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The effects of eucalypt plantations on plant litter decomposition and macroinvertebrate communities in Iberian streams

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ABSTRACT

Eucalypt plantations cover over 1.5 million ha in the Iberian Peninsula. The effects of the replacement of native deciduous forests by exotic plantations on stream communities and litter decomposition, a key ecosystem process in forest streams, are poorly understood. We compared microbially driven and total (microbes + invertebrates) decomposition of alder and oak leaf litter (high and low quality resource, respectively) as well as macroinvertebrate communities associated with decomposing litter and in the benthos, in five streams flowing through native deciduous broad-leaved forests and five streams flowing through eucalypt plantations in central Portugal and northern Spain (20 streams total). Total decomposition rate of alder leaf litter was slower in eucalypt than in deciduous streams, which was attributed to lower macroinvertebrate (and also shredder) colonization. No major effects of eucalypt plantations were found on macroinvertebrate colonization and total decomposition of oak litter, likely due to the low contribution of invertebrates to the decomposition of nutrient-poor litter. Microbially driven litter decomposition was generally not affected by forest change, likely due to high functional redundancy among microbes. Eucalypt streams had fewer invertebrates in Portugal than in Spain, which might be attributed to summer droughts in Portugal and the absence of deciduous riparian corridors in eucalypt plantations. In northern Spain, the relatively wet climate allows streams to flow year-round and eucalypt plantations have riparian deciduous trees that mitigate the effects of plantations. This study highlights the need to consider regional differences in climate, native vegetation, and the importance of macroinvertebrates, when assessing the effects of plantations on stream ecosystem processes such as carbon cycling. It also suggests that preservation of native riparian corridors, especially in drier areas, where the native vegetation provides high quality litter to the streams, and where invertebrates play an important role in aquatic processes, may mitigate the effects of plantations on stream communities and processes.

1. Introduction

Planting of trees for timber, charcoal, and pulp is an important economic activity worldwide (Forest Resource Assessment (FRA), 2010). *Eucalyptus* is the second most common genus used in plantations due to its high adaptability, fast growth, and high economic value. It is now present in over 90 countries, mostly between 35° S and 35° N, covering a global area of over 20 million ha (Iglesias-Trabado and Wilstermann, 2009). *Eucalyptus globulus* Labill. plantations cover over 1.5 million ha in the Iberian Peninsula and have replaced native mixed broad-leaved deciduous forests over large areas (Tercer Inventario Forestal Nacional (IFN3), 2007, Instituto de Conservação da Natureza e das Florestas (ICNF), 2013). These areas are typically drained by small streams, which derive most of their energy and carbon from litter provided by the surrounding vegetation (Fisher and Likens, 1973; Wallace et al., 1997).

Streams flowing through native temperate deciduous broad-leaved forests receive most of their litter input in autumn, and this input is often a diverse mixture of litter species that vary in physical and chemical characteristics (Abelho and Graça, 1996; Pozo et al., 1997; Molinero and Pozo, 2004; Swan and Palmer, 2004). In contrast, streams flowing through eucalypt plantations in the Iberian Peninsula receive their litter input year round (in some

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areas with higher summer intensity), and this input is dominated by eucalypt leaves (Abelho and Graça, 1996; Pozo et al., 1997; Molinero and Pozo, 2004). Leaves of *E. globulus* have low nutrient concentrations, high concentration of secondary compounds (e.g. essential oils and polyphenolics), and a waxy cuticle (Canhoto and Graça, 1999). Annual litter input is also generally lower in eucalypt than in deciduous streams (Pozo et al., 1997; Molinero and Pozo, 2004). However, due to differences in seasonality of litter fall between deciduous broad-leaved forests and eucalypt plantations, and higher stream discharge in autumn/winter than in summer, benthic organic matter storage is generally higher in eucalypt than in deciduous streams (Abelho and Graça, 1996; Molinero and Pozo, 2004). These changes in seasonality, diversity, composition, and quantity of litter inputs to streams have the potential to affect aquatic communities and ecosystem processes but studies tend to provide conflicting results (see below).

Both fungi and invertebrate shredders are key players in the decomposition of allochthonous organic matter in streams (Hieber and Gessner, 2002). This is a key ecosystem process that leads to mineralization of nutrients, incorporation of organic carbon into decomposer biomass, and transfer of nutrients and energy to higher trophic levels (Gessner et al., 1999). Therefore, changes in fungal and invertebrate communities and activity due to eucalypt plantations may have important repercussions for stream ecosystem functioning. The replacement of mixed deciduous broad-leaved forests by eucalypt plantations was found to reduce aquatic invertebrate species richness, diversity, density, and biomass (Basaguren and Pozo, 1994; Abelho and Graça, 1996; Larrañaga et al., 2009a, 2009b). On the other hand, some studies reported an impact on aquatic fungal species richness and conidial production in Portuguese streams, but not in Spanish ones (Chauvet et al., 1997; Bärlocher and Graça, 2002; Ferreira et al., 2006a).

The majority of studies that addressed the effects of eucalypt plantations on streams have been done in the Iberian Peninsula. An exception is Laćan et al. (2010) where litter decomposition rates and macroinvertebrate communities were compared between stream reaches lined by native vegetation or *E. globulus* in California. No strong effects of eucalypt were found in this study, likely due to eucalypt trees forming isolated groves of mostly old trees rather than plantations. Another study (Masese et al., 2014) compared streams flowing through mainly forest, mainly agricultural (with riparian zones dominated by *E. globulus*) or mixed catchments in the Kenian Rift Valley; however, the results were confounded by simultaneous occurrence of eucalypt trees and other types of agricultural impact. In general, some studies from the Iberian Peninsula reported reduced litter decomposition rates in eucalypt when compared to deciduous streams (Pozo, 1993; Abelho and Graça, 1996), while others reported no major change (Pozo et al., 1998; Bärlocher and Graça, 2002; Ferreira et al., 2006a), even though aquatic communities were strongly affected (Bärlocher and Graça, 2002; Ferreira et al., 2006a). These results suggest that (i) the structure of aquatic communities may be more sensitive to eucalypt plantations than ecosystem processes, and (ii) that responses of aquatic communities and processes to forest change may depend on other factors such as identity/quality of litter, type of decomposer community, and region.

In this study, we assessed the effect of the replacement of native deciduous broad-leaved forests by eucalypt plantations on total and microbially driven decomposition of leaf litter of two common tree species, alder and oak, and on the density and family richness of litter-associated and benthic macroinvertebrates by comparing five streams flowing through native forests and five streams flowing through eucalypt plantations in each of central Portugal and northern Spain (20 streams total). This is the largest comparison of deciduous and eucalypt streams using a common methodology (Graça et al., 2002) that allows us to assess if the effects of eucalypt plantations depend on the region (Portugal vs. Spain), litter identity (alder vs. oak), and type of decomposer community (microbes only vs. microbes and invertebrates).

2. Materials and methods

2.1. Study sites

Five streams flowing through deciduous broad-leaved forests and five streams flowing through eucalypt plantations were selected in central Portugal (Vouga and Mondego River basins) and northern Spain (Agüera and Sámano River basins) (Table 1). Climate in central Portugal is temperate with mean annual air temperature of 15.0 °C and precipitation of ca. 1000 mm, mostly occurring in winter (Miranda et al., 2002), while climate in northern Spain is humid oceanic, with mean annual air temperature of 14.3 °C and precipitation of ca. 1500 mm evenly distributed over the year (Elosegi et al., 2002). Deciduous forests in the study areas were dominated by oak (*Quercus* spp.) and chestnut (*Castanea sativa* Miller) in both regions; alder (*Alnus glutinosa* (L.) Gaertner) was also present along the stream banks. Eucalypt plantations differed between regions; in Portugal, *E. globulus* was present up to the stream banks (i.e. mostly with no native deciduous trees along the riparian area), while in Spain, some deciduous trees were found along the stream (e.g. oak, alder, hazelnut (*Corylus avellana* L.), ash (*Fraxinus excelsior* L.)). No human impacts besides eucalypt plantations were apparent at the study sites. More information on the Spanish streams can be found in Larrañaga et al. (2009a).

2.2. Stream characterization

Water temperature was recorded every hour during litter incubation with data loggers (Onset Optic StowAway or ACR SmartButton). Electrical conductivity (WTW LF 330) and pH (Jenway 3310 in Portugal and Hanna HI9025 in Spain) were measured 3–8 times. On the same occasions, water was collected and transported cold to the laboratory. Unfiltered water was used to determine ammonium concentration and alkalinity within 48 h of collection, while filtered (Millipore APFF in Portugal and Whatman GF/C in Spain) water was frozen for later analyses of nitrate, nitrite and soluble reactive phosphorus (SRP) concentrations. Ammonium, nitrate, and nitrite concentrations were determined with automatic analyzers (Dionex DX-120 in Portugal and Traacs 800 in Spain). Nitrite concentration was always below the detection limit and thus dissolved inorganic nitrogen (DIN) concentration was calculated as NO_3-N + NH_4-N. SRP concentration was determined by the ascorbic acid method (APHA, 1995). Alkalinity was estimated by titration with H_2SO_4 to an end point pH of 4.5 (APHA, 1995).

2.3. Litter decomposition

Freshly fallen alder (*A. glutinosa* (L.) Gaertn.) and oak (*Quercus robur* L.) leaves were collected at a single site in each region, air-dried at room temperature, and stored in the dark. These species were selected because they are common along streams flowing through native forests in the Iberian Peninsula, have contrasting litter characteristics (lower nutrient concentration, higher polyphenolics concentration, and higher toughness in oak than alder), have distinct palatability to shredders (higher palatability of alder than oak), and decompose at different rates (faster for alder than oak) (Ferreira et al. 2006a, 2006b, 2012; Gulis et al., 2006). Decomposition of these leaf species has also been used for the assessment of stream health throughout Europe (Pascoal et al., 2003; Gulis et al., 2006; Castela et al., 2008; Riipinen et al., 2009; Woodward et al., 2012). Leaves were weighed (4.75–5.25 g), moistened with