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Temporal dynamics of instream wood in headwater streams draining mixed Carpathian forests

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ABSTRACT

Instream wood can reside in fluvial systems over varying periods depending on its geographical context, instream position, tree species, piece size, and fluvial environment. In this paper, we investigate the residence time of two typical species representing a majority of instream wood in steep headwaters of the Carpathians and located under mixed forest canopy. Residence times of individual logs were then confronted with other wood parameters (i.e., wood dimensions, mean annual increment rate, tree age, class of wood stabilisation and decay, geomorphic function of wood pieces, and the proportion of the log length within the active channel). Norway spruce (*Picea abies* (L.) Karst.) samples indicated more than two times longer mean and maximal residence times as compared to European beech (*Fagus sylvatica* L.) based on the successful cross-dating of 127 logs. Maximum residence time in the headwaters was 128 years for *P. abies* and 59 years for *F. sylvatica*. We demonstrate that log age and log diameter played an important role in the preservation of wood in the fluvial system, especially in the case of *F. sylvatica* instream wood. By contrast, we did not observe any significant trends between wood residence time and total wood length. Instream wood with geomorphic functions (i.e., formation of steps and jams) did not show any differences in residence time as compared to nonfunctional wood. Nevertheless, we found shorter residence times for hillslope-stabilised pieces when compared to pieces located entirely in the channel (either unattached or stabilised by other wood or bed sediments). We also observed changes of instream wood orientation with respect to wood residence time. This suggests some movement of instream wood (i.e., its turning or short-distance transport), including pieces longer than channel width in the steep headwaters studied here ($1.5 \leq W \leq 3.5$ m), over the past few decades.

1. Introduction

Instream wood is a key element in many river systems, as it is interacting with channel and floodplain geomorphology, hydrology, and ecology in many different ways. Instream wood thereby influences channel morphology and geomorphic processes (Montgomery et al., 2003; Gurnell, 2013; Le Lay et al., 2013), or enhances instream (Wohl and Scott, 2017) and floodplain inorganic sediment deposition (Wohl, 2013). Moreover, instream wood accumulations increase frictional resistance to flow (Shields and Gippel, 1995; Curran and Wohl, 2003; Mutz, 2003; Wilcox et al., 2011) and therefore slow down the passage of flood waves or modify flow hydrographs in small streams (Gippel et al., 1996; Davidson and Eaton, 2013; Wenzel et al., 2014) in a way that promotes overbank flow (Triska, 1984; Brummer et al., 2006). In general terms, these physical impacts of instream wood tend to improve habitats for some invertebrates and fish species (Harmon et al., 1986; Nagayama et al., 2012; Pollock and Beechie, 2014) and to increase the retention of nutrients (Smock et al., 1989) and organic material (Bilby and Likens, 1980).

Instream wood usually has a rather limited residence time in fluvial environments. This time is often referred to as the time which a wood piece spends in the channel between its recruitment to the channel (e.g., by windthrow, landslide, or bank erosion) to its removal from the channel reach through decay (by physical and chemical weathering or biological decomposition), downstream transport, or burial in floodplain sediments (Gurnell et al., 2002; Ruiz-Villanueva et al., 2016; Wohl, 2017). Residence time can be approximated by ^{14}C radiocarbon dating for older (i.e., at least several hundred old) wood pieces or by cross-dating of instream wood with living material if the first is well-preserved and/or shows clear tree-ring structures (Hyatt and Naiman, 2001; Stoffel et al., 2010). The latter approach allows determination of the year of tree death, which, however, does not necessarily correspond

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Table 1
Characteristics of studied streams and large wood (LW) and small wood (SW) deposition in the streams.[a]

Stream	*L* (km)	*A* (km^2)	*S* (m/m)	*W* (m)	*Dec*%	*n LW* (per 100 m)	*Vol LW* ($m^3\ ha^{-1}$)	*n SW* (per 100 m)	*Vol SW* ($m^3\ ha^{-1}$)
Mazák 1	0.52	0.13–0.40	0.13–0.25	2.3–3.2	45	48.6	210	27.2	8
Mazák 2	0.25	0.06–0.10	0.19–0.26	1.5–2.4	85	39.2	95	64.4	17
Mazák 3	0.30	0.08–0.13	0.21–0.37	2.3–3.6	95	30	26	66.3	16

[a] *L* – stream length, *A* – basin area, *S* – channel slope; *W* – active channel width, *Dec* – mean proportion of deciduous tree canopy within the valley corridor (± 30 m from the channel banks), *n LW* – number of LW pieces per 100 m channel length, *Vol LW* – volume of LW pieces per channel area, *n SW* – number of SW pieces per 100 m length, *Vol SW* – volume of SW pieces per channel area.

with the exact year of entrance of a particular wood piece into the fluvial system. However, in mountain headwaters, adjacent valley slopes are usually very steep and instream wood tends to be recruited close to the channel, such that storage of wood on the slopes above the channel for extended times is rather unlikely (Jochner et al., 2015).

Turnover time of instream wood depends on many internal and external factors and generally ranges from a few years to several centuries. Instream wood in the humid tropical zone tends to decompose much faster as compared to instream wood in dry and/or cold climatic zones (Wohl, 2013). For example, Wohl et al. (2009) documented frequent removal of logjams by chemical weathering and frequent flash floods in a tropical stream in Panama during a 2-year survey, whereas residence times of hundred years are very common in streams draining conifer boreal forests in Scandinavia (Dahlström et al., 2005) or the Pacific Northwest of the U.S. (Hyatt and Naiman, 2001). In case of completely buried wood in floodplain sediments, wood residence time can be increased up to thousands of years because the material will be conserved under anaerobic conditions (Bilby et al., 1999; Wohl, 2013). Instream wood decay rates also depend on tree species, whereby conifers tend to be preserved for longer periods of time as compared to deciduous species (Díez et al., 2002; Dahlström et al., 2005; Ruiz-Villanueva et al., 2016). In addition, other environmental factors, such as the repetition of drying-wetting cycles or water chemistry will affect instream wood residence time as well (Bilby et al., 1999; Díez et al., 2002; Wohl, 2013). Moreover, Spänhoff and Meyer (2004) documented that the microbiological decomposition of individual logs with relatively large dimension is slower than that of smaller wood pieces, owing to a higher surface area-to-volume ratio of larger pieces when compared to smaller ones. Finally, rivers with channel widths exceeding riparian tree height are also able to transport all wood pieces downstream and potentially out of the reach, whereas the mobility of instream wood in narrower channels is assumed to be much more limited (Gurnell et al., 2002; Hassan et al., 2005; Jones et al., 2011; Wyżga et al., 2015).

Wood decomposition rate (often expressed with the decay or depletion coefficient *k*) is used as a proxy for instream wood residence time in fluvial systems. It takes the form of a negative exponential function:

$$M_f = M_i \bullet e^{(k \bullet t)} \quad (1)$$

where M_i is the initial amount of wood in a fluvial system (represented by wood mass, volume, or number of pieces), and M_f is the quantity of wood left at time *t* (Ruiz-Villanueva et al., 2016). The decay coefficient *k* in fluvial environments usually varies between 0.01 and 3.10 per year; however, this variation is highly dependent on tree species, wood chemistry, piece size, and stream environment (Díez et al., 2002; Scherer, 2004; Janisch et al., 2005; Wohl, 2017).

Therefore, the aim of the study is to assess the residence time of instream wood in headwater streams of the western Carpathians and to determine all those wood parameters that affect depletion rates of instream wood in the study areas. We investigate two locally dominant tree species providing instream wood, namely European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.). Cross-dating was applied to obtain the exact year of tree death and, thus, the year of potential wood recruitment into the channels. Additional instream wood parameters (i.e., wood dimensions, mean annual increment rate, tree age, class of wood stabilisation, class of wood decay, proportion of log length within the active channel and geomorphic function of wood) were investigated to assess their potential relation with wood residence times. Instream wood mobility in the studied headwaters was indirectly evaluated via the plotting of wood residence time (i) by changes in wood orientation against flow direction and (ii) by wood incorporation into jams. We assume that pieces with longer residence times will have their orientation parallel to the flow direction and that they will be aggregated in log jams as the consequence of their fluvial transport.

2. Studied streams

Three steep headwater channels (Mazák 1, Mazák 2, and Mazák 3; Table 1) were examined in this study; they are situated on the south-facing slope of Mt. Lysá hora (1323 m asl), the highest peak of the flysch Outer Western Carpathians in the Czech Republic (Fig. 1). The study site is one of the most humid locations in central Europe, with mean annual precipitation totals at Lysá hora Mt. amounting to 1390 mm on average during the standard 1961–1990 period and ranging from 1090 mm (1990) to 1896 mm (1966) (Šilhán et al., 2013). The region is formed predominantly by thick-bedded flysch containing sandstones and shales of Late Cretaceous age, which have later been shaped into a monoclinally arranged nappe (Silesian unit) (Menčík et al., 1983). Flysch lithologies are famous for the frequent occurrence of slope instabilities, and landslides are indeed also frequent at our study sites (Pánek et al., 2011a, 2011b; Šilhán et al., 2013). As a result, relatively fine particles with a low proportion of boulder fractions are repeatedly delivered into the local channels (Galia et al., 2015). In addition to fluvial transport during flood events, wood and sediment are also mobilized by occasional, small-magnitude debris flows in the steepest valleys and local channels (Šilhán, 2014; Tichavský et al., 2014; Šilhán et al., in review).

All streams analysed here are located in the Nature Reserve Mazácký Grúnik, an area which has been created to preserve nature and therefore also to prevent the removal of instream wood by local residents. This protection status is essential for the purpose of our assessment as wood removal is a common practice in other steep mountain channels of the Czech Carpathians (Galia and Hradecký, 2014). Forests cover 99.6% of the nature reserve and consist mainly of European beech (*F. sylvatica*; 62%) and Norway spruce (*P. abies*; 31%). In addition, Sycamore maple (*Acer pseudoplatanus* L.) and Silver fir (*Abies alba* Mill.) occur occasionally (both with ≤ 2% representation). Typical tree ages range between 60 and 100 years, but much older trees (up to 170 years old) have been reported to grow in the valley corridor of Mazák 1 (www.geoportal.lesycr.cz).

The presence of instream wood in the channels is controlled by mortality of individual trees on the steep, adjacent hillslopes. In addition, and based on field observations, snowloading, windstorms, and rainfall-induced waterlogging of hillslopes can be perceived as additional, yet important wood recruitment agents as well. On the other hand, bank erosion is practically negligible owing to high channel confinement. Instream wood abundance differs between the individual