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The effect of water salinity on wood breakdown in semiarid Mediterranean streams

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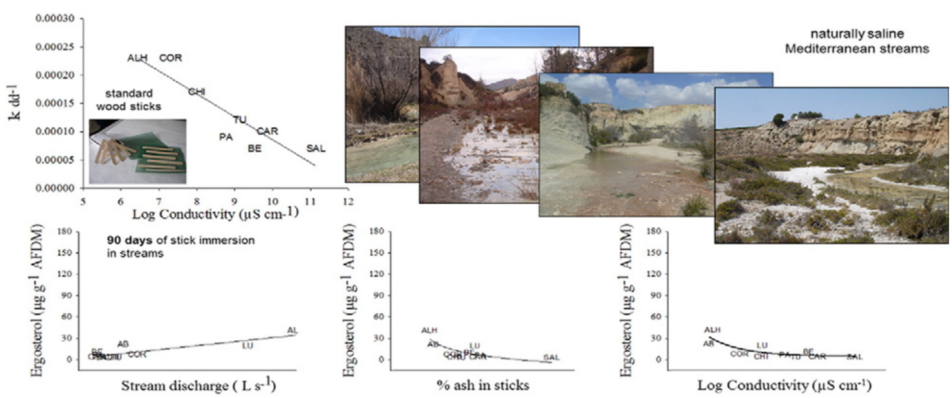
HIGHLIGHTS

- Salinity had a negative effect on the wood breakdown rates and fungal biomass.
- Breakdown rates were low but in the range of freshwater streams rates.
- We suggest mechanical and chemical abrasion by salts as a potential driving factor.

GRAPHICAL ABSTRACT



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ABSTRACT

Saline streams occur naturally and they are distributed worldwide, particularly in arid and semiarid regions, but human activities have also increased their number in many parts of the world. Little attention has been paid to assess increasing salt effects on organic matter decomposition. The objectives of this study were to analyse wood breakdown rates and how salinity affects them in 14 streams that exemplify a natural salinity gradient. We also analysed the effect of this gradient on changes in wood chemical composition, fungal biomass and microbial activity. Our results showed low breakdown rates (0.0010–0.0032 d^{-1}), but they fell within the same range as those reported in freshwater streams when a similar woody substrate was used. However, salinity had a negative effect on the breakdown rates and fungal biomass along the salinity gradient, and led to noticeable changes in wood composition. Water salinity did not affect microbial activity estimated using hydrolysis of fluorescein diacetate. Variation in breakdown rates and fungal biomass across streams was mediated mainly by salinity, and later by stream discharge. Despite the role of fungi in stick breakdown, the potential wood abrasion by salts must be analysed in detail to accurately understand the effect of increasing salinity on organic matter breakdown. Finally, our results indicate that increased salinity worldwide by human activities or by the global warming would imply organic matter breakdown and mineralisation slowing down, even in natural saline streams. However, because many variables are implicated, the final effect of climatic change on organic matter decomposition in streams is difficult to predict.

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1. Introduction

Although widely neglected in the scientific worldwide context, saline streams are geographically widespread, even though they occur mostly in arid and semiarid regions (Williams, 1996) where geology and climate, as the main factors, determine long-term stream water salinisation (Millán et al., 2011). In many parts of the world, human activities have increased salinity levels in lotic and lentic freshwaters over the last century. This anthropogenic salinisation, so-called secondary salinisation, has contributed to vastly increase the number of saline streams (Cañedo-Argüelles et al., 2013), including those in the Mediterranean region (Cooper et al., 2013). This situation is expected to intensify by global warming (IPCC, 2014). Yet given the extent and severity of the likely impacts of salinisation on streams (e.g Nielsen et al., 2003), it is surprising that more attention has not been paid to assess the effects of increasing salt on stream functioning in general, and on fundamental ecosystem processes, such as organic matter decomposition, in particular (Wallace et al., 1997). Although some studies have been performed on this process in coastal and freshwater wetlands (e.g. Hemminga et al., 1991; Mendelssohn et al., 1999), it is not clear how applicable these results are to streams where, to our knowledge, only two studies on the effect of water salinity on litter breakdown rates have been carried out (see Reice and Herbst, 1982 and also Schäfer et al., 2012). Some information on leaf decay in mesocosms is also available (Cañedo-Argüelles et al., 2013; Roache et al., 2006; Van Meter et al., 2012). However, we must be especially cautious when comparing their results with studies carried out in natural systems, mainly because results from mesocosms evaluate short-term stream community responses to salinization.

In the Mediterranean region, many streams are naturally saline (Millán et al., 2011), like those located in arid and semiarid zones of southeast Spain. In these streams riparian vegetation is scarce, and even absent. If present, it is dominated by woody perennials shrubs. Arid and semiarid streams (Jacobson et al., 1999) typically receive a low annual supply of leaves, which are easily flushed away, but they sporadically receive large pools of woody debris, which are retained during longer time periods. But we do not know how fast is wood processed in saline streams and how water salinity affects wood composition and microbial activity.

Despite the fact that woody debris may have a significant impact on carbon and nutrient ecosystem dynamics (Elosegi et al., 2007; Romero et al., 2005; Tank and Winterbourn, 1996), its functional role as an energy source in streams has received much less attention than leaf litter. Even so, it is known that wood size and quality (Melillo et al., 1984; Sinsabaugh et al., 1992) and stream water nutrient availability (Díez et al., 2002; Tank and Webster, 1998), affect the microbial activity on wood, and thus breakdown rates. Nonetheless, the effect of increasing salinity on wood decomposition in streams is practically unknown, in spite of salinization is a major and growing threat to world's freshwater ecosystems (Williams, 2001).

The potential toxicity of high concentrations of sodium and chloride ions at the cellular level, and their capacity to inactivate enzymes and to inhibit protein synthesis, appear to be well-known (Greenway and Munns, 1980). On the other hand, salt-tolerant microorganisms must supply sufficient energy to fulfil cellular requirements for osmoadaptation by diverting less energy in other processes (Oren, 1999, 2001). Thus from a physiological perspective, saline organisms are expected to become less efficient than those living under less saline or freshwater conditions.

The present study investigated: 1) wood breakdown rates and how they vary with increased salinity across 14 streams that exemplified a natural gradient of increased salinity; 2) the effect of this saline gradient on wood chemical quality, and on the structural (fungal biomass) and functional (microbial activity) metrics of wood biofilms. By considering the potential negative effects of salinity on microbial activity, we predicted that wood breakdown and microbial biomass and activity will decrease across streams as salinity increases.

The results from this study will allow us to advance in our knowledge of saline stream functioning and of the potential response of increasing salinity on stream ecosystem functioning and services in the context of human activities and climate change.

2. Methods

2.1. Site description

We studied 14 first-order streams that drain the Segura River catchment (18,815 km^2) located in the southeast Iberian Peninsula distributed from 247 m to 1105 m of altitude (Fig. 1, Table 1). Climate ranges from subhumid Mediterranean (average annual rainfall > 1000 mm, average annual temperature 13 °C) in the north/northwest in the catchment to semiarid Mediterranean (<300 mm and 18 °C) (CHS, 2007) in the south/southeast area, where stream discharge fluctuations are especially acute. Geology is highly heterogeneous, but varies largely from limestone in the uplands to Miocene salt-rich marl in the mid- and lowlands. As a result of the variable geology and climate patterns, freshwater and saline streams dominate the subhumid and the semiarid areas, respectively.

Streams were selected to exemplify a water salinity gradient (Table 1). Water salinity, defined as the total dissolved salts in water, is expressed in this study in terms of electrical conductivity (EC). EC is a measure of water's capability to pass electrical flow which is directly related to the concentration of ions in the water. Thus, EC is an approximate predictor of salinity (Allan, 1995). All EC measures are reported as $\mu S\ cm^{-1}$ at 25 °C. Submerged macrophytes (*Chara* sp., *Cladophora* sp. and *Ulva* sp.) are usually quite scarce in semiarid streams. Overall, riparian vegetation was scarce and variable, and ranged from scattered trees and shrubs forest (*Populus* sp. and *Salix* sp.,) in freshwater streams to communities of open Mediterranean shrubs (*Nerium oleander, Tamarix* sp., *Phragmites australis*) and halophytic small-sized plants (e.g. *Sarcocornia* sp. and *Arthrocnemum* sp.) in saline streams.

2.2. Physical and chemical variables in the studied reaches

A 50 m long reach was selected in each stream as being representative of the first-order section of the stream. During the study period (January–June, 2012), environmental variables were measured and water samples were obtained to characterise stream reaches on each sampling date. All variables were measured and water samples collected at three points ($n = 3$) in the stream reaches. Water salinity (in terms of electrical conductivity, EC), pH, dissolved oxygen (DO) and oxygen saturation (% DOsat) were measured in situ using handheld sondes (Intellical HQD, Hach Lange, Loveland, USA). Discharge was calculated from the instantaneous water velocity measured by a current metre (MiniAir2; Schiltknecht Co., Zurich, Switzerland) and from the average stream section area at two points of the experimental reach. Stream water was filtered through pre-ashed glass fibre filters (GF/F) (Whatman, Maidstone, UK) and transported to the laboratory on ice to be analysed within 24 h after collection. Samples were analysed for nitrogen (NO_3^- and NH_4^+) and soluble reactive phosphorus (SRP) colorimetrically (APHA, 1995) on a Systea EasyChem autoanalyser (Frosinone, Italy). Dissolved nitrogen concentration (DIN) was calculated as the sum of NO_3^- and NH_4^+. DOC was analysed with a Shimadzu TOC-5000A Total Organic C (TOC) analyser (Maryland, USA). Before the analysis, DOC samples were preserved with acid in the dark at 4 °C. The main cations (Na^+, K^+ and Ca^{+2}) and anions (Cl^- and SO_4^{-2}) dissolved in water were analysed in a Fisher Scientific ICP-OES Iris Intrepid II XDL Thermo (Massachusetts, USA).