
Abundance	6	0.714	0.645
Richness	6	0.457	0.829
Biomass	6	0.081	0.997

indicated that during the experiments, the taxa composition of invertebrate assemblages varied more in the preserved than in the altered reach, and the invertebrate assemblages observed after 15 and 45 days in the preserved reach were the most dissimilar (Figure 4). Gripopterygidae (Plecoptera) and Hydroptilidae (Trichoptera) were the indicator taxa of the assemblages in the preserved and the altered reaches, respectively (IVs: 62.8 and 71.8).

Discussion

Changes in the riparian vegetation can influence the ecological processes that occur in streams (Kominoski *et al.* 2011, Boyero *et al.* 2012). In this study, the decomposition of *M. lineata* did not differ between the preserved and altered reaches of Norte Stream. Moreover, leaf mass loss was similar in the fine- and coarse-mesh bags, indicating a low participation of invertebrate assemblages in this process. Some studies have shown that an increase in water nutrient contents may result in higher levels of invertebrate abundance and biomass, supported by the growth of microbial decomposers (Robinson and Gessner 2000, Chung and Suberkropp 2008). Although water temperatures and nutrient contents (P and K) were higher in the altered reach, the effect of microorganisms and invertebrates on the decomposition of *M. lineata* leaves did not differ between the reaches.

In accordance with other studies in tropical streams, our results suggest that the decomposition process of *M. lineata* leaves resulted primarily from abiotic factors and microbial activity

(Wantzen and Wagner 2006, Gonçalves *et al.* 2007, 2012). The removal of riparian vegetation can reduce decomposition rates by sedimentation of leaf litter (Lecerf and Richardson 2010), which inhibits colonization by decomposers (Yule *et al.* 2010), or increase decomposition rates by the abrasion of sediment carried by the water current over leaf surfaces (Benfield *et al.* 2001). However, the relatively high amounts of fine sediment in the altered reach did not significantly affect the decomposition rates, similarly to observations by Sanpera-Calbet *et al.* (2012).

The decomposition of *M. lineata* leaves could be classified as slow (Petersen and Cummins 1974). The observed coefficients of decomposition are probably related to the characteristics of leaf litter, which was little attractive to decomposers. Normally, leaf litter with low nutrient content and high toughness requires longer incubation periods to be colonized by microorganisms and invertebrate decomposers (Graça 2001, Gonçalves *et al.* 2007). The high proportion of mass remaining at the end of the experiments indicates that, after 90 days of incubation, the leaf litter was still in the initial stage of decomposition. The content of phenolic compounds, which is high in species of Myrtaceae (Moretti *et al.* 2009), may also have contributed to the low palatability of *M. lineata* leaves to invertebrate shredders that occur in the preserved reach of Norte Stream (*Phylloicus* sp. and *Triplectides* sp.; F. Mendes, *unpublished data*). The abundance and role of shredders in the present study could have been underestimated, mainly if shredders preferred the more-palatable leaves that were present on the streambed (Rincón and Martínez 2006, Moretti *et al.* 2009).

The high abundance and richness of invertebrate assemblages associated with *M. lineata* leaves in the altered reach are probably related to the reduced availability of organic matter on the streambed (Kobayashi and Kagaya 2004), affording these organisms only limited amounts of food resources and alternative substrates (Delong and Brusven 1998). Thus, the more-tolerant organisms that persist in this reach colonized the leaves quickly (Doeg *et al.* 1989). In preserved environments, the competition for resources is usually the main factor structuring the aquatic invertebrate assemblages (Resh *et al.* 1988). In these environments, organisms with greater competitive capabilities could eliminate weaker competitors, resulting in a lower taxonomic richness (Townsend *et al.* 1997).

The predominance of gathering-collectors in the invertebrate assemblages in both reaches suggests that, in addition to providing refuge, leaf litter of *M. lineata* was also used as an indirect food source (Gonçalves *et al.* 2012). Leaves that decompose slowly remain longer on the streambed, allowing high deposition of fine particulate organic matter (Richardson 1992). The low invertebrate biomass observed in both reaches reflects the smaller size of the organisms, while the low variation in these values among sampling intervals corroborates the assumption that leaf litter from *M. lineata* did not offer adequate resources for the development of invertebrate assemblages (Gonçalves *et al.* 2007).

The lowest values of invertebrate abundance and taxa

richness observed after 15 days of incubation are probably related to an increase in the rainfall that occurred in this period, with more than 50 mm recorded in one week (INMET 2012). The effect of rainfall on the abundance and composition of invertebrate assemblages was also observed by Callisto *et al.* (2004) in a tropical headwater stream. Certain seasonal variations, such as in rainfall, strongly influence invertebrate assemblages in streams and are important abiotic factors (Mathuriau *et al.* 2008).

Larvae of Chironomidae (Diptera) are very abundant in invertebrate assemblages associated with leaf litter (see Moretti *et al.* 2007). Because many genera of this family belong to the functional feeding group of collectors, some investigators have emphasized the importance of chironomid larvae to energy flow and secondary production in streams, particularly in those having leaf litter of low nutritional quality and a scarcity of shredders (Sanseverino and Nessimian 2008). The high abundance of organisms of the family Baetidae (Ephemeroptera) in the two reaches is probably associated with the higher trophic plasticity of these organisms, which allows wide environmental tolerance. Buss *et al.* (2002) and Souza *et al.* (2011) found that baetids were more abundant in streams with intermediate ecological integrity.

Nymphs of Gripopterygidae (Plecoptera) are commonly found associated with leafpacks on the streambed, and feed mainly on this resource (Cummins *et al.* 2005). Bispo *et al.* (2002) observed that members of the genus *Tupiperla* Froehlich, 1969 prefer streams with greater vegetation cover. This preference could explain the greater abundance of this taxon and the high indicator value (IV) for the assemblages sampled in the preserved reach. On the other hand, the higher abundance of Hydroptilidae (Trichoptera) larvae and the high indicator value for the assemblages sampled in the altered reach were probably related to the growth of periphytic algae (Kiffney *et al.* 2003). These organisms belong to the functional feeding group of scrapers and are characteristic of environments altered by the removal of riparian vegetation (Svitok 2006).

In conclusion, the results of this study showed that the removal of riparian vegetation did not change the decomposition rate of leaves of *M. lineata* in Norte Stream, not corroborating our initial hypothesis. However, the values of abundance and taxa richness, and the composition of invertebrate assemblages did differ between the stream reaches. These results are probably associated with lower inputs of organic matter and higher rates of sedimentation and light incidence in the altered reach of Norte Stream. In agreement with other studies conducted in Neotropical streams, the low attractiveness of leaf litter used in the present experiments resulted in the low participation of invertebrate assemblages in the decomposition process. Our results support the notion of the importance of riparian vegetation for the maintenance of aquatic organisms in streams, given that the removal of this vegetation affects the ecological integrity of these ecosystems and alters the availability of organic matter and microhabitats on the substrate.

References

Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. **Annual Review of Ecology, Evolution, and Systematics** 35: 257–284.

APHA (2012) American Public Health Association. **Standard Methods for the Examination of Water and Wastewater**. Washington DC.

Benfield EF, Webster JR, Tank JL, Hutchens JJ (2001) Long-Term Patterns in Leaf Breakdown in Streams in Response to Watershed Logging. **International Review of Hydrobiology** 86: 467–474.

Bispo PC, Froehlich CG, Oliveira LG (2002) Spatial distribution of Plecoptera nymphs in streams of a mountainous area of central Brazil. **Brazilian Journal of Biology** 62: 409–417.

Boyero L, Barmuta LA, Ratnarajah L, Schmidt K, Pearson RG (2012) Effects of exotic riparian vegetation on leaf breakdown by shredders: a tropical-temperate comparison. **Freshwater Science** 31: 296-303.

Buss DF, Baptista DF, Silveira MP, Nessimian JL, Dorvill LFM (2002) Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in southeast Brazil. **Hydrobiologia** 481: 125–136.

Callisto M, Goulart M, Medeiros AO, Moreno P, Rosa CA (2004) Diversity assessment of benthic macroinvertebrates, yeasts, and microbiological indicators along a longitudinal gradient in Serra do Cipó, Brazil. **Brazilian Journal of Biology** 64: 743–755.

Chung N, Suberkropp K (2008) Influence of shredder feeding and nutrients on fungal activity and community structure in headwater streams. **Fundamental and Applied Limnology** 173: 35–46.

Cummins KW, Merritt RW, Andrade PCN (2005) The use of invertebrate functional groups to characterize ecosystem attributes in selected streams and rivers in south Brazil. **Studies on Neotropical Fauna and Environment** 40: 69–89.

Cummins KW, Petersen RC, Howard FO, Wuycheck JC, Holt VI (1973) The utilization of leaf litter by stream detritivores. **Ecology** 54: 336–345.

Delong MD, Brusven MA (1998) Macroinvertebrate community structure along the longitudinal gradient of an agriculturally impacted stream. **Environmental Management** 22: 445–457.

Doeg TJ, Lake PS, Marchant R (1989) Colonization of experimentally disturbed patches by stream macroinvertebrates in the Acheron River, Victoria. **Australian Journal of Ecology** 14: 207–220.

Dufrêne M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. **Ecological Monographs** 67: 345–366.

Gessner MO, Chauvet E (2002) A case for using litter breakdown to assess functional stream integrity. **Ecological Applications** 12: 498–510.

Gonçalves JF, Graça MAS, Callisto M (2007) Litter decomposition in a Cerrado

savannah stream is retarded by leaf toughness, low dissolved nutrients and a low density of shredders. **Freshwater Biology** 52: 1440–1451.

Gonçalves JF, Rezende RS, França J, Callisto M (2012) Invertebrate colonization during leaf processing of native, exotic and artificial detritus in a tropical stream. **Marine and Freshwater Research** 63: 428–439.

Graça MAS (2001) The role of invertebrates on leaf litter decomposition in streams – a review. **International Review of Hydrobiology** 86: 383–393.

Graça MAS, Zimmer M (2005) Leaf toughness. In, Graça MAS, Barlocher F, Gessner MO (Org) **Methods to Study Litter Decomposition**: A Practical Guide. Dordrecht, Springer, pp 121–125.

Greenwood MJ, Harding JS, Niyogi DK, McIntosh AR (2012) Improving the effectiveness of riparian management for aquatic invertebrates in a degraded agricultural landscape: stream size and land-use legacies. **Journal of Applied Ecology** 49: 213–222.

Hepp LU, Santos S (2009) Benthic communities of streams related to different land uses in a hydrographic basin in southern Brazil. **Environmental Monitoring and Assessment** 157: 305–318.

INMET (2012) Instituto Nacional de Meteorologia.

Jinggut T, Yule CM, Boyero L (2012) Stream ecosystem integrity is impaired by logging and shifting agriculture in a global megadiversity center (Sarawak, Borneo). **Science of the Total Environment** 437: 83–90.

Kiffney PM, Richardson JS, Bull JP (2003) Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. **Journal of Applied Ecology** 40: 1060–1076.

Kobayashi S, Kagaya T (2004) Litter patch types determine macroinvertebrate assemblages in pools of a Japanese headwater stream. **Journal of the North American Benthological Society** 23: 78–89.

Kominoski JS, Rosemond AD (2012) Conservation from the bottom up: forecasting effects of global change on dynamics of organic matter and management needs for river networks. **Freshwater Science** 31: 51-68.

Kominoski JS, Marczak LB, Richardson JS (2011) Riparian forest composition affects stream litter decomposition despite similar microbial and invertebrate communities. **Ecology** 92: 151–159.

Lecerf A, Richardson JS (2010) Litter decomposition can detect effects of high and moderate levels of forest disturbance on stream condition. **Forest Ecology and Management** 259: 2433–2443.

Li AOY, Dudgeon D (2008) The effects of leaf litter characteristics on feeding and fitness of a tropical stream shredder, *Anisocentropus maculatus* (Trichoptera: Calamoceratidae). **Marine and Freshwater Research** 59: 897-901.

Mathuriau C, Thomas AGB, Chauvet E (2008) Seasonal dynamics of benthic detritus and associated macroinvertebrate communities in a neotropical stream. **Fundamental and Applied Limnology** 171: 323-333.

Medeiros AO, Rocha P, Rosa CA, Graça MAS (2008) Litter breakdown in a stream affected by drainage from a gold mine. **Fundamental and Applied Limnology** 172: 59-70.

Merritt RW, Cummins KW (1996) **An Introduction to the Aquatic Insects of North America**. Dubuque, Kendall/Hunt Publishing Company.

Moretti MS, Gonçalves JF, Callisto M (2007) Leaf breakdown in two tropical streams: differences between single and mixed species packs. **Limnologica** 37: 250–258.

Moretti MS, Loyola RD, Becker B, Callisto M (2009) Leaf abundance and phenolic concentrations codetermine the selection of case-building material by *Phylloicus* sp. (Trichoptera, Calamoceratidae). **Hydrobiologia** 630: 199–206.

Mugnai R, Nessimian JL, Baptista DF (2010) **Manual de Identificação de Macroinvertebrados Aquáticos do Estado do Rio de Janeiro**. Rio de Janeiro, Technical Books Editora.

Petersen RC, Cummins KW (1974) Leaf pack processing in a woodland stream. **Freshwater Biology** 4: 343–368.

Resh VH, Brown A, Covich AP, Gurtz ME, Li HW, Minshall GW, Reice SR, Sheldon AI, Wallace JB, Wismar RC (1988) The role of the disturbance in stream ecology. **Journal of the North American Benthological Society** 7: 433–455.

Richardson JS (1992) Food, microhabitat, or both? Macroinvertebrate use of leaf accumulations in a montane stream. **Freshwater Biology** 27: 169–176.

Rincón J, Martínez I (2006) Food quality and feeding preferences of *Phylloicus* sp. (Trichoptera: Calamoceratidae). **Journal of the North American Benthological Society** 25: 209–215.

Robinson CT, Gessner MO (2000) Nutrient addition accelerates leaf breakdown in an alpine springbrook. **Oecologia** 122: 258–263.

Sanseverino AM, Nessimian JL (2008) Larvas de Chironomidae (Diptera) em depósitos de folhiço submerso em um riacho de primeira ordem da Mata Atlântica (Rio de Janeiro, Brasil). **Revista Brasileira de Entomologia** 52: 95–104.

Sanpera-Calbet I, Chauvet E, Richardson JS (2012) Fine sediment on leaves: shredder removal of sediment does not enhance fungal colonization. **Aquatic Sciences** 74: 527–538.

Silva-Junior EF, Moulton TP (2011) Ecosystem functioning and community structure as indicators for assessing environmental impacts: leaf processing and macroinvertebrates in Atlantic Forest streams. **International Review of Hydrobiology** 96: 656-666.

Souza HM, Cabette HSR, Juen L (2011) Baetidae (Insecta, Ephemeroptera) em córregos do cerrado matogrossense sob diferentes níveis de preservação ambiental. **Iheringia, Série Zoologia** 101: 181–190.

Sridhar KR, Krauss G, Bärlocher F, Raviraja NS, Wennich R, Baumbach R, Krauss GJ (2001) Decomposition of alder leaves in two heavy metal-polluted streams in central Germany. **Aquatic Microbial Ecology** 26: 73–80.

Svitok M (2006) Structure and spatial variability of mayfly (Ephemeroptera) communities in the upper Huron River basin. **Biologia** 61: 547–554.

Tank JL, Rosi-Marshall EJ, Griffiths NA, Entrekin SA, Stephen ML (2010) A review of allochthonous organic matter dynamics and metabolism in streams. **Journal of the North American Benthological Society** 29: 118–146.

Tedesco MJ, Gianello C, Bissani CA, Bohnem H, Volkweiss SJ (1995) **Análise de Solo, Plantas e outros Materiais.** Porto Alegre, Universidade Federal do Rio Grande do Sul.

Townsend CR, Scarsbrook MR, Dolédec S (1997) The intermediate disturbance hypothesis, refugia, and biodiversity in streams. **Limnology and Oceanography** 42: 938–949.

Trivinho-Strixino S (2011) **Larvas de Chironomidae (Diptera) do Estado de São Paulo**: Guia de Identificação. São Carlos, Universidade Federal de São Carlos.

Wantzen KM, Wagner R (2006) Detritus processing by invertebrate shredders: a neotropical-temperate comparison. **Journal of the North American Benthological Society** 25: 216–232.

Webster JR, Benfield EF (1986) Vascular plant breakdown in freshwater ecosystems. **Annual Review of Ecology and Systematics** 17: 567–594.

Yule CM, Boyero L, Marchant R (2010) Effects of sediment pollution on food webs in a tropical river (Borneo, Indonesia). **Marine and Freshwater Research** 61: 204–213.

Zar JH (2010) **Biostatistical Analysis**. 5 ed Upper Saddle River, Prentice-Hall.