Ecological Engineering 54 (2013) 82–89

Contents lists available at SciVerse ScienceDirect

Ecological Engineering

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

Which stream wood becomes functional following wildfires?

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ARTICLE INFO

Article history:
Received 1 August 2012
Received in revised form 10 January 2013
Accepted 16 January 2013
Available online 26 February 2013

Keywords:
Emulating natural processes
Euro-Mediterranean
Fire
Function
Large wood
Stream restoration

ABSTRACT

Large wood is a critical element in stream ecosystems, but only a subset of wood pieces actually provide hydraulic, geomorphic, and ecological functions. We test the current paradigm that larger pieces provide more function, and examine the role wildfires may play in affecting functionality of recruited wood. We conducted a cross-basin analysis in nine central Portugal watersheds, obtaining a variety of measurements on 1483 wood pieces (diameter ≥ 0.05 m; length ≥ 0.5 m) in 27 streams burned within six years prior. We examined nonlinear relationships and indirect effects on function using Generalized Additive Modeling and Structural Equation Modeling. Variables with direct effects on function were piece diameter, rootwads, anchoring, position (bridging, ramping, loose), longitudinal distance along the stream continuum, and the ratio of piece length to channel width. The effect of length ratio on function was nonlinear. Relatively long pieces were more likely to be functional until they were ~3 times the channel width, at which point longer pieces became less likely to be functional. Post-fire wood likely lacked complexity and longer pieces were more likely to be bridging; both conditions may have prohibited them from interacting with the wetted area. Wildfires had indirect effects on function. Burned pieces were more likely to be large in diameter (thus more likely functional) but not anchored (thus less likely functional); these antagonistic effects may be the reason burned status had no direct effect on function. Our results challenge the well-established idea that the function of wood in streams is simply a matter of wood size, along with indicators of longevity (e.g. stability and decay status). Relatively long pieces may in fact provide less function to the stream, at least until they break or are transported further downstream. Practitioners installing wood to streams should consider pieces with wide diameter and rootwads, approximately 3 times the channel width, and anchored but not bridging the channel.

1. Introduction

Large wood is widely recognized as an important structural element in stream ecosystems, but only a subset of wood pieces actually influence stream hydraulics, channel morphology, sediment and organic matter retention, flow routing and storage, habitat heterogeneity, and biological communities (Gregory et al., 2003 and references therein). We refer to such pieces as functional; that is, performing some observable function in the stream. Major knowledge gaps remain regarding the recruitment of functional large wood, including the influence of disturbance history such as riparian fires (Nakamura and Swanson, 2003). In this study, we evaluated which wood pieces have a high probability of becoming functional in streams following wildfire.

Broadly, the fact that fire affects stream wood input has been well documented and is apparent in the stock of burned wood in streams following a fire (Zelt and Wohl, 2004). In addition to the direct effects on tree mortality and associated wood recruitment, fire may also promote wood recruitment indirectly by increasing the susceptibility of riparian trees to windthrow and disease (Benda et al., 2003). Wood affects stream features, redirects flow, and traps other wood moving through the system only if it remains stable and is of sufficient size and shape (Abbe et al., 2003). Quantification of functional wood is rare and the effects of wildfire on stream wood function (rather than overall stock) remain largely unexplored.

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http://dx.doi.org/10.1016/j.ecoleng.2013.01.009

Over the past several decades, various studies have identified functional roles of stream wood (SW), but only a few characterized the functional wood itself. Most studies have focused on the relationship between SW quantity and channel structure (Thompson, 1995; Manga and Kirchner, 2000; Chen et al., 2008). However, the characteristics of individual pieces can also affect SW function in small streams (Rosenfeld and Huato, 2003). Studies on SW function have separately focused on particular categories: geomorphological, ecological, and hydraulic function. However, it is difficult to isolate such functions, since a single piece of wood can cover all three categories. Cordova et al. (2007), for example, documented up to five functions for one piece of SW. Rather than splitting SW functions into specific sub-categories in the current study, we consider any piece of wood having at least one function recognized in the literature and directly observed in the field to be functional (Montgomery et al., 2003).

Determining stream wood function requires knowledge of both the quantity and "quality" of individual pieces. SW quality depends on critical functional factors such as its physical structure (Vaz et al., 2011), its local position relative to the stream channel, its interaction with other wood, its distance along the stream, and its location throughout the river network (Martin and Benda, 2001; Jones et al., 2011). Among the structural characteristics of SW, there is a set of core variables that interact with the stream to influence wood function (Gregory et al., 2003; Bocchiola et al., 2006; Wohl et al., 2010). Major structural factors that may influence SW function are piece diameter, presence of rootwads and branches, decay state, form, and piece species. Elements of the SW relationship with a stream channel include wood length/channel width ratio, how it rests within the channel (position), degree of anchoring, and horizontal orientation (Braudrick and Grant, 2000; Chen et al., 2008; Cordova et al., 2007; Baillie et al., 2008; Magilligan et al., 2008; Jones et al., 2011). In an earlier study, we documented that burned wood recruited to streams following a fire generally was thicker, had less structural complexity, and was more decayed than wood that was not burned (Vaz et al., 2011). This suggested that SW burned status, while affecting size, geometry, and overall stability, will also likely influence the effect of SW on stream physical processes. In the current study, we incorporated SW burned status with a large suite of potential functional factors and evaluated how they interact to influence stream function.

A few studies have examined relationships between observable functions of a particular category and SW characteristics. For example, probability of pool habitat formation increases with SW diameter and presence of rootwads (Braudrick and Grant, 2000, 2001; Magilligan et al., 2008), and Beechie and Sibley (1997) identified a minimum-diameter threshold below which SW is unlikely to initiate pool formation. In addition, decayed SW contributes more to bank stability, sediment retention, debris jams, and riffle and pool formation (Jones et al., 2011). Abbe and Montgomery (2003) found that wood longer than half the bankfull width could initiate logjams. Only one study (Rosenfeld and Huato, 2003), specifically evaluated the probability of individual SW pieces becoming functional, although the dataset did not capture functions beyond the creation of primary pools.

In this study, we propose an initial framework for using SW critical factors (regarding physical structure and relation to the stream channel) to assess its functionality in streams following wildfire. We conducted a cross-basin analysis in nine central Portugal watersheds, obtaining a variety of measurements on 1483 individual SW pieces in 27 streams burned within six years prior. Large SW amounts within these streams are remarkably low (3.3 pieces per 100 m), and so functional wood acquires additional importance (Vaz et al., 2011, 2013). This work encompassed a range of stream sizes and upland land-uses, including three common fire-prone forest types in southern Europe. We addressed the following objectives and associated hypotheses:

(1) Determine SW critical functional predictors and quantify their influence on the probability of stream function following wildfires. *Hypothesis*: As we had a broad criteria capturing observable SW functions, we expect that major SW critical factors (such as diameter, presence of rootwads or branches, decay state, degree of anchoring, and piece length/channel width ratio) will significantly influence the probability of a given piece being functional following wildfires.
(2) Determine how SW critical functional predictors and burned status interact to influence stream function. *Hypothesis:* As burned status influences SW size positively and complexity negatively (Vaz et al., 2011), we expect no clear direct relationship between SW burned status and function. Instead, we hypothesize that burned status will likely affect stream function indirectly through relationships with SW critical functional predictors.

This knowledge is essential for assisting resource managers in maximizing the effectiveness of riparian management (e.g. selective harvest, thinning) and stream wood installation to mimic natural processes and restore ecological functions.

2. Materials and methods

2.1. Study area and site selection

We conducted this study in east-central Portugal (39°16′ to 39°39′N, 7°30′ to 8°14′W) from October 2009 to August 2011 in nine sub-basins of the Tagus River, which experienced extensive wildfires between 2003 and 2007. The area has gentle relief with altitudes ranging from 19 to 643 m (mean ~266 m). The land cover is dominated by forests, shrublands, and agriculture. The local climate is Mediterranean with hot, dry summers and cool, wet winters. Mean annual precipitation is 512 mm (range: 3 mm in July to 82 mm in November) and mean annual temperature is 15.8 °C (range: 9 °C in December–January to 23 °C in July–August). The selected burned sub-basins (mean drainage area 59 km^2; range: 26–143 km^2) represented three dominant forests in Portugal – eucalyptus (*Eucalyptus globulus*), maritime pine (*Pinus pinaster*), and cork oak (*Quercus suber*). Within each sub-basin, three homogeneous reaches (~500 m each) having a burned sideband of at least 100 m were selected, one each from stream order 1–3 (Strahler, 1957). We selected reaches distributed as evenly as possible from stream sources to mouths across the 27 streams. In total, 27 burned reaches were assessed, totaling ~13,460 m of stream channel. Many of the streams were intermittent, with stretches remaining dry for several months, in a seasonal sequence of flooding and drought events.

Riparian zones (with a distinct riparian community) along streams in maritime pine and eucalyptus forests were often present (0–15 m in width) but cork oak sub-basins generally had more limited riparian zones. The uncultivated riparian vegetation was dominated by ash (*Fraxinus angustifolia*), alder (*Alnus glatinosa*), black poplar (*Populus nigra*), and willow (*Salix atrocinerea*, *S. alba*, *S. salvifolia*), frequently surrounded by edges of bramble-thicket (*Rubus ulmifolius*). In most southern areas, hawthorn (*Crataegus monogyna*) was also common. In addition to the indigenous species, silver wattle (*Acacia dealbata*), an exotic invasive and fire-prone tree, was widespread across the surveyed riparian zones (Silva et al., 2011). Further details about the study area are provided in Vaz et al. (2011).