

Colonization by oligochaetes (Annelida: Clitellata) in decomposing leaves of *Eichhornia azurea* (SW.) Kunth (Pontederiaceae) in a neotropical lentic system

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Abstract – The objective of the present study was to examine the colonization of oligochaetes during the decomposition of leaves of the macrophyte *Eichhornia azurea* in a lentic system in southeastern Brazil. The experiment was conducted between September and November 2007, with the use of 21 nylon bags measuring 15 × 15 cm with 2 mm mesh, each containing 10 g of dried leaves. The bags were removed from the lake after 2, 5, 8, 12, 25, 45 and 65 days. At the end of the experiment, 31.40% of the initial mass remained, and the decomposition rate was 0.018 d⁻¹. The mean density of oligochaetes during the experiment was 32.81 ± 9.58 ind.g⁻¹ DM. The sub-families Naidinae and Pristininae accounted for 99.83% of the oligochaetes. The substrate quality influenced the colonization of *E. azurea* leaves, as observed from the cluster analysis by the formation of two groups based on increased density during the experiment, indicating a degradative ecological succession. During the decomposition there were changes in the community of oligochaetes, resulting from differences in the ability to exploit various food sources, with predominance of predators in the first decomposition phase and of collectors at the end of the experiment.

Key words: Leaf breakdown / macrophyte / naidinae / pristininae / tubificinae

Introduction

Macrophytes are key components of aquatic systems (Thomaz *et al.*, 2008), since they are the main source of autochthonous detritus in these systems (Pieczeńska, 1993) and their decomposition is an important source of carbon, nitrogen and phosphorous, principally in small lakes (Nelson, 2011). These plants are often used by invertebrates as refuge for reproduction and protection against predators (Harrison *et al.*, 2005; Ferreira *et al.*, 2011). The presence of macrophytes in aquatic environments increases the habitat's complexity, providing greater richness and density of invertebrates associated with these plants in relation to those associated with the sediment (Rennie and Jackson, 2005).

The majority of invertebrates do not have the enzymatic capacity to break down the high amounts of cellulose and lignin present in green leaves (Bärlocher and Porter, 1986; Walters and Smock, 1991). Therefore, macrophytes serve both as a direct food source (vegetal

tissue, principally during decomposition) and indirect food source (substrate for development of periphyton) for invertebrates (Newman, 1991; Nelson, 2011). Invertebrates form an important link between the energy stored in detritus and the higher trophic levels of the aquatic food web (Gessner *et al.*, 1999).

The richness and composition of oligochaete species is influenced by the substrate's composition, organic matter content and food quality (Syrovátka *et al.*, 2009; Bojková *et al.*, 2011). Decomposing leaves are used by oligochaetes for shelter (Chauvet, 1997) and also for food, in the form of fine particulate organic matter and the associated periphyton (Galizzi and Marchese, 2009). This group is generally found in high abundance in this material (Chauvet, 1997), sometimes representing over 50% of the invertebrate biomass associated with decomposing leaves (Chauvet *et al.*, 1993).

Studies of the breakdown of leaf litter in Neotropical regions have been receiving larger attention now (Ramseyer and Marchese, 2009; Ligeiro *et al.*, 2010). As occurs in other parts of the world, the majority of these studies have been carried out in lotic environments, using

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material of allochthonous origin (Bohman and Herrmann, 2006; Stoler and Relyea, 2011). Therefore, due to the relative lack of studies in lentic systems and also to the little importance given to the oligochaetes in studies that evaluate the decomposition process, the aim of this study was to examine the colonization by oligochaetes during the breakdown of leaves of the macrophyte *Eichhornia azurea* in a Neotropical lake. We expected to find changes in the community of these organisms during the decomposition process due to physical, chemical and biological changes in the *E. azurea* leaves.

Material and Methods

Study area

The experiment was conducted in Manacás Lake (21°46'68"S, 43°22'22"W), a reservoir with a surface area of 0.02 km² and a maximum depth of 5 m (Azevedo *et al.*, 2003), located in southeastern Brazil (Fig. 1). The lake's marginal vegetation consists principally of bamboo and specimens of *Tibouchina granulosa* Cogn. In the summer, generally booms of *Salvinia* spp. are registered in this lake. However, during the experiment, floating macrophytes were not observed.

The abiotic data were obtained in 2008 (unpublished data) near the lake bottom. The lake's water is murky (Secchi disk: 0.60 ± 0.12 m), with neutral pH (7.10 ± 0.25) and average levels of dissolved oxygen, temperature and electrical conductivity of 5.55 ± 2.04 mg.L⁻¹, 21.35 ± 2.25 °C and 28.25 ± 12.82 µS.cm⁻¹, respectively.

Collection and analysis of the data

Green leaves of *E. azurea* were collected from a nearby lake (21°52'49.6"S, 43°00'28.71"W). This was necessary because before the start of the experiment, all the macrophytes from Manacás Lake had been removed, so it was not possible to collect sufficient senescent leaves to carry out the experiment. The leaves were washed to remove the adhered material (Silva *et al.*, 2011) and then were air-dried and placed in an oven at 60 °C (24 h) to obtain initial dry mass (Ramseyer and Marchese, 2009).

The experiment was conducted from September to November 2007, with the use of 21 nylon bags (15 × 15 cm and 2 mm mesh opening), each filled with 10 g of dried leaves. The bags were immersed near the bottom, about 3 m from the shoreline and 2.30 ± 0.35 m deep. To keep the bags in contact with the sediment, small weights (150 g) were attached to them. Three of the bags were retrieved after 2, 5, 8, 12, 25, 45 and 65 days of incubation. These were placed individually in sealed plastic sacks and transported to the laboratory.

The remaining material in each bag was fixed in 4% formal and passed through a 0.21 mm sieve. The oligochaetes were sorted under a stereoscopic microscope and identified at the species level using the regional

identification guides by Righi (1984) and Brinkhurst and Marchese (1989). Fragments of *Nais* or *Dero* were observed, but due to the absence of the hind regions, it was not possible to separate these genera. Therefore, we considered the fragments as being fragmented Naidinae.

The average numerical density of organisms (ind. g⁻¹ DM), Shannon-Wiener diversity index (H') and richness (number of oligochaete taxa) were calculated for each day of bag removal. We did not consider fragmented Naidinae in calculating the richness and the diversity index. The remaining plant material was again dried in an oven at 60 °C until reaching constant mass and then utilized to calculate the breakdown coefficient (*k*), according to the negative exponential equation (*e.g.*, Petersen and Cummins, 1974). The oligochaetes were classified into functional feeding groups according to Schenková and Helesic (2006).

To analyze the relationship between the density of oligochaetes and the remaining dry mass, we used Pearson's correlation coefficient. We also applied the Bray–Curtis index in the density of oligochaetes to check the dissimilarity between days. To obtain the dendrogram, we used the unweighted pair group method with arithmetic mean (UPGMA). The statistical analyses were performed with the PAST 2.0 program (Hammer *et al.*, 2001).

To determine which species were more important to the oligochaete community structure, we performed indicator species analysis (Dufrière and Legendre, 1997). The indicator species were then tested for statistical significance using a Monte Carlo technique. A limit of 10% was chosen for the indicator species index (Gonçalves *et al.*, 2004).

Results

Leaf breakdown

In the first two days there was rapid mass loss of the *E. azurea* leaves (37.97%) (Fig. 2) and at the end of the experiment the remaining dry mass was 3.14 g DM (31.40% of the initial mass). The breakdown coefficient was 0.018 d⁻¹.

Oligochaetes

During the experiment, we identified 7375 invertebrates, distributed among Diptera (59.17%), Oligochaeta (40.54%), Trichoptera (0.23%) and Coleoptera (0.03%). The abundance of oligochaetes per litter bag varied from 0 on day 2 to 515 organisms on day 65. On days 8 and 65, the density of oligochaetes was similar to that of the other invertebrates found in the bags (Fig. 3).

The 2990 oligochaetes were distributed in three subfamilies, Tubificinae (0.17%), Pristininae (21.45%) and Naidinae (78.38%) (Tab. 1). The average density of oligochaetes in the bags was 32.81 ind.g⁻¹ DM. The

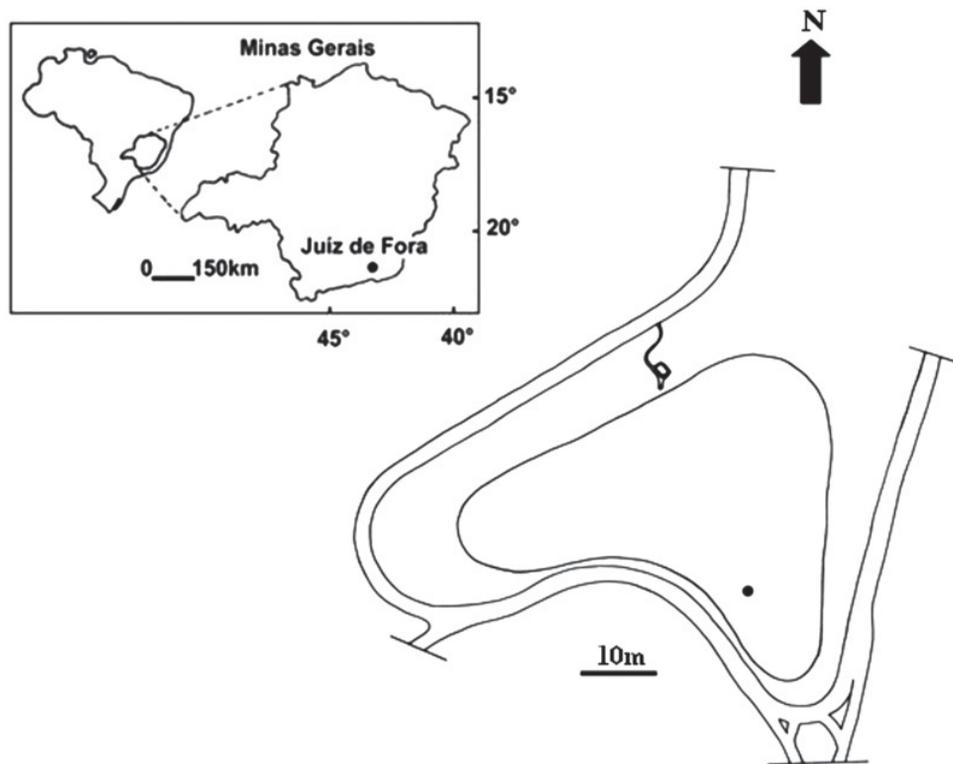


Fig. 1. Bottom: Manacás Lake, the study area. Top: Minas Gerais, identifying the location of Juiz de Fora. Source: Azevedo *et al.* (2003).

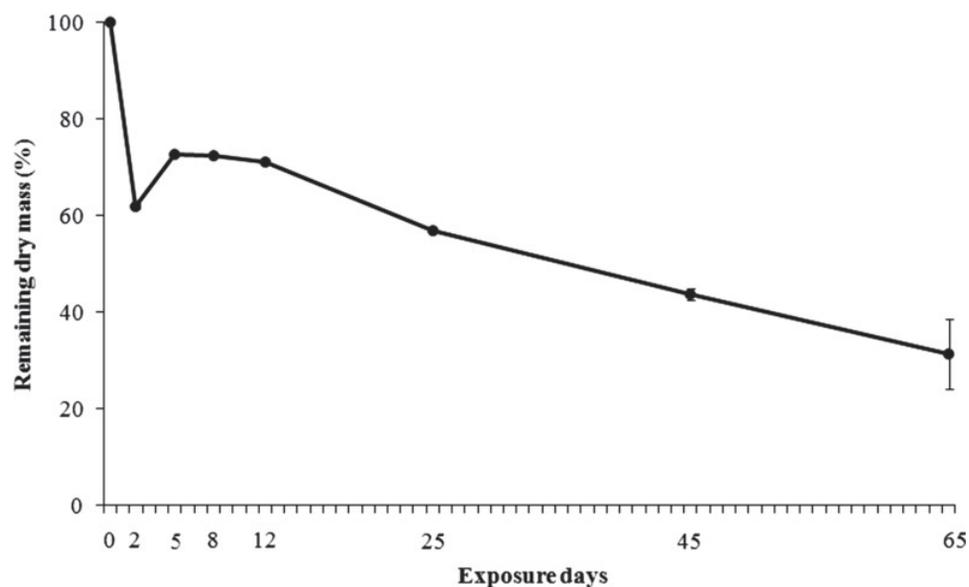


Fig. 2. Remaining dry mass (means of three replicates \pm standard error) of *E. azurea* leaves during the decomposition experiment in Manacás Lake (southeastern Brazil).

values increased progressively during the experiment and were negatively correlated with the remaining dry mass ($P = 0.01$; $r = -0.89$). The highest number of taxa ($n = 9$) occurred after 65 days of exposure. The highest diversity index was observed on day 25 ($H' = 1.94$), while the lowest was on day 2 ($H' = 0.50$) (Tab. 1).

Among the trophic oligochaete groups, only *Chaetogaster diaphanus* and *Chaetogaster diastrophus* were predators. This last species was present in great density after 12 days of exposure, when it reached 85.60% of the oligochaete fauna (Fig. 4). The other oligochaetes found were collectors, and predominated after 25 days of

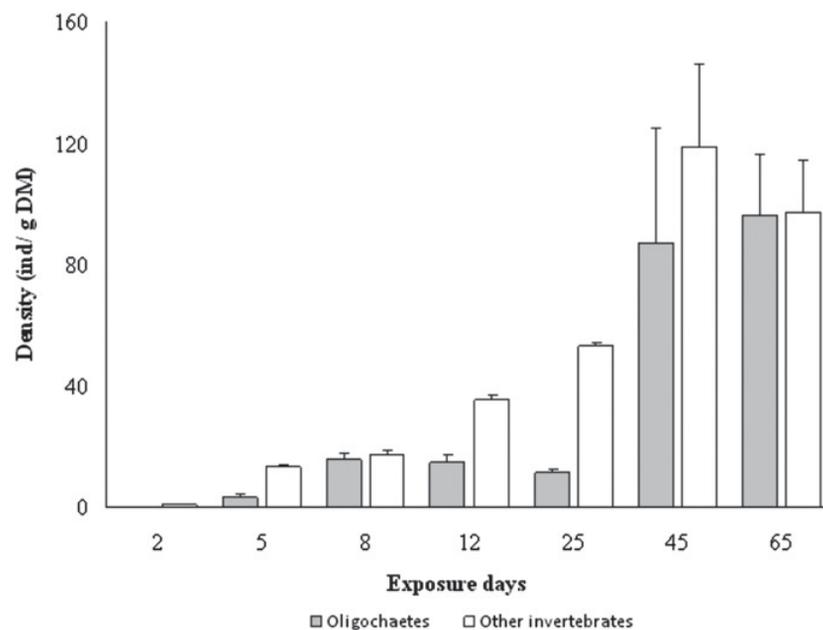


Fig. 3. Densities (means of three replicates \pm standard error, ind.g⁻¹ DM) of oligochaetes and other invertebrates during the decomposition experiment with *E. azurea* leaves in Manacás Lake (southeastern Brazil).

exposure, accounting for over 85% of the oligochaete fauna in this period.

In the cluster analysis (cophenetic correlation = 0.963), samples were separated into two groups (Fig. 5). The first group was composed of days 2, 5, 8 and 12. In this phase, there was no indicator species and predators predominated (64.79%). In the second group, composed of days 25, 45 and 65, *Dero (D.) sawayai* (IV = 94.8), *Pristina aequisetata* (IV = 97.3) and *Pristina americana* (IV = 79.6) were considered as indicator species, and collectors predominated in this phase (88.19%).

Discussion

Leaf breakdown

The breakdown coefficient of *E. azurea* leaves found in the present study ($k = 0.018 \text{ d}^{-1}$) was higher than the values reported for this species in other studies of Brazilian lentic systems: Roland *et al.* (1990) in the Infernáo Lagoon ($k = 0.011 \text{ d}^{-1}$); Pagioro and Thomaz (1998) in the Garças Lagoon ($k = 0.0048 \text{ d}^{-1}$); Stripari and Henry (2002) in a marginal lake of the Paranapanema River (dry season: $k = 0.014 \text{ d}^{-1}$; rainy season: $k = 0.018 \text{ d}^{-1}$). Differences in leaf decomposition rates of the same species can be attributed to different environmental conditions (Schulze and Walker, 1997), such as water temperature, electrical conductivity and dissolved oxygen. Higher values of these variables accelerate the decomposition process, through the increase of the decomposer organisms' metabolism (Gulis and Suberkropp, 2003; Swan and Palmer, 2004). Besides this, the experimental design can influence the results, such as the use of senescent *versus* green leaves, the

quantity of leaves used and the mesh size of the litter bags (Boulton and Boon, 1991; Walpola *et al.*, 2011).

The 37.97% loss of initial leaf mass in the first 2 days can be attributed to lixiviation of the soluble substances, such as phenols and amino acids (Gessner *et al.*, 1999). Generally, up to 30% of the initial mass is lost in the first 24–48 h (Bärlocher, 2005). The high mass loss found in the present study is likely due to the pre-drying of the leaves before immersion in the lake. Drying leaves at high temperature (60 °C) disrupts the membrane structure of the cell walls, making the leaves more susceptible to colonization by micro-organisms and accelerating the loss of soluble compounds (Gessner *et al.*, 1999).

Oligochaetes

The majority of studies of leaf breakdown in aquatic systems use litter bags (Silva *et al.*, 2011), although this method can negatively affect the colonization by invertebrates by limiting access to the leaves (Boulton and Boon, 1991). In the present study, due to the small size of the oligochaetes, the mesh of the litter bags did not impede the entrance of these organisms. On the contrary, it can increase the oligochaetes density, because the bags accumulate detritus and fragments released by the macrophytes (Mormul *et al.*, 2006), thus increasing the quantity of food for collector oligochaetes.

As in the present study, the majority of studies have reported a greater density of Naidinae and Pristininae in relation to Tubificinae (Chauvet *et al.*, 1993; Galizzi and Marchese, 2009; Ramseyer and Marchese, 2009). Since the bags were in contact with the substrate, they were accessible to all organisms and the difference in the density

Table 1. Densities (means of three replicates \pm standard error, ind.g⁻¹ DM), richness (means of three replicates \pm standard error) and diversity indices of the oligochaetes species found during the decomposition experiment with *Eichhornia azarea* in Manacás Lake (southeastern Brazil).

Oligochaetes	Exposure days						
	2	5	8	12	25	45	65
Naidinae							
<i>Chaetogaster diaphanus</i> (Gruithuisen, 1828)	0	0.05 \pm 0.027	0	0	0.58 \pm 0.09	0	0.11 \pm 0.06
<i>Chaetogaster diastrophus</i> (Gruithuisen, 1828)	0.05 \pm 0.03	2.15 \pm 0.49	12.46 \pm 0.82	12.78 \pm 2.72	1.87 \pm 0.40	9.59 \pm 5.47	11.78 \pm 2.33
<i>Dero</i> (<i>A.</i>) <i>furcatus</i> (Muller, 1773)	0	0	0	0	0	0	0.11 \pm 0.06
<i>Dero</i> (<i>D.</i>) <i>sawayai</i> (Marcus, 1943)	0	0.41 \pm 0.05	1.29 \pm 0.35	0.80 \pm 0.10	2.16 \pm 0.12	29.07 \pm 11.18	29.51 \pm 8.21
Fragmented Naidinae	0.05 \pm 0.03	0.37 \pm 0.14	1.10 \pm 0.40	0.33 \pm 0.10	4.56 \pm 0.96	30.59 \pm 11.80	28.24 \pm 5.65
Pristininae							
<i>Pristina aequiseta</i> (Bourne, 1891)	0	0.37 \pm 0.10	0.64 \pm 0.19	0.05 \pm 0.03	0.29 \pm 0.07	17.43 \pm 7.89	18.05 \pm 3.78
<i>Pristina americana</i> (Cernosvitov, 1937)	0	0.05 \pm 0.03	0	0	0.47 \pm 0.03	0.46 \pm 0.20	7.54 \pm 1.73
<i>Pristina biserrata</i> (Chen, 1940)	0	0	0.18 \pm 0.11	0.42 \pm 0.08	0	0	0.53 \pm 0.31
<i>Pristina longiseta</i> (Ehrenberg, 1828)	0	0.05 \pm 0.03	0	0.51 \pm 0.16	1.70 \pm 0.39	0	0.32 \pm 0.11
<i>Pristina proboscidea</i> (Beddard, 1896)	0	0.14 \pm 0.08	0.05 \pm 0.03	0	0	0	0
Tubificinae							
Tubificinae immature without hair-chaetae	0	0	0	0.05 \pm 0.03	0.23 \pm 0.09	0	0.11 \pm 0.06
Total	0.10 \pm 0.06	3.59 \pm 0.94	15.72 \pm 1.89	14.94 \pm 3.21	11.86 \pm 2.15	87.14 \pm 36.54	96.30 \pm 22.29
Richness	0.33 \pm 0.19	4.67 \pm 0.19	4.67 \pm 0.84	4.33 \pm 0.51	6.00 \pm 0.00	4.00 \pm 0.67	7.33 \pm 0.51
Diversity indices	0.50	1.37	0.81	0.64	1.94	1.37	1.58

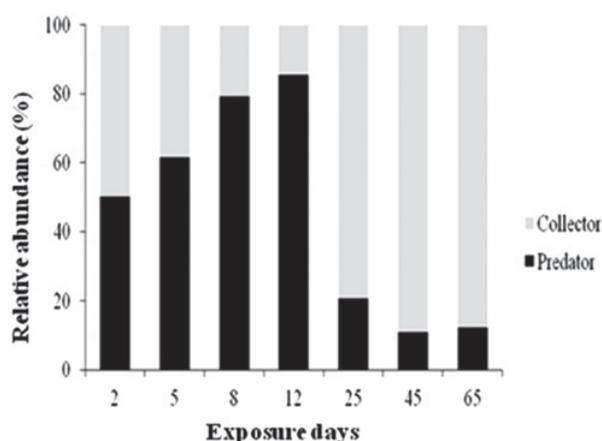


Fig. 4. Relative abundance of collector and predator oligochaetes during the decomposition experiment with *E. azurea* leaves in Manacás Lake (southeastern Brazil).

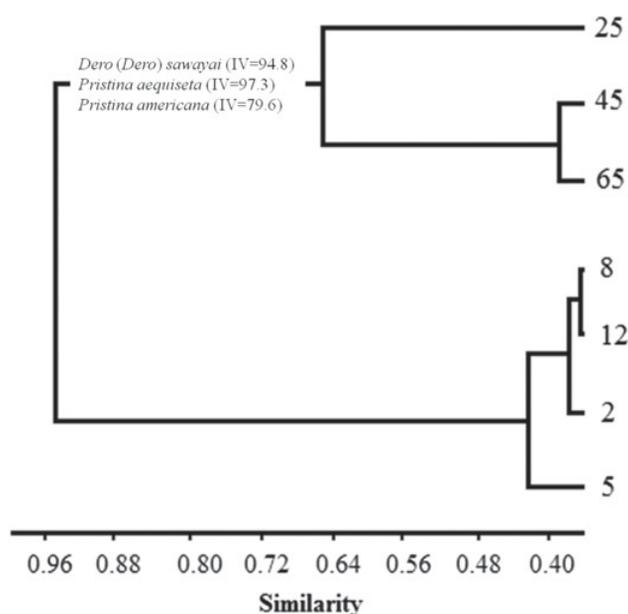


Fig. 5. Cluster analysis (Bray-Curtis, UPGMA, cophenetic correlation = 0.947) based on the density of oligochaetes (ind.g^{-1} DM) during the decomposition experiment with *E. azurea* leaves in Manacás Lake (southeastern Brazil). The indicator species with their respective values (numbers between parentheses) are listed in the cluster.

of these sub-families can be attributed to their lifestyles. Various species of Naidinae and Pristininae can disperse actively in the water column (Learner *et al.*, 1978) and can thus more easily colonize different habitats, including decomposing organic material. In contrast, the Tubificinae live in direct contact with the substrate (Elissen *et al.*, 2008) and are slow colonizers (Levin *et al.*, 1996).

In a river from a temperate region, Chauvet *et al.* (1993) observed high biomass and regular occurrence of Tubificinae in decomposing willow leaves, which resulted in highly fragmented leaf litter, suggesting that these oligochaetes can increase the fragmentation of leaves by

their movement and feeding on leaf parenchyma cells and the associated bacteria. However, in the present study, the low density of Tubificinae in the *E. azurea* leaves did not permit confirming those authors' suggested explanation.

Dero, *Pristina* and *Nais* are generally the genera with the greatest number of species reported in studies of colonization by oligochaetes during the process of leaf litter decomposition (Chauvet *et al.*, 1993; Galizzi and Marchese, 2007). However, organisms of the last genus were absent in this study. In sediment samples from Manacás Lake obtained after the experiment, we found the species *Nais communis* and *Nais variabilis* with low numerical density (unpublished data). Unlike in other reports, in which *Aulodrilus*, *Nais* and *Pristina* were the most abundant oligochaetes (Smock and Stoneburner, 1980; Chauvet *et al.*, 1993; Capello *et al.*, 2004), in this study *D. (D.) sawayai* was the species with the greatest density. The environmental characteristics of aquatic systems (sediment particle size and oxygen concentration) and of the leaves (degree of protection against predators and availability of food resources) influence the species and density of the oligochaetes that colonize decomposing material (Xie *et al.*, 2008; Ohtaka *et al.*, 2010).

A negative correlation between remaining dry leaf mass and invertebrate density was also described by Gonçalves *et al.* (2006, 2007) and Moretti *et al.* (2007). The increasing density during the experiment can be a response to the greater availability of food (Smock and Stoneburner, 1980). As the leaf matter decomposes, there is an increasing supply of micro-organisms associated with the leaves and the quantity of fine particulate matter, both of which are important food sources for oligochaetes (Brinkhurst and Jamieson, 1971).

The numerical dominance of *C. diastrophus* on days 2, 8 and 12 contributed to the low diversity values obtained. This greater abundance of *Chaetogaster* up to day 12 of the experiment is probably related to the supply of protozoa and small invertebrates, such as rotifers, present among the initial colonizers (Gaudes *et al.*, 2009). These organisms are an important source of food for this genus. The increased availability of fine particulate organic matter (FPOM), fungi and bacteria during decomposition (Smock and Stoneburner, 1980; Galizzi and Marchese, 2009) might have contributed to the predominance of collector oligochaetes as of day 25, since these organisms use leaf litter as a substrate and/or indirect food source (Mathuriau and Chauvet, 2002; Alonso *et al.*, 2010).

In the first phase of decomposition (days 2–12), we did not find any indicator species. This can be explained by the fact that the predators that predominate in this phase find prey during the entire decomposition process (Ligeiro *et al.*, 2010), besides the small supply of food for collector organisms. In the second phase, *D. (D.) sawayai*, *P. aequisetata* and *P. americana* were indicator species. This species feed principally periphyton that tends to be more available with elapsing of the experiment (Brinkhurst and Jamieson, 1971; Armendáriz, 2008). Besides, the greatest numbers of collectors were observed in this phase, explained by the fact that as decomposition

progresses, more food becomes available (FPOM, bacteria and periphytic algae) for these organisms (Smock and Stoneburner, 1980).

Oligochaetes are efficient colonizers and were observed from the start to the finish of the experiment. The same was observed in natural and artificial substrates installed in a stream in southeastern Brazil (Carvalho and Uieda, 2004). In the present work, the colonization of *E. azurea* leaves by these organisms was influenced by the quality of the substrate, as can be observed from the cluster analysis, by the formation of two groups based on increasing density during the experiment, indicating a degradative ecological succession (Gonçalves *et al.*, 2004). The same pattern was observed for Chironomidae colonizing *Nymphaea ampla* leaves (Gonçalves *et al.*, 2003) and for the invertebrate fauna in decomposing leaf litter from various plant species (Ramseyer and Marchese, 2009; Ligeiro *et al.*, 2010).

The increasing density during the experiment indicates that oligochaetes are efficient in utilizing the food resources in the detritivorous chain. During the decomposition, the community of these organisms changed because they have different abilities to exploit different food sources, with predominance of predators in the first phase and greater abundance of collectors at the end of the experiment.

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