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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).

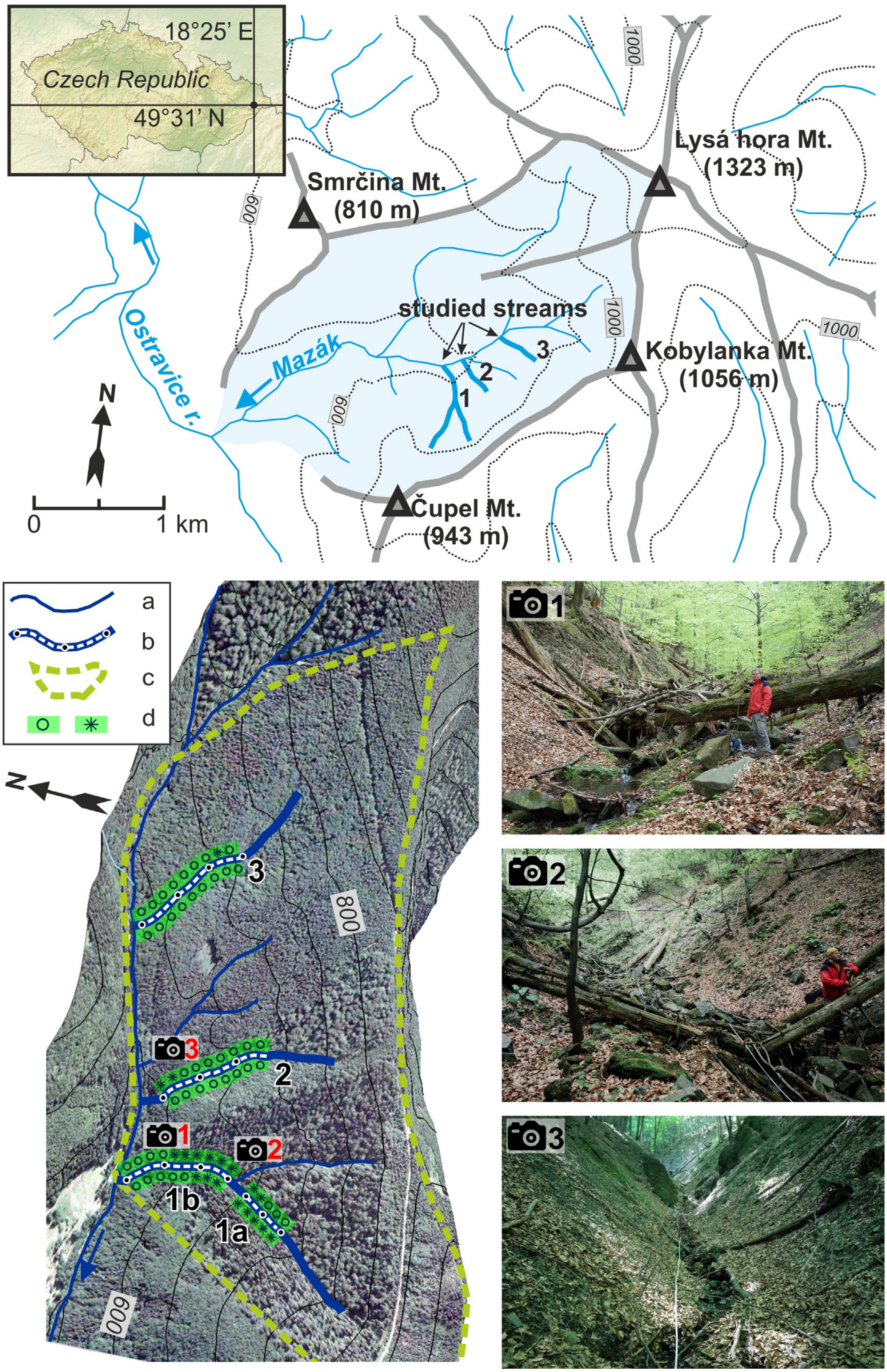

Fig. 1. Overview and selected features of the study area: a – watercourse, b – channels analysed with 100 m distance marks, c – Borders of the Mazácký Grúnik Nature Reserve, d – prevailing tree species in the valley corridor (circle – deciduous species, asterisk – conifer species), 1 – extraordinarily large log jam in Mazák 1b, 2 – large wood attached to adjacent hillslopes (Mazák 1b), 3 – highly confined channel reach with limited space for instream wood storage (Mazák 2),

Table 1
Characteristics of study streams.[a]

Stream	Stream order	*L* (m)	*A* (km^2)	*S* (m/m)	S_{hill} (m/m)	*W* (m)	*Confin.*	*Pres.*	*Dec%*
Mazák 1a	I.	200	0.13–0.21	0.28	0.88	2.4	2.09	1955	40
Mazák 1b	II.	300	0.31–0.40	0.16	0.90	2.7	2.10	1955	55
Mazák 2	I.	240	0.06–0.10	0.23	0.91	2.0	1.02	2004	90
Mazák 3	I.	300	0.08–0.13	0.26	0.78	2.9	1.04	2004	95

[a] *L* – length of study reach, *A* – basin area range, *S* – mean channel gradient, S_{hill} – mean adjacent hillslope gradient, *W* – mean active channel width, *Confin.* – mean valley confinement index , *Pres.* – year of the preservation beginning, *Dec%* – mean percentage of the deciduous tree canopy in the valley corridor.

Channel morphology of the investigated streams consists mostly of cascade reaches accompanied by infrequent bedrock outcrops, especially in their steepest parts. Lithology is dominated by Mesozoic flysch with alternations of sandstones and shales, which favours the occurrence of frequent slope instabilities (Šilhán et al., 2013) and the delivery of relatively fine particles (i.e. gravel and cobbles) with low proportions of boulders into the local channels (Galia et al., 2015, Galia and Škarpich, 2016). Wood supply to the channels is above all related to individual tree mortality on hillslopes adjacent to streams, but strong winds and mass movements during extraordinary rainfall events have been identified by field mapping as important sources of wood supply as well. This field assessment also demonstrated that tree mortality mostly represents a point scattered source of wood at the study sites. Bank erosion, by contrast, is almost negligible as a wood recruitment process.

3. Methods

3.1. Field measurements

Instream wood and channel parameters were collected during low flow conditions between November 2015 and June 2016. No notable hydrometeorological events (i.e. floods or windstorms) occurred during this period. Any major changes in channel geometry or notable changes in the rates of wood recruitment and transport can thus be excluded.

3.1.1. Channel measurements

The streams were surveyed to quantify channel and valley corridor characteristics. The bankfull geometry cannot be assessed systematically in all cross-sections because of strong interactions with colluvial processes. Therefore, we used the active channel width as the area of the low-flow channel (Gomi et al., 2001; Wohl, 2017). Active channel width was measured at regular 20-m intervals along the stream longitudinal profile (with an accuracy of ± 0.05 m), as was mean channel slope and adjacent hillslope gradients, at distances of approximately 20 m from the valley toe (with an accuracy of ± 0.005 m/m). The valley confinement index was calculated as the ratio between the active channel width and total valley floor width. All channel parameters were measured using a tape and a laser rangefinder including a digital clinometer. The proportional ratio of deciduous and coniferous tree canopy on adjacent valley slopes (with an accuracy of ± 2.5%) was estimated for the same 20-m intervals by using actual digital aerial imagery (with a pixel resolution of 25 cm). The width of the valley corridor considered in this study was equal to the average height of 100-year old trees, i.e. 30 m + 30 m for both hillslopes.

3.1.2. Instream wood measurements

The instream wood was divided into large and small wood pieces. Pieces were considered large wood (LW) if they had the conventional dimensions of ≥ 1 m in length and ≥ 0.1 m in diameter at the piece end (Wohl et al., 2010). Small wood (SW) is defined here as all pieces below these conventional dimensions with (i) ≥ 1 m in length and ≥ 0.05 m in diameter at the piece end or (ii) pieces with ≥ 0.5 m in length and ≥ 0.1 m in diameter. Every single wood piece meeting these criteria and interacting at least partially with the active channel width was measured and its longitudinal position was recorded. We omitted pieces located exclusively between the active channel and hillslopes or a few logs hanging above the assumed bankfull flow height ≥ 0.3 m (typically occurring in the form of 'bridges' pinned on the opposite hillslopes).

The dimensions of wood pieces and their orientation with respect to the flow direction, decay class, and stabilisation category were assessed in the field (Table 2). A proportion of the active channel width spanned by a wood piece (i.e., the projection of the piece onto an imagined cross-section) was noted for individual LW or SW pieces. This parameter provided an insight into the geomorphic function of a piece as a hydraulic roughness element during ordinary to high flows. Total and active-channel wood volumes were then calculated using the shape of two joined truncated cylinders, whereby wood diameter on the boundary of the active channel was calculated from the proportion of active-channel wood length and end diameters at either side of the wood pieces. LW/SW species were separated into deciduous and conifer trees, with the first being above all represented by European beech. Conifer pieces observed in the channels were exclusively Norway spruce. However, in several cases, identification of species was not possible as a result of heavy decay. Therefore, species class was only noted for decay classes 1, 2, and 3 so as to guarantee maximal accuracy in species determination. Two accumulation classes of LW/SW were noted in the field, including (i) instream wood forming a channel-

Table 2
Description of the instream wood parameters assessed.

Parameter	Description	Unit (accuracy)
Length	Total wood length	meters (± 0.05 m)
Diameter	Mean wood diameter calculated as mean of diameters taken on both ends or in the middle of piece in the case of irregular wood shape	meters (± 0.005 m)
Orientation	Orientation of a wood against flow direction (0–180°)	degrees (± 11.25°)
% of spanned channel width	Proportion of the active channel width spanned by a wood piece (maximum projected area)	percentage (± 5%)
Active-channel length	Wood length within in the active channel	meters (± 0.05)
Decay class	1 – fresh (presence of the smallest branches or dry leaves/needles), 2 – ≥50% of bark preserved, 3 – without bark or < 50% of bark preserved, 4 – soft, decayed wood	visual estimation
Stability category	A – loose, unattached piece, B – attached (pinned) by hillslopes (i.e. ramps and collapsed bridges sensu Wohl et al., 2010), C – stabilised in the channel by sediments/other wood pieces	visual estimation
Total volume	Calculated total volume of a wood piece	cubic meters
Active-channel volume	Calculated volume of a wood within the active channel	cubic meters

spanning step exceeding a minimal step height of ≥0.3 m and exclusively consisted of 1–2 wood pieces and (ii) the presence of wood jams including ≥3 clustered LW/SW pieces. We ignored channel steps where boulders were the dominant step-forming factor. As flow resistance in these steep channels is controlled by step height (Curran and Wohl, 2003), we used a threshold value of 0.3 m to express morphologically notable steps. The accumulated sediment volumes were measured upstream of steps and jams. This parameter was not used in further analysis due to the low importance of sediment deposits related to instream wood, both in terms of frequency and of stored sediment volume.

3.2. Data analysis

Differences in active channel width, channel slope, hillslope gradient, valley confinement index and the proportion of deciduous trees in the valley corridor were assessed by the non-parametric Kruskal-Wallis test for 20-m intervals within the studied streams. For additional *post-hoc* analyses, we used Dunn's procedure with Bonferroni's correction for the significance level for the pairwise comparisons. The non-parametric Mann-Whitney *U* test was used to assess potential differences between the parameters of LW and SW pieces (i.e. total and active-channel length, total and active-channel volume, mean diameter, and percentage of spanned active channel width by a wood); these tests were done for all measured wood and then for each of the individual streams separately. We tested whether tree species (i.e., conifer or deciduous) control the LW and SW characteristics. To do that, differences between conifer and deciduous characteristics (total volume, length, and mean diameter) were tested using again the non-parametric Mann-Whitney *U* test. All models and statistical tests were set at a significance level of 0.05.

Circular statistics were used for the analysis of wood orientation, and for the purpose of testing potential differences between SW and LW across the streams and for each stream individually. Mean direction, circular standard deviation, and mean resultant length (R_l) were calculated for all datasets as well by NCSS statistical software. R_l is in fact a measure of data concentration, with values close to 1 implying high concentration of circular data and, by contrast, values close to 0 pointing to low concentrations. The Von Mises distribution was used in this study as an approximation of normal distribution for circular data and, therefore, Stephens modified Watson's test was used as a goodness-of-fit test for the Von Mises distribution. Because all circular datasets were falling into Von Mises distribution, equality of distributions and concentrations between LW and SW were then assessed with the Mardia-Watson-Wheeler uniform scores test and by the concentration homogeneity test, respectively (NCSS, 2016). The same tests were also used for pair comparisons between individual stabilisation classes.

The hierarchical clustering of measured instream wood load predictors at 20-m intervals (i.e. active channel width, valley confinement index, channel slope and mean hillslope gradient entering as interval variables and the proportion of deciduous trees cover in the valley corridor entering as the ratio variable) was performed to obtain homogenised channel reaches in the studied streams avoiding autocorrelations between individual 20-m segments. The group average (unweighted-pair group) method was chosen together with a 1.0 cluster cut-off in individual dendrograms. In this way, we acquired 20–120-m long channel reaches which were relatively homogenous in terms of wood abundance control parameters. The arithmetical means of instream wood load predictors were then calculated for and assigned to individual reaches together with the standardised frequencies (i.e. pieces per 100 m channel length) and active-channel volumes (i.e. pieces per channel hectare) of measured LW and SW. Generalised linear models were applied to assess the role of assumed instream wood abundance predictors at the channel reaches. Dependent wood abundance variables in the model were (i) standardised number of LW and SW pieces per 100 m channel length and (ii) standardised active-channel volume per channel hectare (i.e. wood load) of LW and SW. The Durbin-Watson test together with the assessment of serial correlation of residuals was used to check possible multicollinearity in tested variables. Stepwise selection of independent variables has then been realized with R (R Core Team 2016) before the model with the best Akaike Information Criterion (AIC) was selected. Generalised linear models following Gaussian distribution and an identity link function were developed for dependent variables representing LW and SW volumes. Generalised linear models with a Poisson distribution and a log link function were developed for dependent variables representing frequencies of LW and SW.

4. Results

4.1. Studied streams and their morphological characteristics

In a first analytical step, the four reaches of three streams analysed were compared by their morphological parameters measured at regular 20-m intervals (Fig. 2). Mazák 2 had an active channel width which was significantly narrower (p-value = 0.0013) than those measured at Mazák 1b and Mazák 3. Mazák 2 and Mazák 3 were also significantly more confined by surrounding hillslopes as compared to Mazák 1a and 1b, which can be explained by the occurrence of 1–5 m wide debris-flow deposits and fluvial accumulations in the valley bottom of Mazák 1a and 1b. In addition, Mazák 1b exhibited gentler mean channel slopes (mean value = 0.16 m/m) as compared to the other streams (mean values = 0.28, 0.23 and 0.26 m/m, respectively). By contrast, we did not find any significant differences between the channels evaluated in terms of mean hillslope gradients. The highest proportion of deciduous trees in the valley corridor was documented in Mazák 2 and Mazák 3 (p-value < 0.0001).

4.2. Instream wood characteristics and abundance at the stream scale

In total, 453 pieces of LW and 505 pieces of SW were analysed in a total of 1040 m channel length along the studied streams. Large wood was most abundant in the study reaches of Mazák 1a and 1b; in the upstream part of Mazák 1a reach, we counted up to 60 LW pieces per 100 m channel length with a wood load greater than 300 $m^3 \cdot ha^{-1}$ (Table 3). This value represents more than 10 times the wood load estimated for Mazák 3 for which observed LW abundance was smallest (26.2 $m^3 \cdot ha^{-1}$). By contrast, small wood, both in terms of piece frequency and volume metrics, was approximately twice as frequent in Mazák 2 and Mazák 3 (64.4 and 66.3 pieces per 100 m and 16.8 and 15.6 $m^3 \cdot ha^{-1}$, respectively) as compared to Mazák 1a and 1b (22.0 and 30.7 pieces per 100 m and 7.7 and 8.5 $m^3 \cdot ha^{-1}$, respectively). These findings imply different ratios of LW/SW frequencies and volumes in the studied streams, which declined from the less confined streams with considerable proportion of conifers in the valley corridor (Mazák 1a and Mazák 1b with 39.6 and 17.0 LW/SW volume ratio) to the highly-confined sites dominated by deciduous forest canopies (Mazák 2 and Mazák 3 with 5.7 and 1.7 LW/SW volume ratio).

The proportion of deciduous wood in the SW category was dominant in all streams (93.5–100%) for the first three decay classes and the majority of LW was from deciduous species (69.0–96.4%). The ratio between the active-channel volume and total volume of LW pieces was close to 50%, whereby the majority of SW total wood volume (up to 87% in Mazák 3) was documented within the boundaries of the active channel.

Large and small wood abundance was also reflected in the frequencies of morphological steps expressed as the average number of steps per 100-m channel length in the studied streams. No single SW step was observed in Mazák 1a (as compared to the 3 steps per 100 m channel length formed by LW), and only 0.7 SW steps per 100-m channel length were found in Mazák 1b (as compared to the 2.3 steps per 100 m formed by LW). By contrast, SW steps were more frequent in

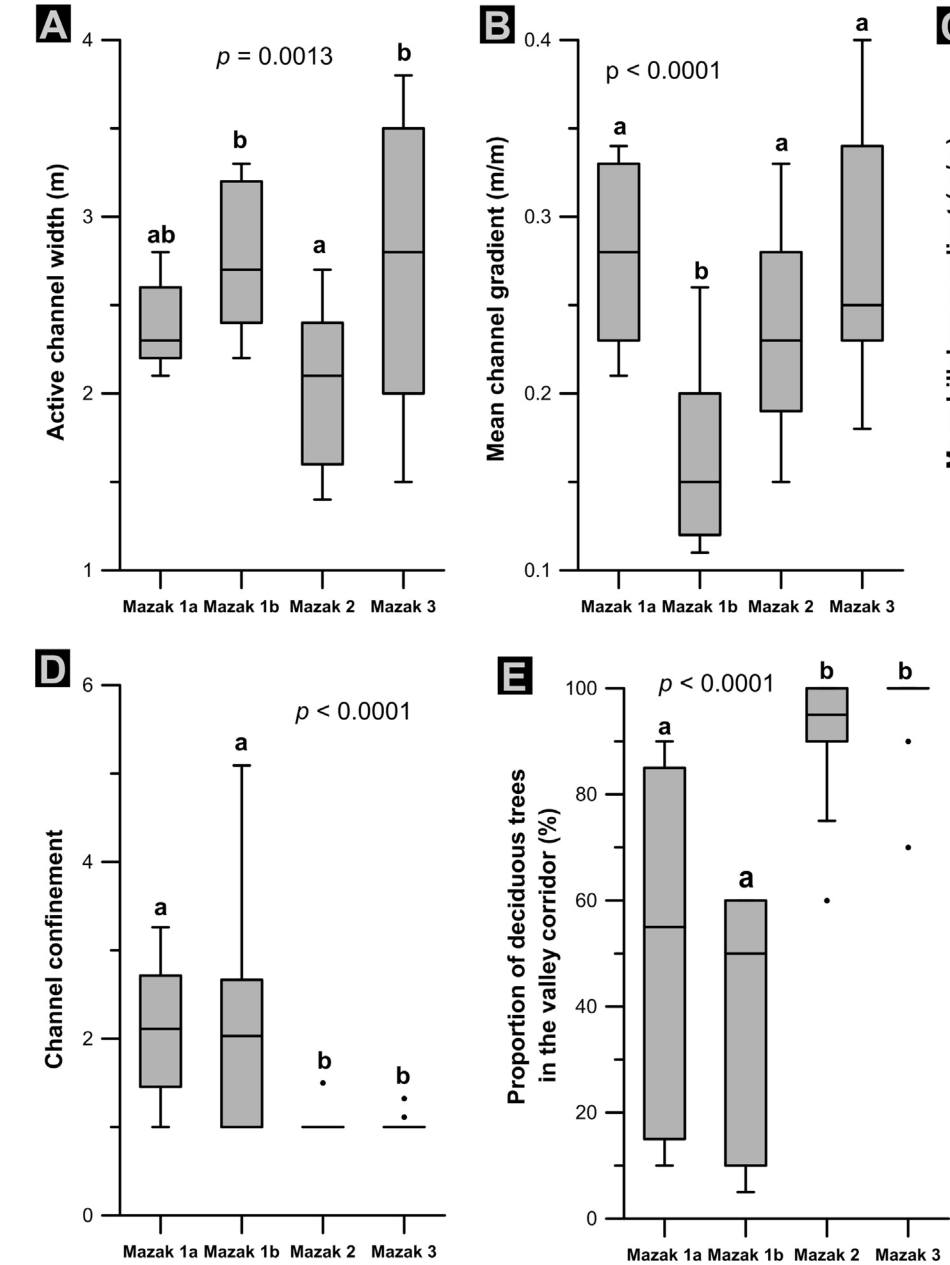

Fig. 2. Boxplots of morphological variables as measured for 20-m long channel reaches in all streams analysed. *p* values provide results of the Kruskal-Wallis test (i.e. active channel width, mean channel and hillslope gradient, channel confinement index and the proportion of deciduous trees in the valley corridor), whereas letters above the boxes point to significantly differing groups (related to post-hoc tests).

Table 3
Abundance of large and small wood in the analysed channels.[a]

Stream	*LW_n*	*LW_vol* m^3ha^{-1}	*LW_vol ch/tot*	*LW steps*	*LW_dec %*	*SW_n*	*SW_vol* m^3ha^{-1}	*SW_vol ch/tot*	*SW steps*	*SW_dec %*	*LW/SW_n*	*LW/SW_vol*	*Jams*
Mazák 1a	58.5	304.6	0.54	3.0	69.0	22.0	7.7	0.78	0.0	93.5	2.66	39.6	1.5
Mazák 1b	42.0	144.2	0.56	2.3	86.8	30.7	8.5	0.82	0.7	100.0	1.37	17.0	1.7
Mazák 2	39.2	95.2	0.49	2.4	90.8	64.4	16.8	0.66	3.2	98.6	0.61	5.7	2
Mazák 3	30.0	26.2	0.47	1.0	96.4	66.3	15.6	0.87	2.0	100.0	0.45	1.7	2.7

[a] *LW_n* – frequency of LW per 100 m channel length, *LW_vol* – active-channel volume of LW load, *LW_vol ch/tot* – ratio between the active-channel volume and total volume of LW, *LW steps* – number of steps created by LW per 100 m channel length, LW_*dec* - percentage of deciduous species in observed LW pieces (decay status 1–3), *SW_n* – frequency of LW per 100 m channel length, *SW_vol* – active-channel volume of LW load, *SW_vol ch/tot* – ratio between the active-channel volume and total volume of SW, *SW steps* – number of steps created by LW per 100 m channel length, SW_*Dec* - percentage of deciduous species in observed LW pieces (decay *status 1–3), LW/SW_n* – ratio between LW and SW pieces per 100 m channel length, *LW/SW_vol* – ratio between LW and SW active-channel load, Jams – frequency of jams per 100 m channel length

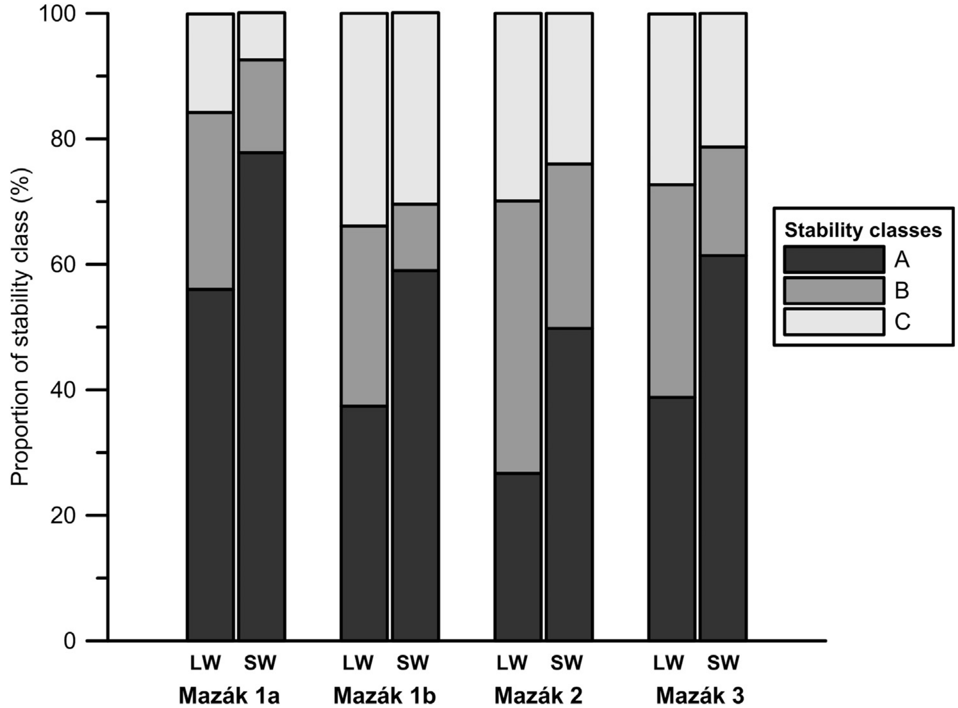

Fig. 3. Distribution of stability classes of LW and SW pieces in the analysed streams: A – not stabilised, B – attached to hillslopes, C – stabilised by other wood or bed sediments.

Mazák 2 and Mazák 3 as compared to the observed number of LW steps in these streams. We observed only 1.5–2.7 jams per 100 m channel length in the studied streams with slightly more frequent occurrences in Mazák 1a and Mazák 1b. These jams usually consisted of 3–7 clustered wood pieces without notable sediment accumulations upstream of these structures. Nonetheless, one extraordinarily large jam was found in Mazák 1b, and consisted of more than 60 LW and SW pieces, thereby damming the complete width of the valley floor (Fig. 2).

In contrast to LW, SW was mostly neither attached to hillslopes nor stabilised in any other way in three out of four analysed reaches (Fig. 3). The only exception was the highly-confined Mazák 2 where a slightly increased population of LW and SW attached to hillslopes (class B in Fig. 3) could be found, representing 43.4% and 26.2%, respectively of all samples found in this stream. The largest number of LW and SW unattached pieces (class A) was observed in Mazák 1a, where this category accounted for 56% and 77.8%, respectively, of the entire population. Although LW was generally more decayed than SW (see Chapter 4.4 for details), one notable exception was found in Mazák 3, where no statistically significant differences are observed in decay classes between the LW and SW populations (p-value = 0.1461, Fig. 4).

4.3. Predictors of instream wood abundance

To confirm observed relations between investigated streams and instream wood abundance, as well as to detect other variables controlling LW and SW occurrence, generalised linear models were used to identify predictors of LW and SW abundance (both in terms of number of individual pieces (*nLW* or *nSW*) and wood load (*VolLWch* or *VolSWch)*) in 20–120-m long channel reaches ($n = 30$) that were homogenised by hierarchical cluster analysis in terms of channel and valley control parameters. Observed differences between streams suggest multicollinearity, especially between channel confinement and proportion of deciduous trees in the valley corridor (Fig. 2). A Pearson's correlation coefficient of -0.42 was obtained between these two variables and by plotting clustered reaches. Nevertheless, the Durbin-Watson test together with the assessment of serial correlation of residuals ruled out the multicollinearity from the tested samples and allowed us to use multiple regression models.

In general, more robust models in terms of observed R^2 are obtained for SW metrics thus suggesting more regular characteristics of SW recruitment into the streams (Table 4). Forest composition in the valley corridors seems to play a key role explaining the abundance of instream wood in the streams, but some contradictory effects of these predictors on LW and SW loads were observed as well (Table 4). The presence of deciduous trees in the valley corridor had positive correlation on SW metrics, but the decrease in the proportion of deciduous trees led to higher abundance of LW in the channel. Channel confinement played an important role in explaining SW abundance, provided that both related metrics indicated increasing number or volume of SW by decreasing channel confinement index. An indirect link between active channel width and three dependent variables (nLW, nSW and VolSWch) was also reported by the models, which suggests a decrease of instream wood with increasing channel width. The same negative relationship existed for nLW and nSW in terms of channel slope.

4.4. Differences between LW and SW parameters

Although LW pieces are expected to be generally longer and thicker than SW, due to their definition, we identified 4% of SW (19 pieces of all measured SW) with lengths exceeding 5 m. Maximum observed SW length was 7.7 m whereas maximum LW length was 19 m. Despite the fact that LW and SW spanned a similar proportion of the active channel width in all studied streams (p-value = 0.6985), LW piece active-channel length (p-value = 0.0098) and LW active-channel and total volumes (both p-values < 0.0001) were considerably greater (Fig. 5). However, this was not true when active-channel lengths of LW and SW pieces were compared separately for Mazák 2 (p-value = 0.4017) and Mazák 3 (p-value = 0.8899). These similarities in active-channel lengths between LW and SW at Mazák 2 and Mazák 3 were not reflected in LW vs. SW active-channel volumes in these streams (both $p < 0.0001$ with greater active-channel volumes of LW). When all streams are looked at simultaneously, SW was mostly unattached, whereas LW had similar proportion of all stabilisation classes (Fig. 6A). We also observed that LW was generally more decayed than SW for the

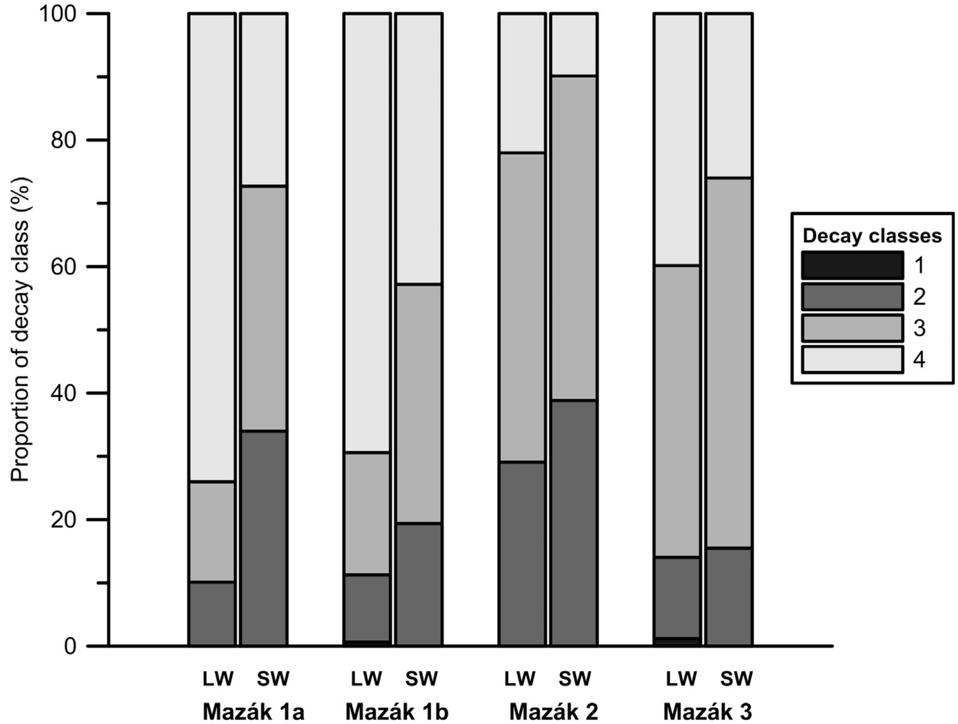

Fig. 4. Distribution of decay classes for LW and SW pieces in the analysed streams.

Table 4
Variables selected for best-fitted generalised linear models by AIC. All partial regression coefficients in presented models are significant at $p < 0.05$.

Dependent variable	Best predictors[a]	R^2	Adj. R^2	p value for the model
nLW	deciduous trees in the valley corridor (−), active channel width (−), channel slope (−)	0.12[b]	–	< 0.001
$VolLW_{ch}$	deciduous trees in the valley corridor (−)	0.14	–	0.041
nSW	deciduous trees in the valley corridor (+), valley confinement (−), active channel width (−), channel slope (−), hillslope gradient (−)	0.80[b]	–	< 0.001
$VolSW_{ch}$	valley confinement (−), channel width (−), deciduous trees in the valley corridor (+)	0.64	0.60	< 0.001

[a] (+) positive correlation, (−) negative correlation.
[b] McFadden's pseudo-R^2 was calculated for generalised linear models with a Poisson distribution and a log link function.

entire dataset (Fig. 6B). As noted previously, the frequency of steps created by LW and SW differed between streams, and SW steps were reported more frequently in highly confined streams under dominant deciduous canopy (Mazák 2 and Mazák 3).

Significant differences in the orientation of LW and SW with respect to the main flow direction could not be observed. Visual comparison resulted in high circular standard deviations and low circular data concentrations (Fig. 7). The orientation angle distributions (p-value = 0.1352) and concentrations (p-value = 0.4753) between LW and SW pieces did not show any statistically significant differences when compared to the entire dataset. Additional pair comparisons between stabilisation classes A, B, and C for LW indicated significant differences in orientation angle distributions with p-values < 0.001 for A-B and B-C comparisons, respectively, and p = 0.012 for A-C comparison. The same significant differences were calculated for SW (p-values < 0.001 for A-B and B-C comparisons, respectively, and p = 0.020 for A-C comparison). Significantly different concentrations of LW were observed only for A-C comparison (p-value = 0.013), whereas significantly different A-C (p-value = 0.047) and B-C comparisons (p-value = 0.015) were obtained in the case of SW.

Conifer LW pieces were significantly larger in all tested parameters when compared to deciduous LW pieces. We sought for differences between the dimensions (i.e. total length, total volume and mean diameter) of individual coniferous LW (n = 23) and deciduous LW pieces (n = 176) belonging to decay classes 1, 2 or, 3. (Fig. 8). We also tested these differences between coniferous SW and deciduous SW pieces, but we only observed significant differences in terms of total volume (p-value = 0.01). However, due to the smaller number of coniferous samples available for analysis (n = 6), as compared to the dataset of deciduous samples (n = 370), results should be taken with caution.

5. Discussion

5.1. Large and small wood abundance in headwater streams

In this study, we measured instream wood loadings in small headwaters by including LW and SW pieces. We observed that active-channel wood loads (i.e. LW and SW summed) in all streams analysed varied between 41.8 $m^3 \cdot ha^{-1}$ and 312.3 $m^3 \cdot ha^{-1}$, whereas the frequency of observed LW and SW pieces was 73–105 per 100 m channel length. Field studies of instream wood abundance and its geomorphic function in headwaters often focus on wider channels with contributing drainage area up to 100 km^2. In spite of the scarcity of other studies focusing on very small headwater catchments ($A < 2\,km^2$) as in this study, we attempted to compare our results with information on small streams of similar dimensions across the globe (Table 5). We expected that the observed wood frequencies and loads in the Mazák streams would be lower than the wood quantities reported from unmanaged forests without wood exploration, as we expected historical logging in all streams analysed. Despite the (assumed) logging history, the studied

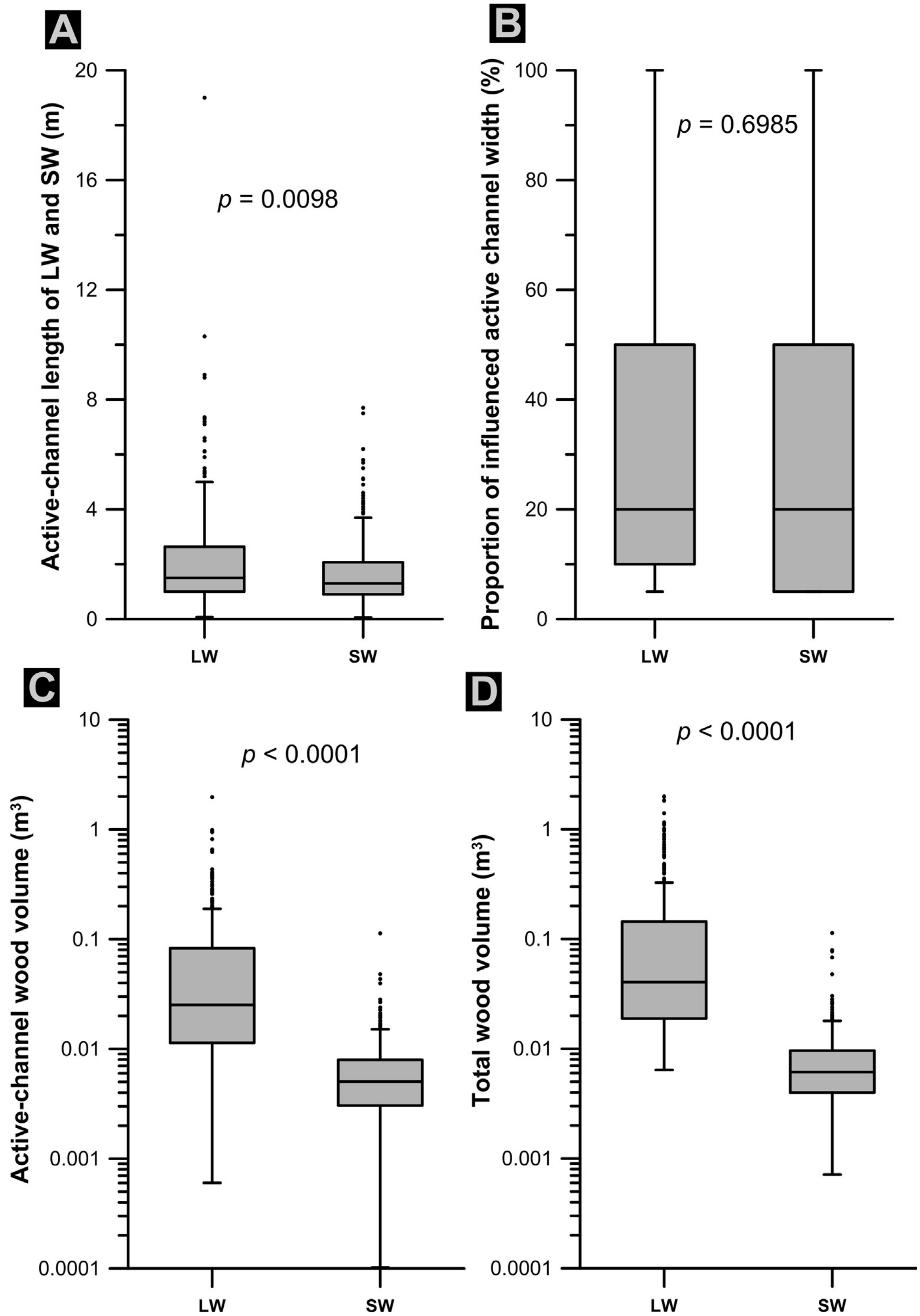

Fig. 5. Boxplots of active-channel length, proportion of spanned active channel width, and active-channel and total volumes for LW and SW. *p* value corresponds to values obtained with the Kruskal-Wallis test.

streams can be considered as mature, secondary-growth forests without recent artificial removal of instream wood.

We realized that whereas the frequency of instream wood analysed in this study was usually quite similar or slightly smaller as compared to other headwater channels, the active-channel wood loads were very high, especially in the case of Mazák 1b and even more so in the case of Mazák 1a. We assumed that the presence of relatively thick LW pieces – as compared to local stream geometry with a mean channel width < 3 m – and their frequent orientation parallel to the flow direction presumably resulted in notably higher active-channel wood volumes in Mazák 1a and 1b, but did not, at the same time, result in higher frequencies of LW pieces per channel length. Active-channel wood volumes of Mazák 1a and 1b were at the upper boundary of observed wood volumes in small headwaters, including examples of unmanaged old-growth forests of e.g. New Zealand (Meleason et al., 2005) or the Rocky Mts (Jones et al., 2011) (Table 5). We found only three studies where wood load values greatly exceeded those reported for the Mazák streams. In the study of Lienkaemper and Swanson (1987), old-growth conifer forests consisting of up to 500 year-old Douglas-fir with individual trees of very large diameters up to 2 m were reflected in the

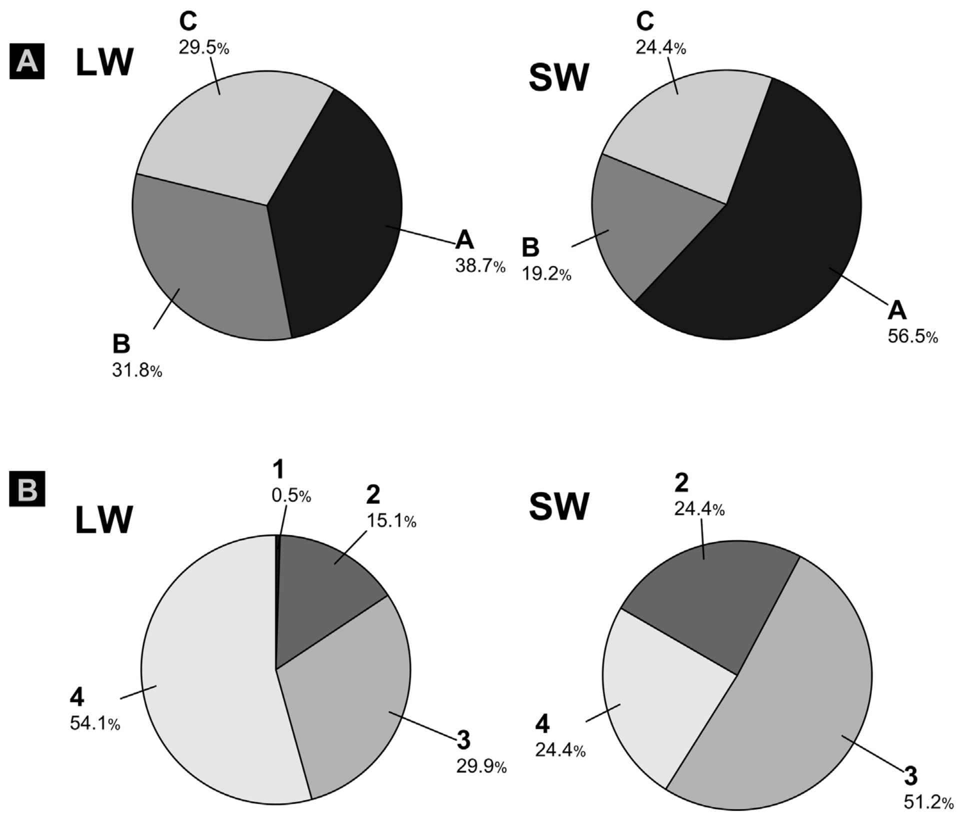

Fig. 6. Proportion of stabilisation and decay classes for all LW and SW pieces.

high instream wood loads in the Cascade Range. Burrows et al. (2012) reported data from managed eucalypt forests and observed much higher frequencies and volumes of instream wood. However, specific forest harvesting activities in the latter contributed large amounts of wood to the stream channels. Another example of extraordinarily high instream wood abundance was reported from tropical headwater streams with very high biomass production (Cadol et al., 2009). On the other hand, the active-channel wood volumes measured in Mazák 2 and 3, dominated by deciduous forests, were relatively low when compared with other small streams draining secondary-growth mixed temperate or deciduous forests (Díez et al., 2000; Curran and Wohl, 2003; Warren et al., 2009; Rigon et al., 2012; Costigan et al., 2015; Rickli et al., 2018). Nowakowski and Wohl (2008) reported very low wood volumes by including SW components (12 m^3/ha) in one of their headwater streams, and attributed this finding to (i) less-confined valley settings preventing direct supply of wood from adjacent hillslopes, (ii) low channel gradients that were not allowing frequent wood transport from upstream reaches, and to (iii) low annual precipitation affecting production of biomass.

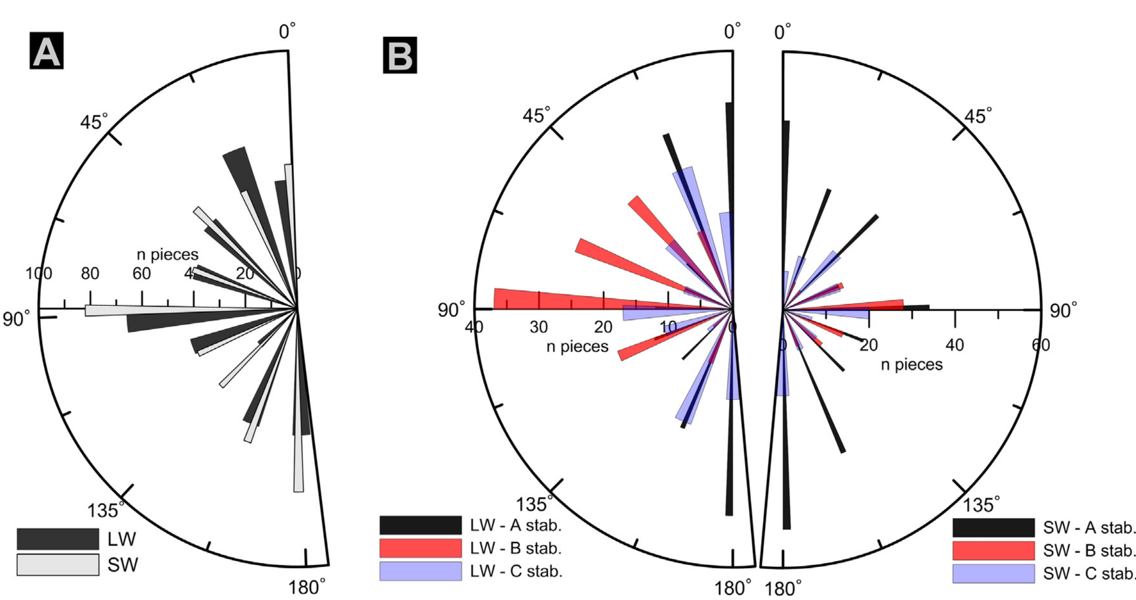

Fig. 7. Distribution of LW and SW orientations in total (A) and corresponding to stabilisation classes (B and C) (A – unattached, B – hillslope stabilised, C – stabilised by other wood or bed sediments).

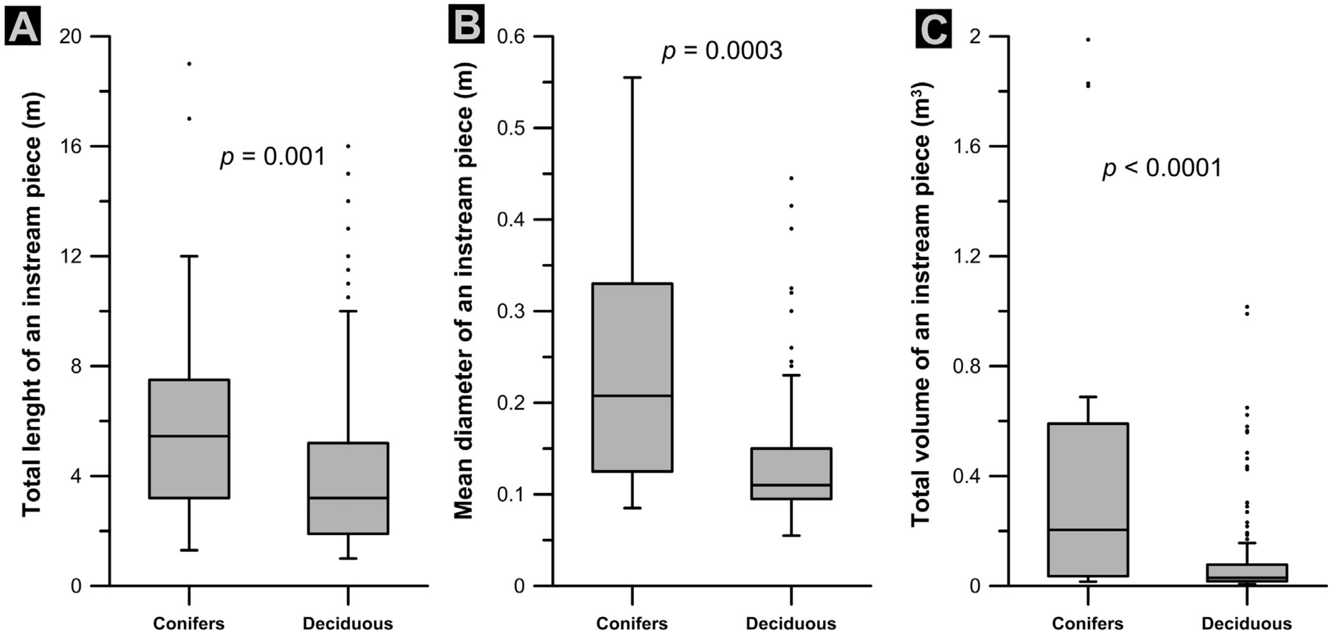

Fig. 8. Boxplots of conifer ($n = 23$) and deciduous ($n = 176$) species accounted in LW (decay classes 1–3). Reported p value corresponds to outputs of the Mann-Whitney U test.

5.2. The role of forest stand and valley confinement in instream wood characteristics and abundance

Instream wood abundance in small mountain channels is controlled by forest stand age, forest basal area and forest management (Bilby and Ward, 1991; Dahlström et al., 2005; Nowakowski and Wohl, 2008; Warren et al., 2009; Costigan et al., 2015). In the case of the secondary-growth mixed forests of similar age surrounding the Mazák streams, the presence of deciduous trees in the valley corridor was a key characteristics decreasing LW frequency and volume and, at the same time, the reason for the positive influence on SW abundance (Table 4). High SW frequency and active-channel volume in reaches dominated by deciduous trees was primarily the result of individual branch supply with sufficiently large dimensions to be attributed to the SW size category than a supply of individual dead trees. This is also supported by the dominance of deciduous species in observed instream SW pieces, when its proportional representation was much greater than the proportional ratio of deciduous trees within the valley corridor (Tables 1 and 3).

One should also take into account that the related decay processes of deciduous species and conifers in channels under mixed forest canopy could be different, and deciduous species would generally deplete much faster from the channel systems as compared to conifers (Hyatt and Naiman, 2001; Dahlström et al., 2005). This was confirmed for the trunks of European beech and Norway spruce in Carpathian forest floors (Holeksa, 2001; Šamonil et al., 2009) and for instream wood with sufficient size (i.e. minimal diameter of 8 cm and preserved tree-ring structure) for successful dendrogeomorphic cross-dating in Mazák streams (Galia et al., 2017). The authors documented that pieces of beech trees disintegrate within a time horizon of max. 50–60 years, whereas the oldest LW pieces of Norway spruces were reported to last for more than 100 years. Moreover, the wood decomposition rate observed depends on other parameters (e.g., wood position, site conditions) as well as on wood size, because smaller pieces have larger surface area-to-volume ratios than larger pieces and therefore their microbiological decomposition might be faster as well (Spänhoff and Meyer, 2004; Ruiz-Villanueva et al., 2016). Our observations also confirmed that LW pieces were generally more decayed, but not totally disintegrated, when compared to SW. Measured LW conifer pieces (for decay class 1–3) had significantly greater dimensions than LW deciduous species (Fig. 8), which together with their slower decay rates point to longer residence times of conifers in the analysed streams. This implies that the increasing number of deciduous trees in the valley (riparian) corridor at the expense of conifers directly affected residence time of supplied instream wood in stream channels and the number of LW pieces together with LW active-channel volume.

Based on our findings, we propose a conceptual model for LW and SW abundance in small headwaters under mixed-forest canopy (Fig. 9). Active channel width together with valley confinement was recognised as the single-most important predictor leading to a decrease in SW active-channel volume by the generalised linear model. Minor increases in channel widths significantly reduce instream wood stability by decreasing the ratio between piece length and channel width (Gurnell et al., 2002; Dahlström and Nilsson, 2004; Chen et al., 2006; Baillie et al., 2008). We suggest that this process allows not only for a redistribution of SW pieces during high flow events, but also their breakage into shorter pieces during transport (Merten et al, 2013). The positive role of valley confinement can be similarly perceived in the SW length/valley width ratio, where SW can be located in the valley floor by its entire length. On the other hand, the decreasing value of the valley confinement index would have led to the suspension of LW pieces above the bankfull channel in 'bridge' positions (*sensu* Wohl et al., 2010), which was reflected by decreased active-channel volumes of LW in highly confined reaches as obtained in the regression model. Nevertheless, the later development of 'collapsed bridges' (*sensu* Wohl et al., 2010) is possible during advanced decay, which then corresponds to the conceptual model of LW dynamics in small channels as presented by Jones et al. (2011). This implies that for the highly confined streams studied in this paper with width of the valley floor smaller than 10 m (and often less than 5 m), even small increases in the valley width will play an important role for potential LW storage in the channel. The role of sufficiently large storage areas (i.e. the presence of unconfined reaches) for the potential deposition of LW was documented in the Colorado Range for wider headwater channels (Wohl and Cadol, 2011; Wohl and Beckman, 2014). The valley confinement control of active-channel LW volumes in Mazák streams is, however, in contradiction with the observations of Costigan et al. (2015), who reported independence of LW abundance on valley geometry including valley

Table 5
Comparison of instream wood abundance in small headwater channels (A ≤ 2 km^2) across the globe.

(i) Instream wood only by LW convent criteria (1 m length, 0.1 m diameter)

Location	Channel width (m)	Channel gradient(m/m)	Forest type	Wood frequency n/100 m	Wood volume m^3/ha	References
Adirondack Mts and White Mts (NE USA)	1.4–4.4	0.01–0.24	Second-growth mixed temperate	7–63	13–237	Warren et al. (2009)
Appalachian Mts (USA)	2.4–6.3	0.01–0.18	Second- and –third growth mixed temperate	24–65	20–160	Costigan et al. (2015)
British Columbia, Canada	1.6–2.8	0.01–0.10	Managed boreal	–	116	Chen et al. (2006)
British Columbia, Canada	2.1–2.5	0.03–0.08	Unmanaged boreal	49–62	45–151	King et al. (2013)
Cascade Range, Oregon (USA)	3.5–5.2	0.26–0.36	Old-growth conifer temperate	–	500–750	Lienkaemper and Swanson (1987)
Cascade Range (Washington, USA)	2.0–3.7	0.06–0.17	Managed mixed temperate	8–94	–	Curran and Wohl (2003)
Highland Water (UK)	1.2	0.0125	Deciduous hardwood	–	76	Gurnell et al. (2002)
High Tatra Mts (Poland)	–	0.08–0.12	Unmanaged conifer temperate	60–62	–	Zielonka et al. (2009)
Costarica (La Selva biological station)	3.1–8.3	0.002–0.08	Tropical	44–113	41–612	Cadol et al. (2009)
New Zealand (all country)	3.0–4.8	0.02–0.10	Mature mixed/conifer	18–66	92–361	Meleason et al. (2005)
New Zealand (North Island)	1.5–2.7	0.03–0.27	Old-growth deciduous	36	–	Baillie et al. (2008)
Rocky Mts (Colorado, USA)	0.7–2.4	0.03–0.10	Old-growth conifer temperate	10–120	–	Ryan et al. (2014)
Rocky Mts foothills (Alberta, Canada)	0.8–3.6	< 0.05	Mature boreal	52–100	90–290	Jones et al. (2011)
Swiss Alps and piedmont	–	–	Second-growth conifer temperate	–	58–178	Rickli et al. (2018)
Western Carpathians (Czech Rep.)	2.0–2.9	0.16–0.28	Second-growth mixed temperate	30–59	26–305	this study

(ii) Instream wood including less-restricted criteria

Location	Wood criteria limits	Channel width (m)	Channel gradient (m/m)	Forest cover	Wood frequency n/100 m	Wood volume m^3/ha	References
Alaska (USA)	0.5 × 0.1 m	0.6–3.7	0.09–0.45	Boreal managed and unmanaged	4–66	–	Gomi et al. (2001)
Coastal Ranges (NW USA)	0.5 × 0.1 m	0.9–3.6	0.05–0.32	Managed mixed/conifer temperate	62	–	Jackson and Sturm (2002)
Big Horn Mts (Wyoming, USA)	0.5 × 0.1	4.4	0.007	Second-growth conifer temperate	–	12	Nowakowski and Wohl (2008)
Eastern Alps (Italy)	0.5 × 0.05 m	2.8–3.3	0.28–0.38	Second-growth mixed temperate	–	71–93	Rigon et al. (2012)
Iberian Peninsula (northern Spain)	all wood	2.8–3.9	0.06–0.09	Mature deciduous temperate	–	97–187	Díez et al. (2000)
Iberian Peninsula (northern Spain)	diameter > 0.01 m	2.5–4.4	0.03–0.41	Indigenous -deciduous mixed	–	2–235	Díez et al. (2001)
Iberian Peninsula (Portugal)	0.5 × 0.05 m	2.0–4.9	–	Mediterranean recently affected by wildfire	11–13	12–27	Vaz et al. (2013)
Scandinavia (Sweden)	0.5 × 0.05 m	1.4–2.6	0.03–0.11	Unmanaged boreal	35–98	38–154	Dahlström and Nilsson (2004)
Scandinavia (Sweden)	0.5x0.05 m	0.7–3.1	0.03–0.14	Managed boreal	6–73	6–47	Dahlström and Nilsson (2004)
South Tasmania (Australia)	0.2 × 0.02 m	0.8–1.3	0.15–0.21	Unmanaged eucalyptus	100	37	Burrows et al. (2012)
South Tasmania (Australia)	0.2 × 0.02 m	0.6–2.4	0.07–0.22	Recently harvested eucalyptus	560	1042	Burrows et al. (2012)
Western Carpathians (Czech Rep.)	1 × 0.05 m + 0.5 × 0.1 m	2.0–2.9	0.16–0.28	Second-growth mixed temperate	73–105	42–312	this study

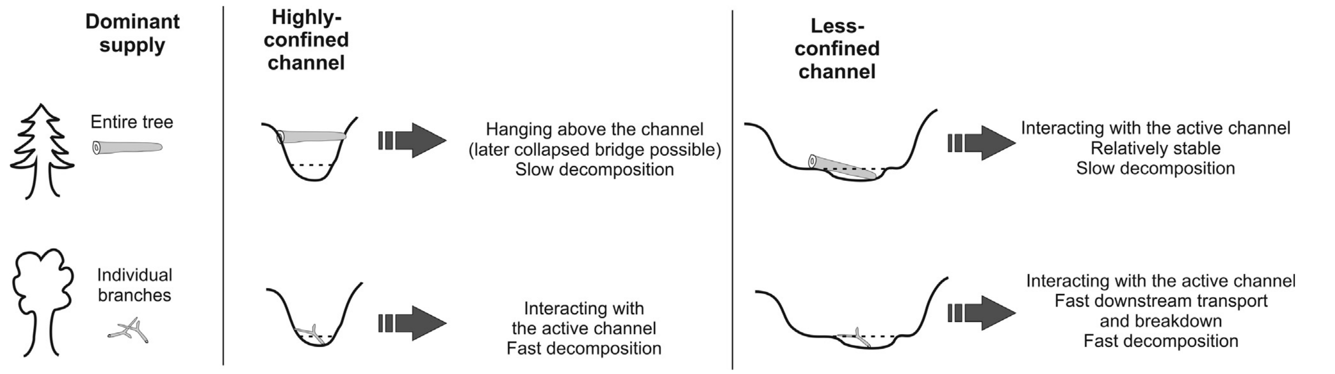

Fig. 9. Conceptual model of LW and SW abundance and stability based on conifer/deciduous tree species and valley confinement. The dashed line indicates bankfull water level.

confinement in small Appalachian headwaters. The authors emphasised only the role of forest stand.

5.3. Small and large wood attributes and their potential of geomorphic function in small headwater streams

Small wood tends to affect geomorphic processes primarily in small, confined headwaters under canopy dominated by deciduous trees. The smaller ratio observed between LW and SW active-channel volumes per 100-m channel length in the more confined Mazák 2 (5.7) and Mazák 3 (1.7) streams, where forest is dominated by deciduous trees, was reflected in a higher frequency of morphological steps (height ≥ 0.3 m) created by SW (as compared to those created by LW in the same streams). This implies that SW pieces are able to act as 'key pieces' forming steps in very narrow channels. Quite comparable proportion of LW and SW steps was observed in some Alaskan steep headwaters by Gomi et al. (2003). Frequent SW steps were also documented in a confined headwater located in a Carpathian beech forest (Přibyla et al., 2016) and in first- and second-order streams of the Pacific Northwest (Jackson and Sturm, 2002). These observations suggest the importance of SW in steep, narrow headwaters with relatively low discharges for flow energy dissipation, upstream sediment deposition or for the development of pools related to these steps. In addition, although SW is perceived to be relatively short by its definition, LW and SW spanned a similar proportion of the active channel width in the case of the Mazák streams (Fig. 5). In Carpathian deciduous forests dominated by *F. sylvatica*, the importance of SW has been documented through the formation of intermittent dammed pools in small headwaters, in which their occurrence was directly related to leaf litter accumulation on SW pieces spanning the narrow channel (Přibyla et al., 2016). Such forced step-pool morphologies do not only increase flow resistance and water storage in headwater channels from autumn to spring, but also lead to the deposition of significantly finer sediments in pools dammed by SW and leaf litter as compared to common scour pools downstream boulder steps. By contrast, the geomorphic potential of LW pieces may decrease in narrow, confined channels due to the fact that LW pieces will more likely span these channels above their bankfull depth without having any geomorphic effect (Chen et al., 2006; Baillie et al., 2008; Jones et al., 2011).

Small wood was mostly unattached (56.5%), which together with its relatively small dimensions predetermine SW for more frequent transport than LW (Fig. 6). Orientations close to 0°or 180° are common for instream pieces affected by fluvial transport (Montgomery et al., 2003; Chen et al., 2008). In general, we observed a higher proportion of LW strictly oriented parallel to the flow than reported in other regions, such as e.g. the Canadian part of the Rocky Mts. foothills (Jones et al., 2011) or low-order Alpine streams of Italy (Comiti et al., 2006). We argue that our observations may reflect the high-intensity bed material transport as typical in flysch Carpathian headwaters (Galia et al., 2015; Galia and Škarpich, 2016), which also affects the mobility and orientation of instream wood and thereby resulted in a high proportion of both LW and SW pieces to be orientated parallel to the flow direction. This was also documented for cross-dated pieces with long residence times in the Mazák streams, as these were more frequently orientated parallel to the flow direction – irrespective of their length – as compared to wood pieces with shorter residence times in the fluvial system (Galia et al., 2017).

We observed a relatively small proportion of jams (1.5–2.7 in average per 100 m channel length) with the higher frequencies of jams being concentrated in more confined streams with a higher proportion of deciduous canopy in the valley corridor (Mazák 2 and Mazák 3). For comparison with other small headwaters, Costigan et al. (2015) reported 2–5 jams per 100 m channel length in the Appalachian Mts, whereas Díez et al. (2000) calculated a frequency of 2–4 jams per 100 m channel length in headwaters of Iberian streams dominated by deciduous forests. We did not notice considerable amounts of sediments stored upstream of these jams, and this is most likely due to their low assumed stability as they usually consisted only from a few LW and SW pieces. A high intensity of bedload transport in local, flysch-dominated streams may decrease stability of these jams as well. One exception occurred in Mazák 1b, where small debris flow capable of transporting relatively large instream wood pieces probably induced the development of the very large wood jam in 1930 s (Fig. 1) (Šilhán et al., in press). Unfortunately, we were not able to accurately calculate sediment deposition volumes upstream this jam since the jam is closely linked to former debris-flow deposits.

6. Conclusions

We documented in this study that tree species composition in valley corridors directly affects instream wood frequency and volume, even in the case of small headwater channels. According to our results, small wood is abundant in narrow, confined mountain streams, even more so under deciduous forest canopy, where the continuous supply of individual branches affected SW loads in a positive manner. However, stability of SW decreases with increasing channel width and valley confinement. The increased number of conifers – at the expense of deciduous trees in the valley corridor – was a relevant variable for LW volume, as conifers tend to supply wood of larger dimensions (usually entire trees) with smaller decay rates to the streams. We also realize that the number of observed instream wood pieces per channel length in a typical Carpathian forest was similar or slightly lower than that reported for other regions, but that two of the analysed, less-confined channel reaches showed very high active-channel volumes per channel area owing to their relatively narrow channel widths and the presence of slow-decaying coniferous LW.

We also argue that the potential geomorphic role of SW in narrow headwaters may have been underestimated in previous works, as the abundance of SW and potential geomorphic functions can be comparable to that of large wood. Hence, the size of structurally important wood pieces should be scaled by channel dimensions or by dominant forest canopy. This is why we call for further research of both large and small wood inventories and for the testing of the obtained relations in confined and unconfined headwater streams in other regions and under various forest canopy and management situations.

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