Science of the Total Environment 409 (2011) 4373–4380

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Leaf litter recycling in benthic and hyporheic layers in agricultural streams with different types of land use[☆]

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ARTICLE INFO

Article history:
Received 13 April 2011
Received in revised form 27 June 2011
Accepted 30 June 2011
Available online 26 July 2011

Keywords:
Vineyard area
Livestock farming
Particulate organic matter dynamic
River sediment
Aquatic macroinvertebrates
Bacterial and fungal biomasses

ABSTRACT

Changes in land use and intensification of agricultural pressure have greatly accelerated the alteration of the landscape in most developed countries. These changes may greatly disturb the adjacent ecosystems, particularly streams, where the effects of pollution are amplified. In this study, we used the leaf litter breakdown rate to assess the functional integrity of stream ecosystems and river sediments along a gradient of either traditional extensive farming or a gradient of vineyard area. In the benthic layer, the total litter breakdown process integrates the temporal variability of the anthropogenic disturbances and is strongly influenced by land use changes in the catchment even though a low concentration of toxics was measured during the study period. This study also confirmed the essential role played by amphipods in the litter breakdown process. In contrast, microbial processes may have integrated the variations in available nutrients and dissolved oxygen concentrations, but failed to respond to the disturbances induced by vineyard production (the increase in pesticides and metal concentrations) during the study period. The response of microbes may not be sensitive enough for assessing the global effect of seasonal agricultural practices. Finally, the leaf litter breakdown measured in the hyporheic zone seemed mainly driven by microbial activities and was hence more affected by vertical exchanges with surface water than by land use practices. However, the breakdown rate of leaf litter in the hyporheic zone may constitute a relevant way to evaluate the impact on river functioning of any human activities that induce massive soil erosion and sediment clogging.

1. Introduction

In most developed countries, changes in land use associated with agricultural intensification have greatly accelerated the alteration of the landscape (removal of hedgerows, increase in field size, and reduction of habitat diversity) in the last 50–60 years. The contribution of agriculture to the nutrient enrichment in rivers (Meybeck, 1982; Vitousek et al., 1997) or the rising concentration of pollutants (herbicides, fungicides, and metals) (IFEN, 2007) have been widely considered. Several studies have pointed out changes in assemblage structure and composition of microbial, invertebrate, and fish communities following landscape modifications (see review in Harding et al., 1998; Allan, 2004; Dolédec et al., 2006; Hagen et al., 2006; Pesce et al., 2010), but changes of their role in ecosystem processes were rarely considered (Piscart et al., 2009).

In recent years, there has been a growing interest in the use of leaf litter breakdown to assess the functional integrity of stream ecosystems (Gessner and Chauvet, 2002; Lecerf et al., 2006; Piscart et al., 2009). This particulate organic matter (POM) represents the main source of organic carbon and nutrients in low-order streams (Cummins, 1974; Webster and Meyer, 1997). In such streams, leaf litter breakdown is partially controlled by physical factors (e.g. abrasion and fragmentation) but the major part of leaf mass loss is due to the complementary activities of a wide variety of organisms (aquatic fungi, bacteria, and shredder invertebrates) (Gessner et al., 1999). Anthropogenic disturbances of river watersheds can severely affect the production and recycling rates of POM through decreases in quantity and quality (Lecerf and Chauvet, 2008b) and changes in microbial activities (Lecerf and Chauvet, 2008a, b; Piscart et al., 2009) and in the density and composition of microbial and invertebrate assemblages (Hagen et al., 2006; Lecerf and Chauvet, 2008a,b; Piscart et al., 2009). In western France, Piscart et al. (2009)

[☆] Capsule: This study highlights the consequences of land uses on benthic and interstitial leaf litter recycling in streams.

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doi:10.1016/j.scitotenv.2011.06.060

showed that agricultural practices can strongly affect the activity of shredders and reduce litter breakdown by up to 75% in farming areas. Physical disturbances of the bed sediment also have a strong influence on litter breakdown (Tillman et al., 2003; Marmonier et al., 2010). For example, up to 50% of autumnal allochthonous leaf input was reported by Herbst (1980) to be buried in sediment, and the breakdown rate of this leaf litter is known to be highly reduced by burial in sediments (Crenshaw and Valett, 2002; Marmonier et al., 2010; Cornut et al., 2010). However, the effects of land use changes on sediment quality are still poorly understood and nothing is known about the consequences of sediment disturbance for the litter breakdown rates in the hyporheic zone. Indeed, vertical connectivity controls the movements and the activities of benthic shredders inside sediments (Marmonier et al., 2010; Navel et al., 2010) while pesticides and metals may lead to a shift in structure of microbial communities of biofilms (Huang et al., 2000; Morin et al., 2010).

Our work is unique in studying of leaf litter breakdown rates in the benthic and hyporheic layers along gradients of agricultural activities in the same watershed: a traditional farming area bordered by hedges used as a control gradient (livestock production with low use of pesticides and fertilizers) and a gradient of vineyard area considered as highly disturbed in its downstream part (with regular use of pesticides and heavy metals during the growing period, Pesce et al., 2008). Six sites were selected in two rivers along a downstream gradient of either traditional hedged farming or vineyard areas. We hypothesized that traditional farming areas (1) should have a limited effect on invertebrates, and consequently on the breakdown activity of shredder invertebrates (Piscart et al., 2009; Hladyz et al., 2010). However, the increase in available nutrients along the river should increase the microbial breakdown activity in the benthic layer (Suberkropp and Chauvet, 1995; Gulis et al., 2004; Paul et al., 2006; Hladyz et al., 2010). For the vineyard area, we hypothesized (2) a deleterious effect of pesticides on invertebrates (Schäfer et al., 2007) and fungal assemblages (Solé et al., 2008) and a resulting decrease in breakdown rates in the benthic layer along the gradient of vineyard density (Piscart et al., 2009; Medeiros et al., 2010). For the hyporheic layer, we predicted (3) that the increase in available nutrients along the river in the control area should increase the microbial breakdown activity (Claret et al., 2001). However, in the vineyard area a decrease in the vertical connectivity between the river and the hyporheic zone, due to tillage and soil erosion in vineyards, river sediment clogging, and accumulation of toxicants inside the sediment, may result in a decrease in breakdown rates in the hyporheic zone.

2. Material and methods

2.1. Study sites

The study took place in the upstream first-order part of the Ardières River and its first-order tributary, the Morcille River, in the well-known wine area of Beaujolais, France. The upstream part of the Ardières River lies in a patchy landscape with forests, pastures, and traditional extensive livestock farming. The Morcille River flows in a region of intense wine growing (more than 70% of the catchment area is occupied by vineyards). For each river, three different sites were selected with similar riparian vegetation (with at least one forested bank) and instream characteristics (e.g. riffles with similar local water velocity, discharge and geomorphology) but different surrounding land-uses. The three sites of the Ardières River (A1, A2, and A3) were all located in the upstream part of the stream along extensive farming area with a weak downstream gradient of increasing livestock production. The three sites of the Morcille River (M1, M2, and M3) were subject to an increasing vineyard pressure from M1 with less than 5% of the catchment covered by vineyard and 90% by forest (considered as a reference site), to M2, where vineyard represents 30%, and M3, with more than 50% of the catchment devoted to wine production (Dorigo et al., 2007). Bottom sediments are similar in all stations (coarse gravel and sand) with high hydraulic conductivity (from 7.13^{-3} to 2.10^{-2} m sec^{-1} at -20 cm).

2.2. Water chemistry

Water temperatures were measured at each site in surface water and in the hyporheic zone (at 20 cm deep) every hour throughout the study period, using MINILOG8-TDR miniature data logger (WEMCO division, Amirix Systems Inc, Halifax, Canada). Electrical conductivity, pH, (LF92, WTW™, Weilheim, Germany), dissolved oxygen concentration (HQ20, HACH™, Dusseldorf, Germany) and vertical hydraulic gradient were measured in the field on each sampling date. Water samples were collected from surface and hyporheic waters every month from January to March 2009 and analyzed the same day. In the laboratory, filtered-water samples (GF/C, 1.2 μm pore size, Whatman™, Maidstone, UK) were analyzed for NH_4^+, NO_3^-, and NO_2^- using an Easychem Plus automatic analyser (Systea, Italy) based on standard colorimetric methods (Grasshoff et al., 1983). Water samples for dissolved organic carbon (DOC) were filtered through 0.22 μm pore size Whatman GSWP filters (Millipore), acidified with three drops of HCl (35%) and stored at 4 °C for further analysis. DOC concentration was measured with a total carbon analyser (multi N/C 3100; Analytik Jena, Jena, Germany) based on combustion at 850 °C after removing dissolved inorganic C with HCl and CO_2 stripping under O_2 flow. The eight most frequently found pesticides (Morin et al., 2010) were analyzed in the surface water samples using standardized protocols and a ESI-LC-MS/MS (API 4000, Applied Biosystems). Additionally, the seven most frequently found metals were analyzed by ICP-MS (Thermo Electron X7) following the NF EN ISO 17294-2 standard procedures (AFNOR, 2005). To evaluate the residuals of toxicant in the hyporheic zone, bottom sediment was sampled in January for metal analysis. After acidification of samples with HNO_3 SUPRAPUR 0.5%, the analyses were performed by ICP-MS (THERMO ELECTRON X7 Series 2) to meet the standard NF EN ISO 17294-2 (AFNOR, 2005). The limit of detection (LOD) of metals was 0.05 μg/L.

2.3. Leaf litter decomposition

The litter-bag method (Chauvet, 1987; Boulton and Boon, 1991) was used to assess the leaf litter breakdown rate along the gradient of agricultural impact. Freshly fallen leaves of *Alnus glutinosa* were collected in December 2008 from forests adjacent to the study sites.

To study the breakdown rate in the surface water, about 2 (±0.1) g of air-dried leaves were enclosed in coarse (3 mm mesh, 15×15 cm plastic bags) and in fine (0.5 mm mesh, 12×8 cm nylon bags) mesh bags (Piscart et al., 2009). The coarse mesh allowed large shredders (such as Gammaridae and Limnephilidae) to enter the bag and feed on leaves, whereas the fine mesh excluded most of the invertebrates without interfering with microbial colonization (Boulton and Boon, 1991; Boulton, 1993). Twelve bags of each type were firmly tethered to steel pegs placed within shallow riffles with similar current velocities (range from 0.2 m s^{-1} in M1 to 0.3 m s^{-1} in A1) at each site, on 21 January 2009. Three bags were collected at each site, weekly for coarse mesh bags and every 2 weeks for fine mesh bags, because the leaf litter breakdown rate without invertebrates was much lower.

Small bags were used to measure breakdown rates in the hyporheic zone to avoid modifications of sediment characteristics linked to the burial process (Marmonier et al., 2010; Navel et al., submitted). About 0.5 (± 0.1) g of air-dried leaves were enclosed in coarse mesh bags (3 mm mesh, 5×4 cm plastic bags). In order to reduce the disturbance of the river bed, bags were carefully introduced inside the sediment using a mini-piezometer (1 m long, 3 cm diameter) pushed to a 20 cm depth into sediment using an internal metallic rod (Navel et al., submitted). Twenty-four hyporheic bags per site were buried at the upstream end of shallow riffles (i.e. downwelling zone with negative