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Large wood mobility processes in low-order Chilean river channels

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ABSTRACT

Large wood (LW) mobility was studied over several time periods in channel segments of four low-order mountain streams, southern Chile. All wood pieces found within the bankfull channels and on the streambanks extending into the channel with dimensions more than 10 cm in diameter and 1 m in length were measured and their position was referenced. Thirty six percent of measured wood pieces were tagged to investigate log mobility. All segments were first surveyed in summer and then after consecutive rainy winter periods. Annual LW mobility ranged between 0 and 28%. Eighty-four percent of the moved LW had diameters ≤40 cm and 92% had lengths ≤7 m. Large wood mobility was higher in periods when maximum water level (H_{max}) exceeded channel bankfull depth (H_{Bk}) than in periods with flows less than H_{Bk}, but the difference was not statistically significant. Dimensions of moved LW showed no significant differences between periods with flows exceeding and with flows less than bankfull stage. Statistically significant relationships were found between annual LW mobility (%) and unit stream power (for H_{max}) and H_{max}/H_{Bk}. The mean diameter of transported wood pieces per period was significantly correlated with unit stream power for $H_{15\%}$ and $H_{50\%}$ (the level above which the flow remains for 15 and 50% of the time, respectively). These results contribute to an understanding of the complexity of LW mobilization processes in mountain streams and can be used to assess and prevent potential damage caused by LW mobilization during floods.

1. Introduction

The significance and effects of instream large wood (LW) on the morphology and ecology of stream ecosystems are widely recognized, especially on steep and narrow mountain streams (Bilby and Ward, 1989; Robison and Beschta, 1990; Beechie and Sibley, 1997; May and Gresswell, 2003; Chen et al., 2008). Instream large wood, either isolated or jammed, has the potential to alter local flow by reducing stream power and increasing flow resistance and by creating log-steps, trapping sediments and dissipating hydraulic potential energy (Beschta and Platts, 1986; Bilby and Ward, 1989; Bilby and Bisson, 1998; Gurnell et al., 2002; Faustini and Jones, 2003; MacFarlane and Wohl, 2003; Montgomery et al., 2003; Rosenfeld and Huato, 2003; Comiti et al., 2008). The presence of LW is also important for the ecology of fluvial systems as it increases the heterogeneity and quality of stream habitats and the biological diversity of aquatic biota (Beschta and Platts, 1986; Bisson et al., 1987; Bilby and Ward, 1989; Maser and Sedell, 1994; Diez et al., 2001; Chen et al., 2008; Vera et al., 2014).

Avalanches, landslides, and debris flows are the dominant processes that determine wood delivery to streams in steep forested low-order catchments, whereas tree mortality and bank erosion are relatively more important in recruiting LW in medium-sized streams (Keller and Swanson, 1979; Robison and Beschta, 1990; Bilby and Bisson, 1998; Hairston-Strang and Adams, 1998; Martin and Benda, 2001; May and Gresswell, 2003; Reeves et al., 2003). Overall, land use and management history of the catchments, forest density and composition, species and age of the riparian forests, and inclination and stability of the streambanks also condition the supply of LW to river systems (Hairston-Strang and Adams, 1998; Gurnell et al., 2002; Hassan et al., 2005; Iroumé et al., 2011; Ulloa et al., 2011).

Besides the morphological and ecological benefits, LW loading and downstream mobilization can increase the associated hazard of floods. Instream wood becomes potentially dangerous to human infrastructure only during high-magnitude events, during which log recruitment and transport can be very important (Castiglioni, 1974; Ishikawa, 1990; Braudrick and Grant, 2000; Daniels and Rhoads, 2003; Andreoli, 2006). Yet wood entrainment and transport have often been overlooked and have received relatively little research attention, as reported by Braudrick and Grant (2000) and ratified 10 years later by Curran (2010) and Schenk et al. (2013).

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Key properties of wood dimensions and fluvial processes determine wood dynamics (Gurnell et al., 2002; Merten et al., 2010). The ratios of piece length and diameter to bankfull channel width and depth are undoubtedly the two dimensionless parameters most commonly adopted to predict wood mobility (Lienkaemper and Swanson, 1987; Bilby and Ward, 1989; Abbe et al., 1993; Nakamura and Swanson, 1994; Young, 1994; Berg et al., 1998; Diez et al., 2001; Martin, 2001; Gurnell et al., 2002; Gurnell, 2003; Warren and Kraft, 2008; Wohl and Goode, 2008; Cadol and Wohl, 2010; Merten et al., 2010; Wohl, 2011). From theoretical models and flume experiments, Braudrick and Grant (2000) found that piece length did not significantly affect the threshold of movement for logs shorter than channel width, noting also that extrapolation of their results was likely limited to low-gradient alluvial systems. Although logs shorter than bankfull width do not always move (Warren and Kraft, 2008), wood pieces tend to travel when the ratio of piece length to bankfull channel width is <0.5 in large rivers (Abbe et al., 1993) or <1.0 in smaller rivers (Lienkaemper and Swanson, 1987). According to Mazzorana (2009), the ratio of piece diameter to bankfull channel depth that conditions the entrainment for smooth logs with an approximate cylindrical form is between 0.8 and 1 and decreases to 0.7 and 0.6 for LW with branches and with rootwads, respectively. Unattached, less dense, and more decayed wood pieces without rootwads and oriented at 45° and 90° to the flow are more mobile (Abbe and Montgomery, 1996; Braudrick and Grant, 2000; Bocchiola et al., 2006; Cadol and Wohl, 2010); while logs buried, anchored, and capable of sprouting are more stable (Gurnell et al., 2002; Scherer, 2004; Wohl and Goode, 2008; Merten et al., 2010).

Large wood dynamics is also highly dependent on flow regime and channel slope (Gurnell et al., 2002; Van der Nat et al., 2003; Cadol and Wohl, 2010; Merten et al., 2010). Large wood elements are more stable in first-order streams and are mobilized only during episodic extreme events (Bilby and Ward, 1989; Robison and Beschta, 1990; Gurnell, 2003; Swanson, 2003), but as stream size and depth increase, hydraulic processes dominate and LW is less stable (Keller and Swanson, 1979; Harmon et al., 1986; Abbe and Montgomery, 2003; Gurnell, 2003). The magnitude and sequence of a series of flows are key factors for LW movement (Haga et al., 2002; Wohl and Goode, 2008) and for rapid increases of the hydrostatic forces of buoyancy and lift and the hydrodynamic force of drag facilitate transport of instream wood (Wohl et al., 2012). The ratio of peak water level to log diameter exerts a great influence over LW mobility (Wohl and Goode, 2008), temporal variation of mobility rates are explained by variation in peak flows and peak unit stream power (Wohl and Goode, 2008; Cadol and Wohl, 2010), a flow magnitude greater than the previous flows is necessary to retransport most logs (Haga et al., 2002), and MacVicar et al. (2009) reported for a single flood on the Ain River (France) that wood transport rates are one order of magnitude higher on the rising than on the falling limb of the hydrograph.

Large wood moves farther and more frequently in large streams (greater than fifth-order) than in small streams (Bilby, 1985; Lienkaemper and Swanson, 1987; Bilby and Ward, 1989, 1991; Martin and Benda, 2001), smaller pieces move farther than larger pieces (Lienkaemper and Swanson, 1987; Young, 1994), and piece diameter strongly influences depth of flow required to entrain and transport logs, thereby influencing the distance of their displacement length (Bilby and Ward, 1989; Abbe et al., 1993; Braudrick et al., 1997; Braudrick and Grant, 2000). Pieces tend to stop when the water depth of the segment at peak flow is less than the diameter of the logs (Haga et al., 2002), or approximately half the piece diameter for Abbe et al. (1993). The locations of stable or recurring LW jams can reduce LW movement distances for wood of all sizes (Braudrick and Grant, 2001; Haga et al., 2002; Warren and Kraft, 2008).

In Latin America, besides a few anecdotal references to instream wood (Vidal Gormaz, 1875; García-Martínez and López, 2005), the first reports on LW are those by Montgomery et al. (2003) and Wright and Flecker (2004). More abundant research has developed since 2007 focusing mainly on LW morphologic and hydraulic roles (Andreoli et al., 2007; Comiti et al., 2008; Mao et al., 2008; Cadol et al., 2009; Wohl et al., 2009; Cadol and Wohl, 2010; Iroumé et al., 2010, 2011; Ulloa et al., 2011; Wohl et al., 2012; Mao et al., 2013; Iroumé et al., 2014) and also on the ecology of low-order mountain channels (Vera et al., 2014). First analyses of LW mobilization in Latin American streams are the reports by Andreoli et al. (2008), Mao et al. (2008), and Iroumé et al. (2011).

Despite the general agreement on the need of a minimum relative dimension for logs to be moved in low-order streams, this evidence still needs to be proved in a variety of mountain environments. Furthermore, the dependency of wood transport and dynamics to channel morphology needs to be further explored and verified under different flow regimes and over long time periods. This paper addresses these gaps by examining LW mobility over several years in channel segments of four low-order (Strahler's ordering system) mountain streams located in southern Chile. These streams represent two contrasting mountain environments: one from the Andes with higher slopes and rainfall, geology of pyroclastic rocks, and old growth native forests; and the other from the Coastal range with gentler slopes, geology of metamorphic rocks, and a mixture of second growth native forests and plantations with exotic tree species. The transport from a sample of over 1000 tagged logs was surveyed during several time periods characterized by peakflows with return periods (recurrence interval, RI) up to 5 years. The study is focused on verifying that wood pieces shorter and thinner than bankfull channel width and depth, respectively, are transported more than longer and thicker pieces, as reported by previous researchers. Also, we expected wood dynamics to relate to higher flows thus expanding the actual knowledge in an area of considerable uncertainty but high importance for river management and flood risk control purposes.

2. Materials and methods

2.1. Study sites

Large wood mobility was studied over several time periods in channel segments of the Pichún (37°30′12″ S.; 72°45′54″ W., catchment area of 431 ha), El Toro (38°09′11″ S.; 71°48′12″ W., catchment area of 1783 ha), Tres Arroyos (38°27′57″ S.; 71°33′44″ W., with a catchment area of 907 ha), and Vuelta de Zorra (39°58′12″ S.; 73°34′13″ W., catchment area of 587 ha) streams, located in the Coastal and Andes mountain ranges in southern Chile (Fig. 1). Geographic coordinates and catchment areas correspond with the location of the downstream end of the study segments.

The southernmost study catchment is Vuelta de Zorra located in the Valdivian Coastal Reserve some 40 km to the southwest of the city of Valdivia, Región de Los Ríos. Seventy-five percent of its area is covered by a second growth evergreen native forest, 24% with a *Eucalyptus nitens* plantation established in 1999, and 1% corresponds to several sites where native species are regenerating. Long-term annual rainfall in the area exceeds 2300 mm. An exhaustive description of this site can be found in Iroumé et al. (2010, 2011) and Ulloa et al. (2011).

The Tres Arroyos catchment is located within the Malalcahuello–Nalcas Forest National Reserve in the Andes mountain range, some 2 km northeast of the small town of Malalcahuello, Región de La Araucania. A little more than 64% of the catchment area is covered by old-growth native forests, 23% by herbs and shrubs near the tree line, 6.4% by younger (<40 years) conifer plantations (*Pseudotsuga menziesii*, *Pinus radiata*, *P. ponderosa*, *P. monticola*, and *P. contorta*), and 6.4% are unvegetated sandy volcanic ashes around the watershed divide. Long-term mean annual rainfall in the area exceeds 2500 mm. Additional information is presented in Andreoli et al. (2007, 2008) and Comiti et al. (2008).

The El Toro catchment is located within the Malleco Forest National Reserve in the Andes mountain range, some 80 km northeast of the