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Coarse sediment movement in the vicinity of a logjam in a neotropical gravel-bed stream

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ABSTRACT

Wood influences channel morphology by increasing channel roughness, altering flow hydraulics, and decreasing sediment transport in most fluvial systems where it is present. In many locations, the collection of wood into jams leads to even greater interruption of sediment transport by means of sediment impoundment and the creation of low-velocity backwater flow zones. We examined tracer clast movement near a wood jam in a neotropical gravel-bed stream in order to evaluate the effect of wood mobility and piece transience on the ability of the jam to impede sediment transport. We found that the jam had minimal influence on the passage of any individual clast, with tracer clast mobilization and travel distance being best predicted by flow magnitude and grain size rather than location relative to the jam. The rate of clast passage through the jam did not correlate with either the piece retention rate of the jam or with the density of the jam. The jam did, however, temporarily trap a sediment wedge during a period when fluvially imported wood pieces blocked flow under a key wood piece, diverting flow to a secondary flow path. These results suggest that there is an upper bound on the flows in which wood is able to disrupt sediment transport, and unlike for bedrock roughness elements, this bound is frequently crossed at our study site.

1. Introduction

Wood has been entering channels for more than 400 million years (Montgomery and Piégay, 2003), where it increases flow resistance, reducing the energy available for sediment transport (Keller and Tally, 1979; Curran and Wohl, 2003; MacFarlane and Wohl, 2003; Daniels and Rhoads, 2004; Wilcox and Wohl, 2006), and forms jams, which act as barriers to sediment movement and create low-velocity backwater storage locations (Keller and Swanson, 1979; Lisle, 1995; Abbe and Montgomery, 1996; Brooks et al., 2003; Comiti et al., 2008). In the extreme, wood may create forced alluvial reaches (Montgomery et al., 1996, 2003; Massong and Montgomery, 2000), in which jams initiate sedimentation where degradation to bedrock would otherwise occur. In historical times, however, humans have reduced global forest cover to about half its maximum Holocene extent, and most management efforts, until very recently, focused on removing wood from channels to facilitate navigation, increase flood conveyance, or for use as fuel. Though modern forests still cover almost a third of Earth's land surface, the prevalence of anthropogenic instream wood reduction has the potential to increase sediment mobility and yield.

A major mechanism by which wood interacts with sediment transport is the trapping of sediment behind jams, as documented in studies throughout the temperate zone (Marston, 1982; Megahan, 1982; Thompson, 1995; Faustini and Jones, 2003; Webb and Erskine, 2003; Comiti et al., 2008; Fisher et al., 2010). Synthesizing across all of these studies, we can roughly generalize that wood jams in small temperate streams double in-stream sediment storage and impound sediment volumes exceeding the mean annual sediment yield. In Peninsular Malaysia, one of the few tropical study sites available for comparison, instream wood-induced sedimentation accounts for more than half of instream sediment storage in streams draining both logged and unlogged catchments (Gomi et al., 2006).

The longitudinal spacing, size, and average longevity of jams in a given system are expected to be major controls on the ability of wood to reduce sediment transport. The ability of wood in tropical settings to alter sediment dynamics may be reduced relative to the temperate zone because of differences in prevailing jam characteristics. Jam frequencies in minimally disturbed low-order temperate streams generally fall in the range of 10–60 jams/km (Megahan, 1982; Gurnell and Sweet, 1998; Morris et al., 2007; Comiti et al., 2008; Wohl and Cadol, 2011), although variation in the definition of a jam makes comparison problematic and frequency is likely to decrease with increasing drainage area (Martin and Benda, 2001). In comparison, seven channel-spanning jams were found in 600 m of surveyed streams at a wet tropical study site in Costa Rica, an average of 12 jams/km (Cadol et al., 2009), which is at the lower end of the range observed in the temperate zone. Jam persistence is also likely to change with climate, as wood in tropical streams has been observed to be more transient than in comparable temperate zone streams (Cadol

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and Wohl, 2010). Jams may be persistent features even in streams where wood is relatively transient, in part because they are commonly anchored by immobile 'key pieces' that may take tens to hundreds of years to decay (Abbe and Montgomery, 1996) and in part because the feature may persist even as individual pieces are exchanged (Gregory et al., 1985; Wohl and Goode, 2008). These processes may lead to a wide range of jam persistence times, even within a single system (Megahan, 1982; Wohl and Goode, 2008), as in the case of the New Forest of southwest England, where 20% of jams on the Highland Water persisted for over 30 years, while 36% were removed within one year (Gregory et al., 1985; D. A. Sear, University of Southampton, personal communication, 2010). Yet, because wood transience in tropical streams is likely attributable to higher discharge per unit of contributing area and higher decay rates relative to temperate zones (Cadol and Wohl, 2010), factors which should also affect key pieces and thus jam transience, we expect shorter-lived jams and less sediment trapping in tropical streams.

In order to evaluate the influence of jams on sediment transport in tropical streams, we monitored tracer clasts, scour chains, and wood piece locations in the vicinity of a channel-spanning wood jam on a small channel in Costa Rica from June 2007 to November 2009. The use of tracer clasts to study sediment movement in gravel-bed streams is well established (e.g., Church and Hassan, 1992; Foster et al., 2000), and Haschenburger and Rice (2004) used the technique to study sediment movement around three jams on Vancouver Island, Canada. Using tracer clast data from our wet tropical study site we tested two hypotheses relating to the impact of the jam on sediment transport. The first hypothesis (H_1) is that clast position with respect to the jam will have the greatest influence on transport distance. Assani and Petit (1995) invoked erosion in jam plunge pools and deposition in subsequent jam backwaters to explain sediment transport rates observed in a forest ditch in Belgium. We expect lower transport distances for clasts upstream of the jam and greater transport distances for those downstream. Although we expect flow history and clast size will affect clast transport distance (Church and Hassan, 1992; Haschenburger and Rice, 2004), we hypothesize that clast position with respect to the jam will be a more influential variable. The second hypothesis (H_2) is that decreased jam integrity will increase sediment transport. We hypothesize that periods with high rates of piece turnover in the jam, i.e., low temporal integrity, and periods with reduced jam size, density, and integration, i.e. low spatial integrity, will correlate to increased rates of sediment passage through the jam.

2. Study site

The study site is located on Quebrada Esquina, in La Selva Biological Station, Costa Rica (Fig. 1). La Selva is located in NE Costa Rica and includes 730 ha of old-growth tropical forest. Elevation at the station ranges from 20 to 150 m and reflects the transition from the low, steep foothills of the Central Volcanic Cordillera to the Caribbean coastal plain. At the study site, Quebrada Esquina drains 1.6 km^2 of preserved old-growth tropical wet forest and has an average local gradient of 3.2%. Bed material particles range from coarse sand to boulders, with a median grain diameter of 100 randomly sampled clasts of 180 mm, 16th percentile diameter of 40 mm, and 84th percentile diameter of 350 mm. The inclusive graphic standard deviation of our sample, a measure of sorting (Folk, 1980), is 1.57 φ. Particles are moderately rounded and frequently have concave depressions, knobs, and necks or waists. Channel morphology varies between step-pool and pool-riffle (Montgomery and Buffington, 1997) (Fig. 2). The bedrock at La Selva consists of highly weathered andesitic lava flows, with the basin upstream of the study site being composed almost entirely of the Esquina Andesite (Alvarado, 1990, in Kleber et al., 2007). Bedrock outcrops are common in the stream bed and banks near the study site. The upper meter of bedrock is typically weathered into a weak saprolite and the clasts that compose the bedload are also weakened by weathering. The bed clasts could not be used to drive rebar benchmarks into the gravel; even 20-cm-diameter cobbles broke in half after a few strikes.

Hurricanes seldom reach the area, but intense frontal rains are generated from November to January. Rain falls throughout the year, and a dry season is effectively absent because of the prevalence of nightly condensation drip even in periods with relatively little rain.

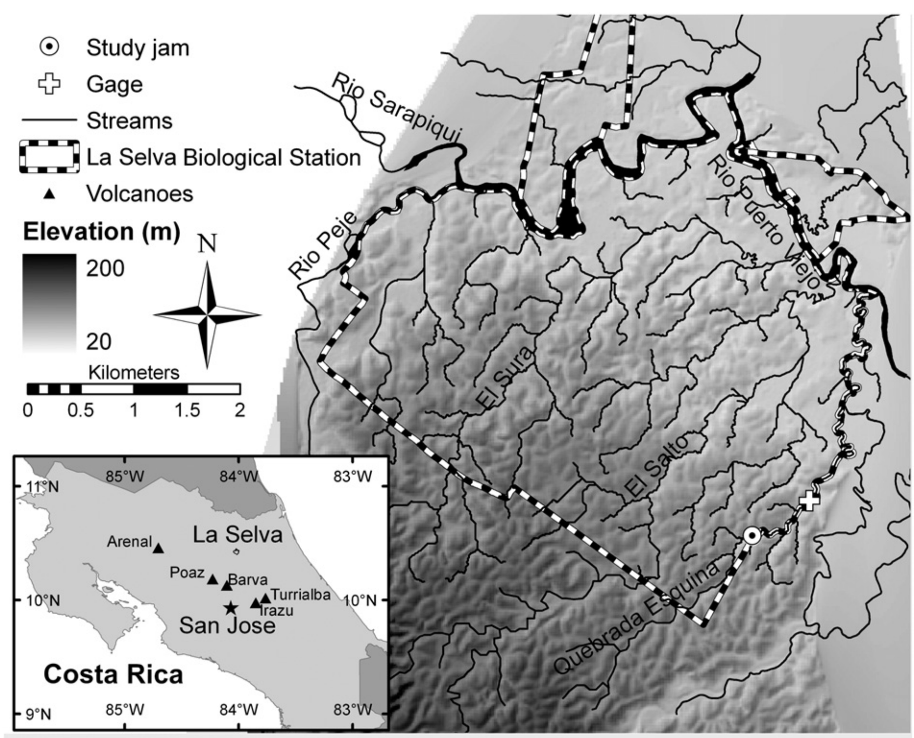

Fig. 1. Location map.