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Characteristics and abundance of large and small instream wood in a Carpathian mixed-forest headwater basin

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ABSTRACT

The effect of instream wood on stream hydraulics and geomorphic processes depends on wood and channel dimensions. We investigated abundance and characteristics (i.e., wood orientation, proportion of spanned channel width, stability and decay classes) of large wood (LW; defined here as having a length ≥ 1 m and a diameter ≥ 0.1 m) and small wood (SW; including two categories with length ≥ 0.5 m and diameter ≥ 0.1 m or length ≥ 1 m and diameter ≥ 0.05 m) in three steep, confined headwater channels of medium-high mountain ranges of the Western Carpathians (Central Europe). Results show that SW is more frequent than LW, however, active-channel LW load varied between 26 and 305 $m^3 \cdot ha^{-1}$, whereas SW showed much lower active-channel load (8–16 $m^3 \cdot ha^{-1}$). Differences between LW and SW active-channel volumes were considerably smaller in streams under dominant deciduous canopy. In these streams, morphological steps – created exclusively by SW – were more frequent than LW steps. This higher frequency of SW in streams surrounded by a deciduous tree canopy can be explained by the continuous supply of branches rather than entire dead trees. On the other hand, the volume and frequency of LW was related to the proportion of conifers in the valley corridor. We observe very high active-channel load in two channel reaches for which values exceeded most of those observed in similarly small streams across the globe. We also observe an unusually large proportion of instream wood (both LW and SW) oriented parallel to the flow direction, which might suggest a higher mobility of bed material in the flysch-dominated headwater channels of our study site.

1. Introduction

Instream wood plays an important geomorphic role in aquatic ecosystems including steep mountain channels in confined forested valleys, as its presence leads to notable increases in stream habitat heterogeneity (Montgomery and Buffington, 1997; Gurnell et al., 2002; Chen et al., 2008). Single or multiple wood pieces spanning a channel contribute to the formation of channel steps, controlling flow direction, increasing bed roughness, sediment storage, and channel stability, reducing bedload transport rates and affecting bed sediment calibre (e.g., Bilby and Ward, 1989; Smith et al., 1993; Woodsmith and Swanson, 1997; Gomi et al., 2001; Curran and Wohl, 2003; May and Gresswell, 2003; Hassan et al., 2005; Andreoli et al., 2007). Wood jams (defined as ≥3 closely interacting wood pieces according to Wohl and Cadol (2011) and Costigan et al. (2015)) tend to alter longitudinal transfer of sediments and can thus represent relatively stable elements in a mountain channel. Their residence time depends on local hydrologic regime as well as on the channel and jam dimensions (Wohl and Beckman, 2014; Hassan et al., 2016; Ruiz-Villanueva et al., 2016). The presence of instream wood in mountain basins is also beneficial for aquatic organisms, as it provides a source of food, storage of organic material, and maintenance of living habitat (Lester and Wright, 2009; Wohl et al., 2012). This explains why reintroduction of wood has recently been used for stream restoration (Kail et al., 2007; Lester and Boulton, 2008).

In general terms, instream wood exerts its greatest physical influence in channels having widths similar to or smaller than the length of the wood pieces (Bilby and Ward, 1989; Piegay and Gurnell, 1997; Montgomery et al., 2003). Therefore, wood tends to play a disproportionately larger role in small streams (Hassan et al., 2005). In geomorphic research, great attention has been paid to the presence of 'large wood' (LW) in rivers over past decades (Bisson et al., 1987;

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Gurnell et al., 2002; Wohl, 2017). LW is generally defined as a piece with a length ≥ 1 m and a diameter ≥ 0.1 m, although some differences may exist between individual studies (e.g. ≥0.1 m diameter in the middle of a piece vs. minimal diameter at the log end or slightly shifted criteria of a minimal length varying between 0.5 and 3 m; Gomi et al., 2003; Hassan et al., 2005; Wohl et al., 2010). A plethora of scientific papers quantifying instream wood volumes does not take account of wood pieces below the typical LW size even if thinner and/or shorter wood pieces may play an important geomorphic role and thus, affect stream habitat in headwater channels. Such wood pieces are usually described as 'small wood' (SW) or 'fine wood'. Whereas SW is typically loaded almost continuously to the channel, LW is usually recruited by temporally and spatially limited natural or human-induced disturbances or hydro-geomorphic events (wildfires, windthrows, floods, landslides or timber harvesting; Díez et al., 2001; Hassan et al., 2005; Manners and Doyle, 2008; Hassan et al., 2016). Headwater streams are characterised by a large volume of organic matter (including large and small wood), and they are crucial for downstream ecosystems (Naiman et al., 1987; Gomi et al., 2002; Wipfli et al., 2007). Abundant occurrence of SW can indeed lead to the formation of stepped-bed morphologies in steep, narrow headwaters, and thereby affect channel stability and fluvial transport processes in these channels (Gomi et al., 2001, 2003; Jackson and Sturm, 2002; Přibyla et al., 2016), despite the fact that SW is generally perceived as less stable than LW and considered to be affected by faster decomposition (Díez et al., 2000; Wallace et al., 2000; Chen et al., 2008). In addition, it is also known that SW has critical effects on macroinvertebrate communities and their habitat (Hoffman and Hering, 2000; Lester and Wright, 2009; Enefalk and Bergman, 2016), and that wood pieces with diameters ≤ 0.1 m can indeed account for a majority of the total wood load in small channels (Wallace et al., 2000).

Wood recruitment processes, forest stand age, and channel geometry exert an important control on reach-scale wood abundance, delivered size of individual wood and formation of jams (Bilby and Ward, 1991; Wohl and Cadol, 2011). A downstream decreasing tendency of instream wood load (i.e., volume per channel area) was reported especially for small basin areas (< 50 km^2) and explained by the increase in channel bed area, and/or by the decoupling of hillslope recruitment processes which dominate in steep headwater streams (Bilby and Ward, 1989; Gurnell et al., 2002; Comiti et al., 2006; Seo and Nakamura, 2009; Rigon et al., 2012; Wyżga et al., 2015). However, more complex situations may occur in confined small headwater channels (here defined as streams with basin area < 2 km^2), where individual logs with lengths exceeding channel width can often be pinned on the opposite hillslope ('bridge' positions *sensu* Wohl et al., 2010) and therefore remain suspended above bankfull depth without any noticeable influence on geomorphic processes and stream hydraulics, at least during normal flows (Chen et al., 2006; Baillie et al., 2008; Jones et al., 2011). Because headwater channels are relatively narrow, they are confined by the hillslopes, and streamflow is usually limited or insufficient to transport instream wood (Hassan et al., 2005). Therefore, in headwater channels void of debris-flow processes, even relatively small logs can remain where they fall, and wood is therefore arrayed in random orientations, whereas in wider channels, where wood is usually more mobile and can be entirely located within the channel, it becomes reorganized into different types of wood jams (Montgomery et al., 2003). Besides the ratio between supplied wood size and channel dimension, potential wood mobility and its subsequent clustering into jams will also depend on bank and bed irregularities, living vegetation obstructions, and the hydrological regime (Wohl and Cadol, 2011; Vaz et al., 2013; Ruiz-Villanueva et al., 2016).

In this paper, we seek to determine whether wood pieces smaller than the convent LW sizes, e.g. individual branches or short trunks including here all SW pieces (i) with a length ≥ 0.5 m and a diameter ≥ 0.1 m, or (ii) a length ≥ 1 m and a diameter ≥ 0.05 m, are similarly abundant and potentially capable of performing the comparable geomorphic functions as LW in a series of very small unmanaged headwater streams with basin areas smaller than 0.5 km^2. These headwater streams flow through secondary-growth, mixed Carpathian forests composed of European beech and Norway spruce and showing varying percentages of deciduous canopy along the valley corridor. The main hypotheses of this paper are that:

- in these small steep channels, SW is as abundant as LW in terms of wood volume and number of wood pieces, and
- differences in forest canopy composition play a noticeable role in the distribution and size of wood pieces in streams.

To test these hypotheses, we systematically analysed all instream wood (small and large) deposited along three streams and compared results with stream and forest characteristics as well as with data from other headwaters of similar dimensions.

2. Study site

Three steep headwater streams were selected in the southern part of the Lysá hora massif (1323 m asl), the highest peak of the Moravskoslezské Beskydy Mts belonging to the Czech part of the flysch Western Carpathians. The Lysá hora Mt. is located in one of most humid regions of Central Europe with mean annual precipitations of 1400 mm and the mean annual number of days with snow cover equal to 170 days (Šilhán et al., 2013). Floods in this environment are typically triggered during the occurrence of above-average precipitation events over multiple days during the summer half-year, whereas flash floods have been observed to occur after heavy summer downpours. Spring snowmelt is less important in triggering floods (Šilhán, 2015).

The streams analysed in this study are located in the Nature Reserve of Mazácký Grúnik. The Reserve has an area of 88.08 ha and a forest coverage of 99.6%. Mazák 1 Stream was divided into two subreaches, named Mazák 1a and 1b, because a notable drop in channel slopes can be seen in the downstream portion of subreach Mazák 1b and the tributary between 1a and 1b represents a potential instream wood source. To avoid the introduction of additional uncertainties in later statistical analysis through possibly increased wood loads or abrupt changes in channel geometry in relation to the stream confluence, the starting point of reach 1b of Mazák was defined at ca. 20 m downstream of the confluence. The entire basin area of Mazák 1 has been protected since 1955; the nature reserve was extended in 2004 to include the other basins analysed in this work, Mazák 2 and Mazák 3 (Fig. 1, Table 1). All streams analysed in this study have basin areas < 0.5 km^2, channel gradients varying between 0.13 and 0.31 m/m and were confined by steep hillslopes. Based on the information contained in 1:50,000 soil maps, the predominant soil subtype in the basins is cambisol modal (AOPK, 2007). European beech (*Fagus sylvatica* L.) is the most common species (61.5%) within the nature reserve, accompanied by Norway spruce (*Picea abies* (L.) Karst.; 36.1%), Sycamore maple (*Acer pseudoplatanus* L.; 2.1%), and remnants of Silver fir (*Abies alba* Mill.; 0.3%). Note the dominance of deciduous forest canopy reported for the valley corridor of Mazák 2 and Mazák 3, and the prevalence of conifers in the upstream part of Mazák 1 (Table 1). Logging likely occurred in all the studied basins during the Vallachian and Pastoral colonisation phases (i.e. approximately from the beginning of the 17th and until the first half of the 19th centuries) when the region was extensively grazed and when the demand for wood was important (Škarpich et al, 2013). Thus, riparian forests along the studied streams can be considered as mature secondary-growth forests. The current age structure of the forest close to the investigated streams ranges from 60 to 100 years, with a limited number of additional, yet considerably younger (20 years old) trees located close to Mazák 2 (but still outside the riparian corridor), as well as 50–170-year old trees close to Mazák 1a and 1b, respectively. Average height of 100-year old trees is estimated to be between 25 and 30 m (www.geoportal.lesycr.cz).