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Allochthonous leaf litter from riparian vegetation represents the main energy source in small lotic systems, where canopy limits autochthonous primary production. In this study, leaf packs of two tree species (the native *Salix neotrichia* and the introduced *Populus* x *canadensis*) were positioned in the Fardes Stream (southern Spain) to analyze the macroinvertebrate colonization. On two dates, leaf packs were removed, and colonizing macroinvertebrates were collected and identified; at the same time, Surber samples were collected to characterize the riverbed macroinvertebrate coenosis. Leaf packs attracted rich and varied communities of benthic macroinvertebrates, with an increase of the abundance of most taxa over time. No significant differences were found between the colonizing communities of the two leaf types. Some macroinvertebrate species showed a preference for leaf packs, probably due to trophic or hydrologic factors. Considering functional feeding groups, increases in shredders and scrapers and decreases in predators and filterers were detected over time, while collector-gatherers almost did not change in abundance.

Keywords: functional feeding groups; *Salix neotrichia*; *Populus x canadensis*; Ivlev's electivity index; southern Iberian Peninsula

Introduction

It is well-known that in low-order streams the autochthonous primary productivity is reduced and that a great part of the energy input of lotic food webs is derived from non-living sources of allochthonous organic matter (Cummins 1979; Vannote et al. 1980). In fact, autumn-shed leaves represent the most important source of organic material in temperate headwater lotic systems (Power and Dietrich 2002). Leaves falling into streams are trapped by riverbed structures, mostly cobbles and woody debris, forming masses called leaf packs. Aquatic decomposition of deciduous leaves is a complex process involving physical and biological processes; among these, fungi, bacteria, and macroinvertebrates play a main role (Hieber and Gessner 2002). The

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decomposition process starts with a conspicuous initial mass loss of leaves through leaching of soluble contents (Yoshimura et al. 2008). After a few days, microbial conditioning (Gessner et al. 1999) leads to changes in the chemistry and structure of leaves; fungi and bacteria enhance the degradation process by producing enzymes that digest remaining nutrients. Through conditioning, leaves become an attractive resource for invertebrate shredders (Merritt and Cummins 1996; Hieber and Gessner 2002), which play a main role in the decomposition process (Allan and Castillo 2007). Apart from the direct consumption of leaves, shredders produce fecal pellets and orts (fine fragments shredded from leaves but not ingested), transforming coarse particulate organic matter (CPOM) into fine particulate organic matter, that is distributed downstream and ingested by many other consumers (collector-gatherers and filterers; Merritt et al. 2002; Pretty et al. 2005). In temperate woodland streams, leaves enter the system in autumn and processing takes place through the winter. For this reason, the amount of allochthonous organic material in temperate lotic systems is variable, being extremely abundant in fall-winter and declining after this period. Some studies emphasized that this seasonal change in leaf-derived material influences presence, abundance, and distribution of stream invertebrates, particularly shredders (Beisel et al. 1998; Fenoglio et al. 2005). Apart from the basic and pure ecological interest (reviewed in Allan and Castillo 2007), leaf breakdown studies have been recently applied to assess functional integrity of streams at the ecosystem level (Gessner and Chauvet 2002; Pascoal et al. 2003). Some studies focus on the processing of different leaf species (Maloney and Lamberti 1995), underlining the presence of fast, moderate, and slow decomposing species, but little information is available on the macroinvertebrate preference for different allochthonous detritus types. The aim of our study was to investigate if two leaf types (one native and abundant in the hydrographic basin and one not native to the basin) would show different macroinvertebrate colonization in a southern Iberian stream.

Materials and methods

The study was conducted in Fardes Stream (Sierra de Huétor, Granada, Spain; UTM: 30SVG465413, 1200 m a.s.l.), a typical Mediterranean stream in the southern Iberian Peninsula (annual data (mean $\pm$ SD): temperature $= 11.13 \pm 4.40°$C; O_2 saturation percentage $= 85.08 \pm 5.43$; pH $= 8.05 \pm 0.46$; conductivity $428.08 \pm 102.73\,\mu$S/cm; alkalinity $= 51.04 \pm 21.73$ meq/L)). The substrate was composed of 45% sands, 35% pebbles, 15% mud, and 5% stones. The riverside vegetation was abundant and principally represented by Juncaceae or Ciperaceae, and *Salix* sp. but also by Poaceae, *Equisetum* sp., and *Mentha* sp.

This research was carried out during the autumn of 2009, when the leaf-fall started. Two tree species were selected, *Salix neotrichia* (native) and *Populus* x *canadensis* (introduced), whose leaves were collected from a plantation in a nearby area. Recently fallen leaves were collected directly from the ground on October 3, 2009, transported to the laboratory, and dried for 13 days at ambient temperature. Five grams of leaves were enclosed in packs using a netting (15 mm mesh size). Fifty leaf packs were introduced in the stream on October 16, 2009. Steel, U-shaped, grips were used to fix leaf packs to the riverbed. Two leaf packs, one of *S. neotrichia* and one of *P.* x *canadensis*, were placed in close proximity, both linked to the same steal grip. They were positioned in eight rows from upstream to downstream, separated

2 m approximately. Each row contained five grips, separated approximately 1 m from each other, from one riverside to the other.

A randomized block design for data collection was applied to assess possible differences in macroinvertebrate colonization patterns of *S. neotrichia* leaves and *P.* x *canadensis* leaves. This type of design was used because conditions, and so macroinvertebrate community, differed with distance from the riverside. Thus, a gradient in CPOM existed, with higher natural accumulations occurring at the edge of the study site. We blocked the experiment in relation with the distance of the grips to the riverside. The slow flow conditions allowed us to consider every single grip within a row as a replicate, and so flow could not be considered a gradient (nor a blocking variable). We distinguished five blocks, and two grips were randomly removed every date in each block, for a total of 10 leaf packs every date. Thus, 10 leaf packs (five for each species) were collected on November 11, 2009 and 10 were collected on December 02, 2009. At the same time, five samples of the macroinvertebrate community were collected using a Surber sampler ($0.1 \, \mathrm{m}^2$ area and $250 \, \mu\mathrm{m}$ mesh size), one downstream of each row. All the samples (leaf packs and the Surber sample) were fixed in 4% formaldehyde and subsequently sieved ($150 \, \mu\mathrm{m}$ mesh) to remove detritus. Macroinvertebrates were identified to the family level when possible except for Tanypodinae, which were considered apart from other Chironomidae. Functional feeding groups (FFGs) were determined following Merritt and Cummins (1996) and Tachet et al. (2010).

Statistical analyses were done using Statistica v8.0. Because data were not normally distributed (Kolmogorov–Smirnov test with $p < 0.05$ for every variable) and variables were not independent, non-parametric tests were used. First, the Wilcoxon matched pairs test was used to evaluate the possible differences in (1) the communities of both dates (November 11, 2009 and December 02, 2009); (2) the communities of the leaf packs of the same species on the two dates; (3) the communities of the leaf packs of the two species (*P.* x *canadensis* and *S. neotrichia*) on the same date; and (4) the Surber sample communities and the communities of each of the two species leaf packs (Surber vs. *P.* x *canadensis* and Surber vs. *S. neotrichia*). For those cases in which differences existed in the communities of leaf packs from the same species on the two dates, a sign test was used to determine the percentage of taxa in which more or fewer individuals were collected on the second date. Finally, a Friedman analysis of variance (ANOVA) was used to assess possible differences between both species leaf packs and the Surber sample.

We used Ivlev's index (Ivlev 1961) to calculate taxon electivity for each leaf pack species as: $E = (r_i - p_i)/(r_i + p_i)$, where r_i is the relative abundance of a particular taxon in the leaf pack and p_i is the relative abundance of the same taxon in the benthic community from the Surber. This index ranges from -1 to 1. A value of -1 means total rejection, 1 indicates complete election, and 0 indicates that the species is present in the leaf pack in a proportion equal to that in which it is found in the benthic community.

Results

A total of 4728 individuals belonging up to 33 taxa was collected in *P.* x *canadensis* leaf packs; 5068 individuals belonging up to 36 taxa were collected in *S. neotrichia*

leaf packs; and 4581 individuals belonging up to 29 taxa were found in the Surber samples (Table 1).

No differences were detected in the riverbed macroinvertebrate community between the two collection dates (Wilcoxon $T = 143.50$, $p > 0.05$). This eliminated the possibility that differences in the macroinvertebrate communities of leaf packs were due to differences in the riverbed community.

Significant differences were found between the macroinvertebrate community in the *P.* x *canadensis* leaf packs on the first collection date and that of the second date (Wilcoxon $T = 6515.00$, $p < 0.05$) but not in *S. neotrichia* leaf packs (Wilcoxon $T = 6787.00$, $p > 0.05$). For 59.1% of taxa, more individuals were collected on the

Table 1. Number of individuals of each taxon collected at both dates in *P.* x *canadensis* leaf packs, *S. neotrichia* leaf packs, and Surber samples.

Taxon	*P.* x *canadensis*		*S. neotrichia*		Surber samples	
	11/11/09	02/12/09	11/11/09	02/12/09	11/11/09	02/12/09
Ancylidae	2	9	0	5	3	2
Athericidae	62	65	67	59	17	21
Baetidae	74	74	118	46	39	42
Caenidae	67	67	112	112	571	362
Calopterygidae	115	0	183	0	0	0
Capniidae	12	410	12	375	306	224
Ceratopogonidae	70	4	73	4	10	14
Dytiscidae	21	0	17	0	0	0
Elmidae	6	263	4	296	532	422
Ephemerellidae	11	20	7	56	0	0
Ephemeridae	2	1	0	3	5	19
Gomphidae	12	3	9	16	83	49
Heptageniidae	8	23	1	25	160	62
Hydracarina	8	14	12	7	2	0
Hydridae	216	88	284	65	0	7
Hydropsychidae	27	36	39	17	5	7
Leptophlebiidae	144	217	121	153	307	213
Leuctridae	4	96	4	94	66	46
Lymnaeidae	7	8	4	17	3	3
Nemouridae	7	8	26	12	4	2
Oligochaeta	392	16	395	10	126	70
Ostracoda	264	0	334	0	0	0
Other Chironomidae	85	667	68	536	44	154
Perlidae	0	0	0	1	0	0
Perlodidae	18	4	18	6	6	7
Philopotamidae	0	9	0	1	1	2
Planorbidae	24	4	8	1	1	0
Polycentropodidae	0	25	1	14	1	2
Rhyacophilidae	0	0	0	1	0	0
Scirtidae	35	0	38	0	1	0
Sericostomatidae	36	317	17	507	310	156
Sialidae	24	1	9	1	0	0
Simuliidae	7	75	1	34	4	16
Stratiomydae	300	13	452	7	4	4
Tanypodinae	9	122	6	144	25	36
Tipulidae	0	0	0	3	2	1

second date in *P.* x *canadensis* leaf packs than on the first date (Sign test with $p < 0.05$).

When comparing the macroinvertebrate community on a same date between both leaf pack species, differences were not found in any case (Wilcoxon $T = 4845.00$, $p > 0.05$ for the first date; Wilcoxon $T = 5264.00$, $p > 0.05$ for the second date).

Within dates, significant differences between the different leaf pack species and the Surber were found only on the second date (Friedman ANOVA = 1.43, $p > 0.05$ on the first date and Friedman ANOVA = 7.03, $p < 0.05$ on the second date). Particularly, significant differences (though just marginally significant) were found between the community in the *P.* x *canadensis* leaf packs and the one of the Surber (Wilcoxon $T = 143.50$, $p < 0.1$ on the second date). For 30.0% of taxa on the second date, more individuals were collected in the Surber than in *P.* x *canadensis* leaf packs (sign test with $p < 0.05$).

The application of Ivlev's index (Figure 1) revealed that some taxa showed a positive electivity for leaf packs (e.g., Planorbidae and Hydropsychidae in *P.* x *canadensis* packs, Lymnaeidae and Tanypodinae in *S. neotrichia* packs). In other cases, some taxa exhibited a great negative electivity or directly they were never present in the leaf packs. For some taxa (e.g., Calopterygidae, Ostracoda, Hydridae, Perlidae, Dytiscidae, Sialidae, Rhyacophilidae) a value of 1 was obtained, which means that they were found in the leaf packs but not collected in the Surber. This was probably due to their scarcity in the benthos or to a brief presence in the leaf packs. In fact, this incongruence has been previously pointed out in feeding studies that compare, for instance, the stomach contents of planktivorous fishes with the freshwater invertebrate community (Mills et al. 1992).

The main FFGs represented in samples were shredders and collector-gatherers (Figure 2). Scrapers were always more abundant in the benthic community than in the leaf packs, predators and filterers were more abundant in the leaf packs (mainly in the first collection date), and shredders were first more abundant in the community but later more abundant in the leaf packs. Collector-gatherers did not show a clear tendency over time.

Discussion

Allochthonous leaf litter breakdown is a critical ecosystem-level process in most streams and low-order rivers. Many studies investigated different temporal aspects of this process, focusing on the succession of three main stages (leaching, conditioning, and fragmentation). In our study, mass loss was not considered, but we just focused on the macroinvertebrate presence and colonization in the leaf packs. Low-order lotic systems are highly heterogeneous environments in which habitat characteristics vary drastically over small distances (Townsend and Hildrew 1994). Many studies underlined the idea that the distribution of macroinvertebrates depends on many factors, such as physical-chemical characteristics (Sandin 2003), substratum (Wright et al. 2003; Bo et al. 2007), hydrodynamics (Malmqvist and Mäki 1994), biological interactions (Bo et al. 2010), and food availability (Richardson 1992; Fenoglio et al. 2005).

In this context, leaf packs represent an interesting research topic. Leaf packs positioned in Fardes Stream attracted a rich and varied community of benthic macroinvertebrates. Interestingly, the abundance of most taxa in the leaf packs
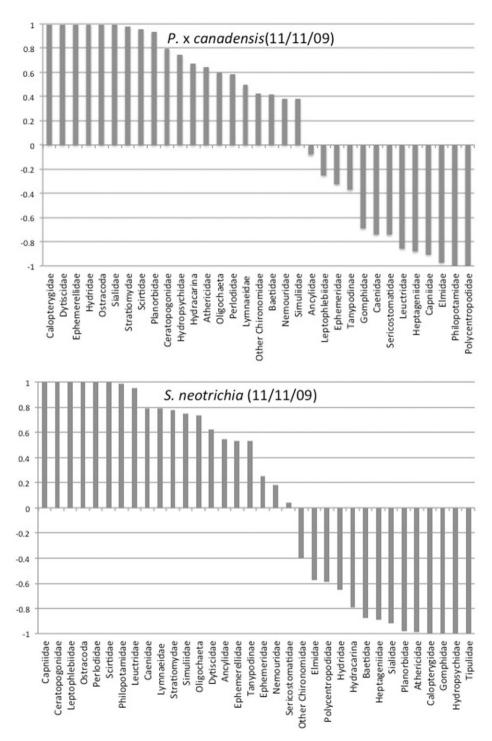
Figure 1. Ivlev's electivity index on both dates in *P. x canadensis* leaf packs and *S. neotrichia* leaf packs.
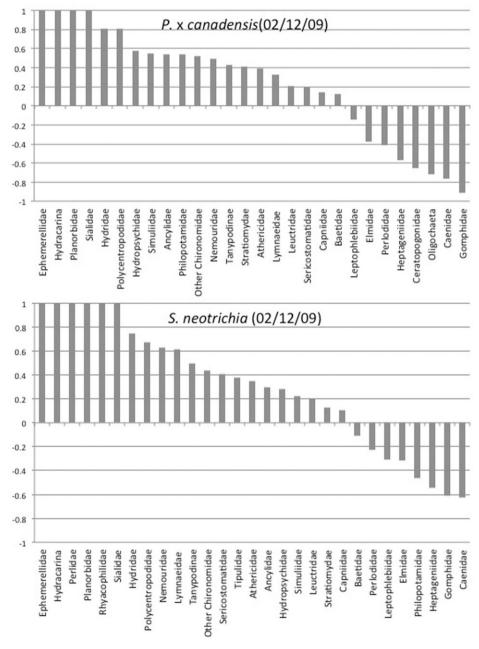
Figure 1. Continued.

changed between dates, with an increase in organism number on the second date. Some studies underlined that the characteristics of CPOM vary with the time of exposure in the water, especially because of microbial and fungal colonization (Gessner et al. 1999). In particular, hyphomycetes with extra-cellular cellulolytic enzymes break down leaf tissues (Graça 1993; Gessner et al. 1999), transforming the
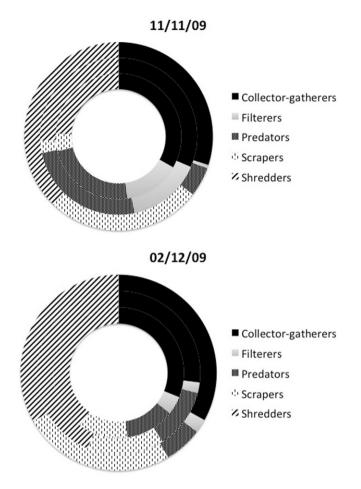
Figure 2. Proportion of the different FFGs on both dates in *P.* x *canadensis* leaf packs (inner ring), *S. neotrichia* leaf packs (middle ring) and benthic community (Surber samples) (outer ring).

leaf matrix and increasing the attractiveness of detritus for macroinvertebrates (Graça et al. 2001). We can hypothesize that by the second removal date fungal conditioning had already acted, increasing the palatability and thus the ability to attract macroinvertebrates. Another reason could be related to the natural variation of the abundance of allochthonous CPOM in the streambed. In temperate lotic systems, the number of leaves that fall in the stream increases during the late autumn-early winter, as does the quantity of fallen leaves that are washed into the streambed; so, we could hypothesize that the increase of colonizing invertebrates reflects the colonization process that naturally occurs in temperate environments.

No significant differences were found between the colonizing communities of the two leaf types. This finding is interesting because some studies indicated that macroinvertebrates may prefer some leaf species and reject others (Canhoto and Graça 1995). This preference could be related to different leaf characteristics, such as the amount of nutrients, the presence of secondary compounds (e.g., tannins), or the

physical structure. In some cases, chemical and physical plant defenses may remain active after senescence, so that fungal conditioning is not very effective: in these species, such as eucalyptus (*Eucalyptus globulus*), the attractiveness for macro-invertebrate shredders is strongly reduced (Canhoto and Laranjeira 2007). This seems not the case in our study; both *P.* x *canadensis* and *S. neotrichia* leaf packs attracted a rich and diverse colonizing community. Comparing communities in the riverbed and in the leaf packs, we observed that some groups seemed to be attracted by leaf packs, reaching very high densities. For example some predators, such as Odonata Calopterygidae, Coleoptera Dytiscidae, Plecoptera Perlidae, and Megaloptera Sialidae were more abundant in the leaf samples than in the riverbed. This could be related to the fact that these large-sized predators colonize patches of organic matter, such as leaf packs or fish carrion (Fenoglio et al. 2010) where they are able to find high amounts of prey. Other taxa, such as Ostracoda and Hydridae were abundant and widespread in the leaf packs; for these groups, with semi-lentic or limnophilous habits, organic detritus could constitute an important refuge from hydrological stress (Robertson et al. 1995).

Regarding FFGs, shredders and collector-gatherers dominated the community in Fardes Stream. Filterers (such as Diptera Simuliidae, for instance) were more abundant in the leaf packs than in the community (mainly on the first collection date) probably because they found a good support media in this substrate. Predators were also quite abundant, as they would find in the leaf packs a microhabitat with a great concentration of potential prey, though their abundance decreased on the second date. Scrapers were not well-represented probably due to their main feeding resource (i.e., biofilm composed of bacteria, fungi, and diatoms) did not have enough time to develop. Nevertheless, an increase of this FFG was detected over time. Shredders colonized the leaf packs rapidly and clearly increased their importance on the second date.

Comparing the FFGs composition in both dates, the importance of collector-gatherers did not change appreciably either in the riverbed community or in the leaf packs. At the beginning, on the first collection date, both types of leaf packs supported communities with a similar feeding guild composition. On the second date, shredders increased their numbers in both leaf types but mainly in the *S. neotrichia* ones, while filterers increased in importance mostly in *P.* x *canadensis* leaf packs. Scrapers were more abundant on the second date than on the first, probably because biofilm was developing.

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