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Exposure of wood in floodplains affects its chemical quality and its subsequent breakdown in streams

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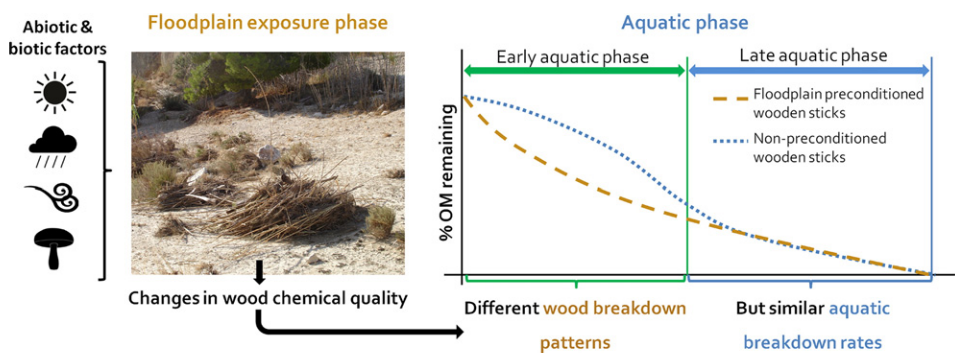
HIGHLIGHTS

- Storage on the floodplain may affect organic matter quality ("preconditioning").
- We measured the effect of wood preconditioning on its subsequent aquatic breakdown.
- Preconditioning increased wood quality and microbial activity.
- Preconditioning enhanced initial breakdown in streams.
- Preconditioning limited the microbial activity after 4 months of breakdown.

GRAPHICAL ABSTRACT



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ABSTRACT

In stream ecosystems, coarse organic matter from the riparian vegetation, a key food resource, is often retained in the floodplains before reaching the channel. During floodplain exposure, organic matter can be affected by abiotic and biotic processes ("preconditioning"), which alter its quality and affect its subsequent decomposition in streams. We analyzed the effect of floodplain preconditioning on wood quality (lignin, C, N, P, K, among others), and its subsequent aquatic breakdown, paying special attention to microbial activity. We simulated preconditioned standard wooden sticks on one arid stream floodplain for 3 and 4 months, and then monitored their breakdown in three different streams, together with control (non-preconditioned) sticks. Preconditioning reduced lignin mass and C:N and lignin:N ratios, caused the leaching of soluble nutrients such as P and K, as well as N immobilization by microbes. These changes enhanced the breakdown of wood in the first week of immersion, but had no effect on breakdown rates after 4 months of incubation in the streams, although N immobilization was diminished. Our results suggest that terrestrial preconditioning could alter the role of wood as a long-lasting nutrients and energy source for freshwater ecosystem.

1. Introduction

In most forested streams, leaf litter is the most important fraction of allochthonous organic matter inputs (Benfield, 1997; Wallace et al., 1995), and is thus an essential energy source for ecosystems (Fisher and Likens, 1973; Kuehn, 2015; Tank et al., 2010). Additionally, wood litter can represent an important energy source for aquatic heterotrophs

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and also a relevant structural support for microorganisms that grow on its surface (i.e. Golladay and Sinsabaugh, 1991; Rabeni and Hoel, 2000). Whereas leaves are rapidly flushed away, wood litter is a long-lasting resource that increases the pool of nutrients (Romero et al., 2005) and stored carbon and significantly contributes to the energy flux in streams (i.e. Elosegi et al., 2007). In arid and semiarid regions, where deciduous vegetation is scarce, or even absent, and riparian vegetation is dominated by perennial woody shrubs (Bruno et al., 2014; Salinas and Casas, 2007), wood litter may represent an essential energy resource for freshwater ecosystems functioning (Jacobson et al., 1999).

The dynamics and breakdown of organic matter in streams are affected by climate, flow regimes and the riparian vegetation structure (Larned, 2000; Schade and Fisher, 1997). In dryland streams, before entering the stream channels, most coarse organic matter from terrestrial and riparian vegetation is usually transported by floods and retained in floodplains (Jacobson et al., 1999), where its preconditioning may have a substantial effect on its subsequent use by aquatic organisms (Fellman et al., 2013; Pu et al., 2014). These dynamics differ from those occurring in more humid regions, where the bulk of leaf litter inputs from riparian trees tend to enter the stream channel directly (Pozo et al., 1997; Winterbourn, 1976). Today arid regions occupy almost 40% of the land surface (Safriel et al., 2005), but are likely to increase as a result of ongoing climate change (Döll and Schmied, 2012; Reynolds et al., 2007). Therefore, it is important to improve the knowledge on the effects of preconditioning on breakdown.

When exposed in floodplains, organic matter may be affected by abiotic (solar radiation, wind, rain and soil burial) and biotic factors (microbial colonization and grazing by invertebrates). However in dry areas, abiotic factors usually have a stronger influence on organic matter breakdown than biotic ones due to water scarcity (Austin, 2011; King et al., 2012; Whitford and Wade, 2002). In these environments, photodegradation can be an important process in organic matter breakdown as it can affect mass loss and chemical composition (Austin and Ballaré, 2010; Brandt et al., 2010; Day et al., 2007; Gallo et al., 2009). For instance, photodegradation can degrade recalcitrant compounds, such as lignin or phenolic compounds, which absorb solar radiation (Austin and Ballaré, 2010; Gallo et al., 2009). This fact has been proved to increase the leaching of soluble phenolic compounds (Fellman et al., 2013; Gallo et al., 2009) and to facilitate access of microorganisms to labile C resources (Foereid et al., 2010; Henry et al., 2008; Pu et al., 2014). Nevertheless, photodegradation may also reduce organic matter quality by promoting the leaching of nutrients and labile C compounds (Dieter et al., 2013). Hence, it is well know the positive linear relationship between organic matter decomposition rates and N and P concentration (e.g. Enríquez et al., 1993). As the chemical composition of organic matter is a key factor in determining its decomposition and use by microorganisms (Webster and Benfield, 1986; Zhang et al., 2008), any change in organic matter quality that occurs during its exposure in floodplains is expected to have implications on its subsequent aquatic decomposition. Previous studies found contrasting effects of terrestrial preconditioning of leaf litter on its aquatic decomposition. Some showed increased decomposition rates (Fellman et al., 2013; Pu et al., 2014), whereas others reported the opposite or no effects (Dieter et al., 2011, 2013; Mora, 2014). Given the potential significance of organic matter preconditioning in floodplains, which could also extend to more humid streams in the near future, this study aimed to analyze the effect of a long exposure period of wood in a stream floodplain on both its chemical quality and its subsequent aquatic decomposition. Special attention was paid to leaching and microbial activity in streams. For this purpose, we compared changes in chemical quality, aquatic decomposition and microbial activity between preconditioned and non-preconditioned wood. We hypothesized preconditioning to affect wood chemical composition and to increase aquatic breakdown rate due to greater microbial activity.

2. Material and methods

2.1. Experimental approach

To carry out this study, we designed an experiment divided into two phases, firstly we simulated wood exposure in a stream floodplain during a summer drought (terrestrial phase); then we simulated its arrival at streams (aquatic phase). In both phases, we analyzed changes in wood quality, breakdown rates and microbial activity. For this experiment we used standard wooden sticks (untreated tongue depressors made of *Betula* sp.), hereafter *sticks*. Standard wooden sticks have proved to perform similarly to natural wood or leaf litter (Arroita et al., 2012; Gulis et al., 2008). Hence this substrate is very often employed in freshwater studies (Abril et al., 2015; Tank and Winterbourn, 1995).

2.2. Study site

The experiment was carried out in four streams located in the Segura River Catchment in Murcia (SE Spain). The terrestrial phase was undertaken in the floodplain of a temporary stream, called Rambla de la Parra (1°05′20″, 38°13′51″), whereas the aquatic phase took place in the perennial stream reaches of the Chícamo (1°01′09″, 34°14′25″), Turrilla (1°53′13″, 37°46′28″) and Corneros (1°51′39″, 37°43′37″) streams. All three streams are located in an arid region (Peel et al., 2007) and have a Mediterranean climate (<300 mm average annual rainfall and an average annual temperature of 18 °C) (SHC, 2007). Marls and limestones are the dominant lithology of these streams, characterized by their low flow discharges, broad channels, and wide floodplains with sparse riparian vegetation.

2.3. Field procedures

For the terrestrial phase, 5 sticks ($15 \times 2 \times 0.2$ cm) were set up on plastic meshes (a set) with fishing line. Prior to constructing the stick sets, each wooden stick was dried, weighed and numbered with an aluminum tag. The field experiment began in July 2012 by installing 10 stick sets in an open fully exposed area of the Rambla de la Parra floodplain. One month later in August, 10 more stick sets were placed in the same area to test the effect of 4 and 3 months of floodplain exposure; that is, the typical length of a summer drought in this area. Stick sets were nailed down to the ground. In November 2012, stick sets were removed from the floodplain. Once in the laboratory, sticks were washed and dried out at room temperature for 48 h and then weighed. Subsequently we applied a correction factor to estimate dry weight at 60 °C. For that we previously calculated the relationship between the sticks weight at room temperature and at 60 °C from a set of 15 new sticks. 10 sticks from the 3-month exposure and 8 sticks from the 4-month exposure (as we lost two sticks), were used to analyze the effect of floodplain exposure on the chemical composition and microbial activity. All the other sticks were preserved for the experimental aquatic phase. In the terrestrial phase, soil temperature was recorded in hourly intervals using iButtons temperature loggers (iBCod 22L, Alpha Mach Inc., Mont St. Hilaire, Canada). Climatic variables (UV and global solar radiation, air relative humidity, air temperature and total precipitation) were obtained from the closest meteorological station (Abanilla) through the Spanish State Agency of Meteorology (AEMET). Data are showed in 3.1 Results section "Climatic and environmental variables".

To carry out the aquatic phase, we constructed new stick sets. Each set was made up of the 3- and 4-month exposed sticks, plus the control sticks (with no prior floodplain exposure). At each sampling date, 4 replicates of 3- and 4-month exposed sticks and control sticks were removed from each stream. Stick replicates were distributed between four different stick sets. Sticks sets were staked firmly to the streambed along a 50-meter long reach on similar substratum, and pools were avoided. Long axes of sticks were oriented in parallel to the direction