LANDSLIDE-INDUCED CHANGES OF VESSEL SHAPE IN *BETULA PENDULA* ROTH. – A PRELIMINARY STUDY

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ABSTRACT

Investigation of relationship between vessel structures and exogenous geomorphic processes like landslides, rockfalls, debris flows as well as snow avalanches are common in present dendrogeomorphology. However, very little is known yet about change of the shape characteristics of vessels of *Betula pendula* as a result of different mass movements.

Analysis of vessel lumen length (LL) and width (LW) change on 49 microsections prepared from 15 landslide-disturbed-birches was the goal of this study. A relationship between LW and LL was reported for the year before (2010) and after (2011) landslide separately using equation of linear regression. To evaluate inter-annual variability of changes in shape parameters of tracheas, the proportions of LW and LL in year 2009 was also described for 8 disturbed trees. Slope of the regression line very well characterizes the relationship between LW and LL and evaluation of inter-annual change between LW and LL was carried out based on annual change index (ACI). ACI was defined as a value of percentage change in the slope of the regression lines before and after the landslide disturbance.

There is statistically significant change in vessel shape parameters between the years 2010 and 2011. Overall, the highest values of ACI were calculated in microsections sampled in the direction of slope distribution – side of reaction wood production, where $ACI_{2010/11}$ average value was higher than 43% which is twice more than values from other samples. Increasing of isodiametricity is also typical, while it was found at 65% of analysed disturbed samples.

Key words: mass movements, dendrogeomorphology, *Betula pendula*, wood anatomy, vessel

1. Introduction

Numerous geomorphic events and processes have significant impacts on trees and leave permanent signs within the wood anatomy (Schweingruber 1996). These signals, manifested as variations in tree-ring widths, as well as structural modifications of the wood mass, allow us backward reconstruction of the beginning, duration, scope and frequency of many geomorphic processes (Sass and Eckstein 1995; Strunk 1997). Since 1960s, tree-ring analysis have been used as a leading method of climate reconstruction, environmental changes analysis, and geomorphic processes – such as debris flows, landslides, rockfalls and snow avalanches – dating (Alestalo 1971; Braam et al. 1987; Schweingruber 1996; Lang et al. 1997, etc.). The recent studies focus on wood anatomical reactions (variations in tension or compression wood, varying vessel sizes and numbers) and application of wood anatomical techniques to study additional information of severity and intensity of past impacts on tree growth (Stoffel et al. 2005b; Perret et al. 2006; Casteller et al. 2007; Heinrich and Gärtner 2008; Schneuwly and Stoffel 2008; Gärtner and Heinrich 2009; Sorg et al. 2010; Bollschweiler et al. 2010; Corona et al. 2010; Bollschweiler et al. 2011; Casteller et al. 2011; Lopez Saez et al. 2011, etc.).

Although dendrogeomorphology is worldwide method used for analysis of many geomorphic processes the vast majority of published studies focus on species of spruce – *Picea* (Casteller et al. 2007; Perret et al. 2006; Bollschweiller et al. 2007 and others), larch – *Larix* (Stoffel et al. 2005a, 2005b; Schneuwly and Stoffel 2008; Corona et al. 2010 and others), pine – *Pinus* (Santilli and Pelfini 2002; Muntán et al. 2009; Bollschweiler et al. 2010; Lopez Saez et al., 2011 and others), firs – *Abies* (Yoshida et al. 1997; Bollschweiler et al. 2010; Köse et al. 2010) and deciduous trees, house beech – *Fagus* (Šilhán and Pánek 2008; Van Den Eeckhaut et al. 2009; Burda 2010; Žížala et al. 2010 and others), oak – *Quercus* (Fantucci and Sorriso-Valvo 1999; Stefanini 2004; Moya et al. 2010 and others), or maple – *Acer* (Daňhelka 2001; Šilhán 2010 and others). Selection of analysed trees or examined species is given by geographical conditions of the habitat, which directly determine the growth of individual species. It is noteworthy that the surveys based on analysis of birch species (*Betula*) are sporadic in published studies, mainly because it has very difficult anatomy of wood, which results in poor visibility of its tree-rings. From number of dendrogeomorphological mass movements' studies this species was used by Casteller et al. (2007); Decaulne and Sæmundsson (2008); Arbellay et al. (2010); Szymczak et al. (2010) and Decaulne et al. (2012).

The recent trend in dendrogeomorphology focuses on describing of the relationship between changes in the environment and the size, spatial distribution and the shape of vessels. For example, the information about the history of inundations (Kozlowski 1997) and flash floods (Ballesteros et al. 2010; Tardif et al. 2010; George 2010) is present in changes of Vessel Lumen Area (VLA) and

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spatial distribution of vessels in the tree-ring. Both processes mentioned above usually tend to the formation of larger number of smaller tracheas (Kozlowski 1997; Ballesteros et al. 2010; George et al. 2010). Changes in size, shape and spatial distribution of vessels were also used to identify the year of root exhumation caused by erosion (Hitz et al. 2008) or for debris-flow activity reconstruction (Arbellay et al. 2010, 2012). The aim of this preliminary study was to test the potential of *Betula pendula* Roth. trees to reconstruct past landslide activity in anthropogenic mining landscapes as well as outline of future research needs. Hence we tested the possibility of using shape parameters of vessels of inclined *B. pendula* trees in order to describe its changes before and after the landslide.

Anthropogenic relief of Most Basin (Czech Republic), intensively formed from the second half of the 20th century, was chosen as an ideal model locality for this research (Figure 1). Extensive areas of dump bodies, heaps and abandoned open-pit mines are the places of evolution of a number of new geomorphologic landforms. These areas remain aside of interests the professional and lay public very often, which also means aside research or monitoring. Numerous slope deformations, many of which have not been mapped or not further investigated, evolved in the past in these areas (e.g., landslides on dumps).

Except for reclaimed areas there were many sites left to natural succession, therefore many of these sites are dominated by self-seeded tree species, especially Silver Birch – *B. pendula* (Lipský 2006). Dendrogeomorphological investigation of *B. pendula* is one of few possibilities of retrospective research of the dynamics and scope of geomorphic processes and exact dating of newly evolved landforms.

2. Material and methods

Twenty Silver Birches were selected for purposes of this dendrogeomorphological experiment in the area of Jezeří landslide (Figure 1). Overall morphology, morphometry as well as triggering factors and landslide evolution were described by Burda et al. (2013). The self-seeded forest stand (8–18yr old) was damaged during the main movement activity in 15 January 2011 (Figure 2), which means before the beginning of growing season.

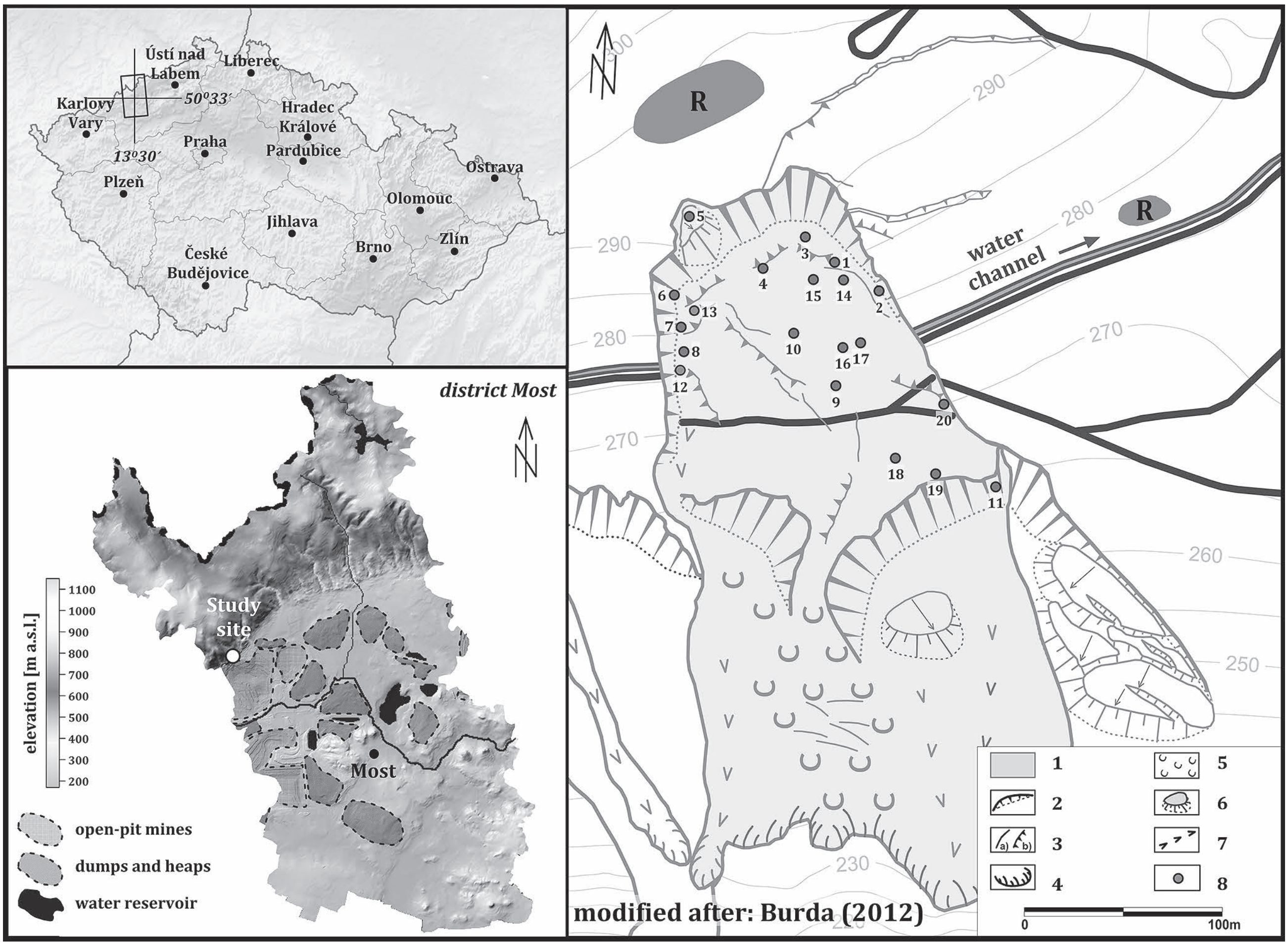


Fig. 1 The experimental research area (right) is located in the edge of Most basin in the Most town district (bottom left) in the northwest of the Czech Republic (top left). The position of sampled trees is shown in the geomorphology sketch map (right): 1 – investigated January 2011 landslide; 2 – headscarps; 3 – (a) tension cracks, (b) tension cracks with vertical offset; 4 – accumulation toes; 5 – accumulation surfaces of landslides; 6 – landslide blocks within the landslide complex; 7 – earthflows; 8 – selected trees; R – reference group

In the study site, we selected trees with different degree and type of macroscopic deformations, four different disturbed groups (T1 to T3) and one undisturbed reference group (R) were set up (Figure 3). Figure 2 shows the positions of all of the 20 sampled disturbed trees. From the sampled trees, 11 stem discs were sawn and polished (nos. 1–11) and 9 increment cores were extracted from rest 9 trees (nos. 12–20). Increment cores were drilled trough the stem in B–D direction that corresponds to the direction of slope disturbance (Figure 4). Other 10 cores were extracted from 10 undisturbed trees near the landslide area (Figure 1). We used these samples as a reference group for comparison to disturbed groups (T1, T1er, T2 and T3) and as these trees are situated in the flat relief, the exact determination of directions A–D lose the sense. Because the reference group should represent the common behaviour of undisturbed trees we artificially set these samples as A–C directions because we expect, that cores coming from disturbed trees in respective direction will record no or very low changes caused by tension (direction B) or compression (direction D) resulting from stem inclination. The field-work was performed during August and September 2011.

Both stem discs and increment cores were extracted at the height of stem curvature whenever possible, otherwise at breast height (~130 cm). The position, macroscopic stem defects (angle of inclination, stem curvature, etc.), local morphology and position of each sample were recorded.

According to Schweingruber et al. (2008), the stem sections and increment cores were cut into 20 μm thick transverse microsections using GSL 1 core-microtome. Four microsections (A–D) were prepared from each stem disc and two (in respective directions) from each increment core; subsequently stained using Safranin and AstraBlue in order to increase the contrast between lumens and walls of vessels. The preparation of microsections from birch proved to be very complicated process due to the high hardness of xylem. Particularly in the case of increment cores it was often impossible to saw a microsection of sufficient quality for subsequent image analysis. Therefore we were able to prepare 49 microsections from 15 disturbed trees and 18 microsections from 9 reference trees.

2.1 Variations in vessels parameters

In this experimental research, we focused on measurement of parameters of shape of vessels and its changes after the slope disturbance. The measurement was performed using the WinCell Pro 2011a software (Regent Instrument Inc.) and vessel parameters were analysed in two years; in the year preceding the slope disturbance (2010) and the year after landslide (2011). We also measured vessels in tree-rings formed in 2009 to compare inter-annual variability of trachea shapes; unfortunately the difficulties with preparing samples of birch wood with appropriate quality limited this only to microsections coming from 8 disturbed cross-sections. The proper measurement was performed from microimages of anatomical structure of the xylem captured in 40× magnification using digital camera and light microscope.

Unlike other studies, which also investigated the relationship between structure of vessel elements and exogenous factors (e.g., Arbellay et al. 2010, 2012; Ballesteros et al. 2010; Kames et al. 2011) and which are most focused on Vessel Lumen Area changes, in our case much more attention was paid to the shape characteristics of vessels (i.e., mainly the length and width of vessels and their mutual relationship). As some studies (e.g., Gonzáles and Eckstein 2003) pointed out the strong influence of spring precipitation on VLA in a specific tree-ring, difficulties with filtering this climatic effect can occur in applications of VLA as pointer of the geomorphological disturbance. Although strong positive correlation between VLA and diameter of the vessel has been documented (Arbellay et al. 2010), climate probably can have only a very limited influence on the ratio between perpendicular diameters of lumens, which are further analysed and discussed.

The WinCell software can understand the concept of width and length in different ways, depending on the user settings – in our case, the length of the vessel lumen (LL) was defined as the longest possible connecting line of lumen borders and width (LW) as the longest possible connecting line perpendicular to the LL (Figure 4). So always LW < LL, only in the case of regular geometric shapes (circles, squares) is LW = LL (Figure 4).

A relationship between LW and LL is reported for each year (2010, 2011 and for some samples also 2009) and each sample separately using developed equation of linear regression based on all vessels that were measured in the annual ring (after manual exclusion of outliers). Slope of the regression line very well characterizes the relationship between LW and LL in the annual ring. It is in addition to our hypothesis, that inter-annual rate of percentage change in slope of the regression lines is a good indicator of the possible effect of external disturbance (Figure 5). Evaluation of inter-annual change between LW and LL was carried out based on annual change index (*ACI*). ACI was defined as a value of percentage change in the slope of the regression lines before and after the landslide disturbance.

$$ACI = 100 \cdot \left| \frac{slope\ (2011)}{slope\ (2010)} - 1 \right|$$

Respective form of equation above was used also for describing changes of the vessel shapes between years 2009 and 2010. Various differences in ACI between reference and disturbed trees and also between different orientations of sample around the stem have been described by means of statistical procedures described e.g., by Hendl (2009). To test the significance of annual changes in

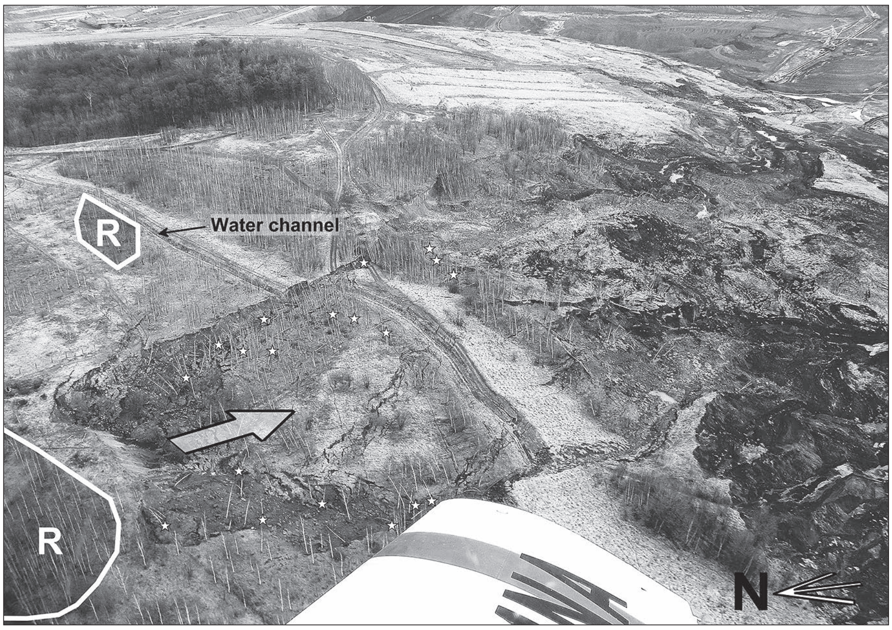


Fig. 2 Aerial view on the study site with marked position of selected trees; R – reference group (foto: J. Burda, 2011)

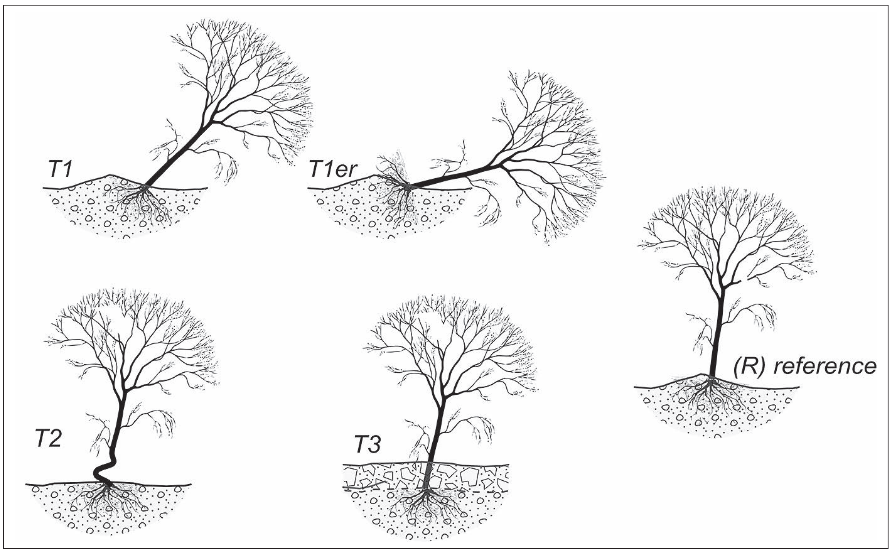


Fig. 3 Basic groups of macroscopic stem defects found in the study site: T1 – stem tilted from vertical direction; T1er – stem tilted from vertical directions and with exposed roots; T2 – significant stem curvature; T3 – buried stem; R – undisturbed tree

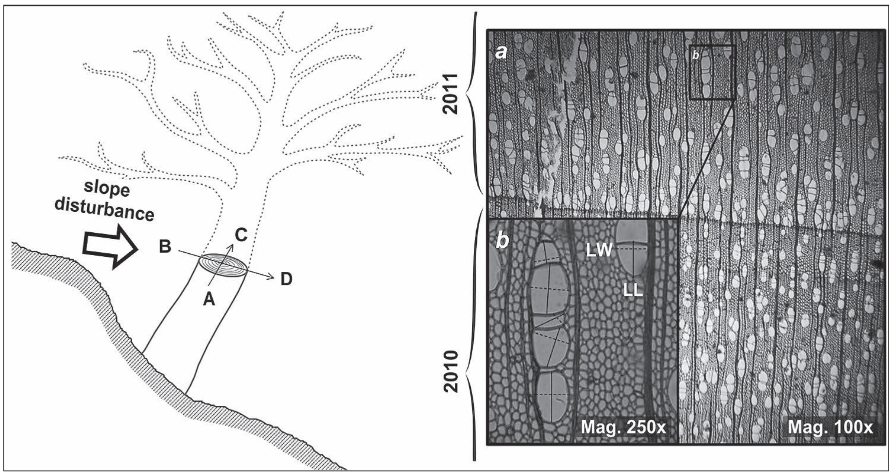


Fig. 4 A method of sampling strategy in respective directions (left). Micro-photo of anatomical structure of xylem of *B. pendula* (right). Solid lines represent orientations of measurement of LL, dashed lines orientations of measurement of LW (a – approximate magnifications 100×, b – Approximate magnifications 250×)

slopes, non-parametric tests of mean (Wilcoxon test, Sign test) were used. Differences in ACI values among 4 directions of sampling were tested with One-way ANOVA (and subsequent post-hoc tests).

3. Results

In total, 67 microsections from 24 trees of *B. pendula* specie were analysed in order to describe parameters of shape of vessels. From these, 8236 vessels were measured (in tree-rings 2010 and 2011), which corresponds to an average of about 340 vessels per tree and 123 vessels per sample. In general, more vessel elements were measured on disturbed samples (134 per sample) and substantially less on reference samples (102 per sample). This is mainly due to larger surface of microsection prepared from the stem section than from the increment core.

3.1 Variations in vessel parameters

Calculated values of $ACI_{2010/11}$ fluctuated between 1 to 85.3% in disturbed trees and in the range from 1 to 70.3% in undisturbed trees. The distribution of $ACI_{2010/11}$ values for disturbed group is very similar in A, C and D directions; the most of calculated $ACI_{2010/11}$ values is lower than 20% (Figure 6), that is also reflected in $ACI_{2010/11}$ average values (Figure 7). The $ACI_{2010/11}$ exceeds 60% only in one case which relationship to the distribution of other observations showed the character of remote observation (outlier), and was therefore excluded from further analysis. $ACI_{2010/11}$ averages for samples A, C and D are 21.1%, 21.7% and 26.2%. Similar values, but with more uniform distribution (Figure 6 and Figure 8), were found in both directions (A and C) of reference group. In these cases the $ACI_{2010/11}$ value did not reach 45%, higher value (70.3%) was found only in one sample and was excluded as an outlier.

The analysis of change of vessels shape parameters in the microsections prepared from samples B, which corresponds to the direction of slope deformation and the side of tension wood production, looks quite different. Most of the values of $ACI_{2010/11}$ is in the range of 30 and 50% with an average value of 43.7% (Figure 6 and Figure 8). In general, the values fluctuated between 1.1% and 85.3% – which is the highest identified value in the data set.

If we compare values of $ACI_{2009/10}$ and $ACI_{2010/11}$ in 8 selected disturbed trees, results indicate that changes in shapes of vessels are more significant after the landslide event comparing the year without slope activity. Average $ACI_{2009/10}$ (group of 8 disturbed trees) for A, B, C and D are 12.6%, 22.1%, 24.2% and 16.7%; $ACI_{2010/11}$ values in respective directions are generally slightly higher: 22.5%, 53.3%, 19.9% and 26.2%. Only in the case of ACI values in direction C, there is small decrease of their level. Although 6 of samples from this orientation record very small values of $ACI_{2009/10}$ (below 15%), the result is strongly influenced by one tree (no. 4) with $ACI_{2009/10}$ almost 95% (Figure 9). If we exclude this observation as an outlier, the average value will decrease from 24.2% to 14.1%.

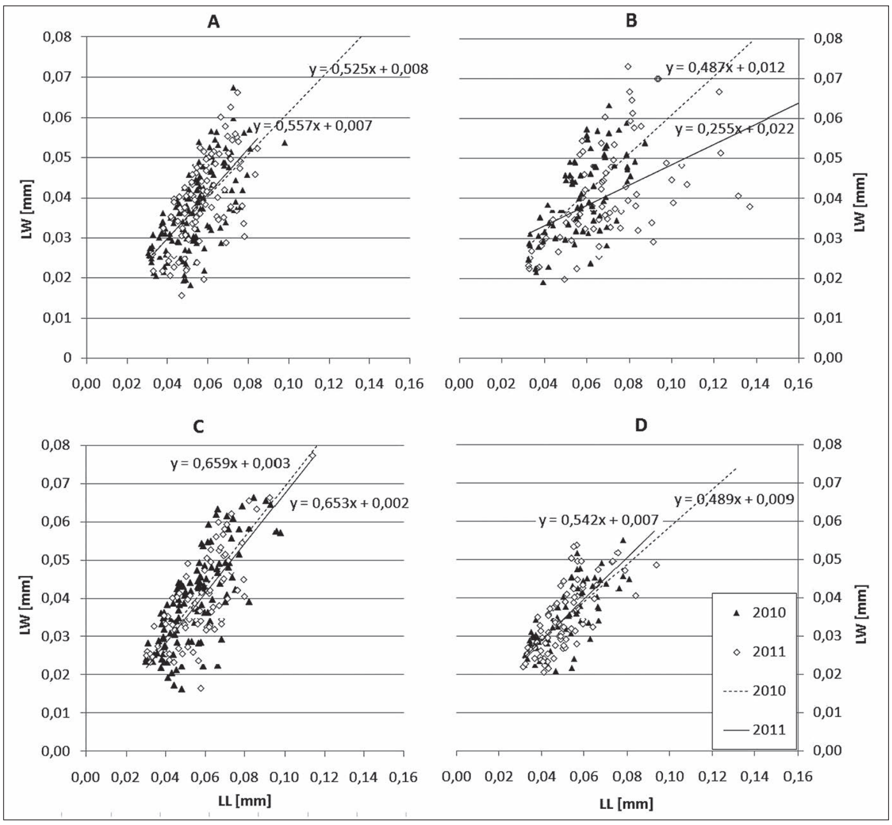


Fig. 5 Charts of LW–LL relations for vessels from disturbed tree no. 11

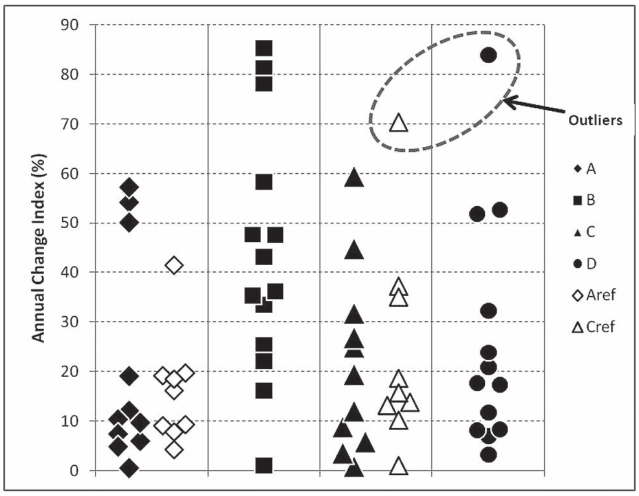


Fig. 6 $ACI_{2010/11}$ values for individual samples with respect to their category (reference or disturbed) and position around the stem circumference

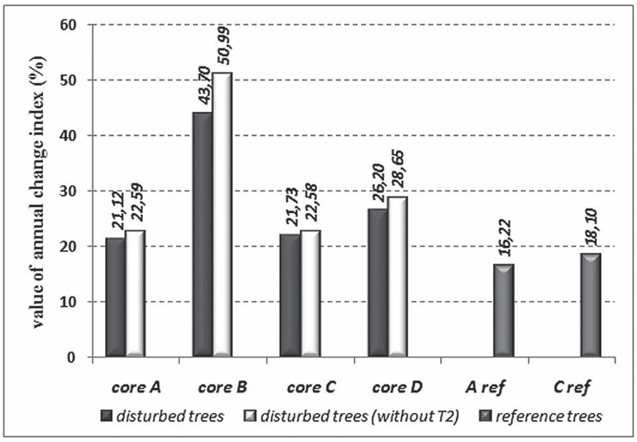
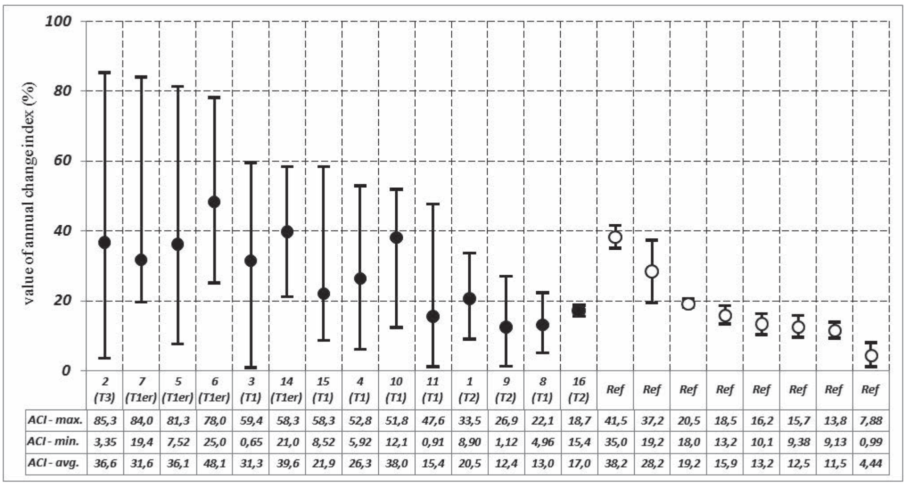


Fig. 7 Average values of annual change index ($ACI_{2010/11}$) for respective directions of disturbed and undisturbed trees as well as with excluded trees from T2



	2 (T3)	7 (T1er)	5 (T1er)	6 (T1er)	3 (T1)	14 (T1er)	15 (T1)	4 (T1)	10 (T1)	11 (T1)	1 (T2)	9 (T2)	8 (T1)	16 (T2)	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
ACI - max.	85,3	84,0	81,3	78,0	59,4	58,3	58,3	52,8	51,8	47,6	33,5	26,9	22,1	18,7	41,5	37,2	20,5	18,5	16,2	15,7	13,8	7,88
ACI - min.	3,35	19,4	7,52	25,0	0,65	21,0	8,52	5,92	12,1	0,91	8,90	1,12	4,96	15,4	35,0	19,2	18,0	13,2	10,1	9,38	9,13	0,99
ACI - avg.	36,6	31,6	36,1	48,1	31,3	39,6	21,9	26,3	38,0	15,4	20,5	12,4	13,0	17,0	38,2	28,2	19,2	15,9	13,2	12,5	11,5	4,44

Fig. 8 Fluctuation of $ACI_{2010/11}$ values in individual trees; maximal, minimal and average ACI values have been plot for every single tree separately

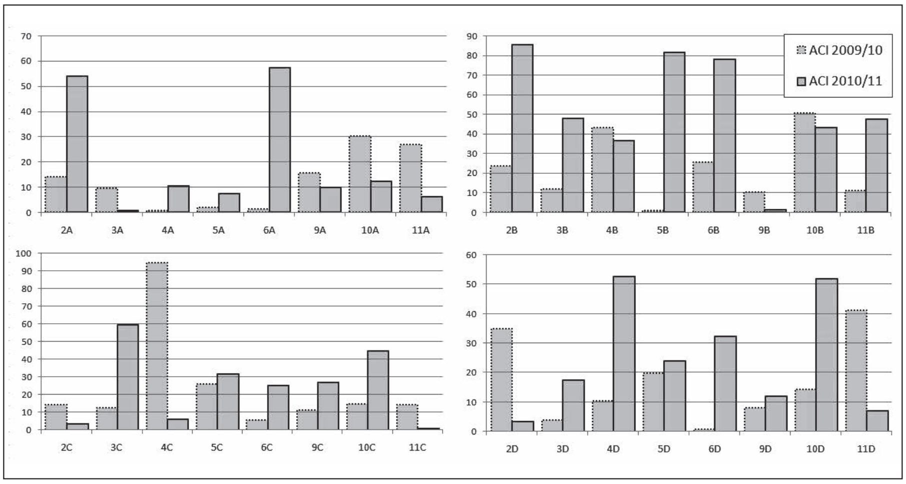


Fig. 9 Comparing of $ACI_{2009/10}$ and $ACI_{2010/11}$ for cross-sections coming from 8 disturbed trees

3.2 The relationship between the values of slope of the regression lines in 2010 and 2011

While in the case of disturbed trees, differences between the slope of regression line in years before and after the event were clearly demonstrable (p-value < 0.001 in both tests), no significant change occurred in reference trees (p-values 0.814 respectively 0.711). ANOVA analysis also pointed (p-value 0.0459), the $ACI_{2010/11}$ is different when it is calculated at disturbed trees in different directions in relation to the effect of slope movement. As it was already mentioned above, the highest is in the direction B, i.e. in the direction similar to the slope disturbance. The second highest values (26.2%) of $ACI_{2010/11}$ were found in the opposite direction (D), while the lowest and almost identical values were found in the directions perpendicular to the slope disturbance (A and C). The post-hoc test (LSD test) documented significant difference of $ACI_{2010/11}$ values calculated in the direction B comparing to other directions, among which there is no demonstrable difference. On the contrary, in the case of reference trees, the differences between the $ACI_{2010/11}$ values measured in different directions are not statistically significant (p-value 0.344).

The direction of change in the slope of the regression line (i.e. whether there was increase or decrease in vessels' isodiametricity after the landslide) was significantly represented by both possibilities in analysed microsections. In microsections from disturbed trees, 32 samples of vessels' isodiametricity increase was observed after the slope disturbance, which is almost twice as much in comparison to isodiametricity decrease – formation of asymmetric vessels (17 samples). The situation is quite balanced in reference group where 10 samples show isodiametricity increase and 8 samples decrease. From these results, there is no clear pattern of these changes with respect to the direction of the slope disturbance.

4. Discussion

Slope of the regression line defining the relationship between LW and LL has a positive value in all analysed samples before as well as after the landslide (minimum value recorded before the landslide was 0.16 and 0.18 after the landslide). This is consistent with the findings of Arbellay et al. (2010), who pointed out the positive correlation of these characteristics of vessels parameters (LL and LW) to each other as well as to the VLA. This means that with increasing vessel' cross-section also both dimensions grow and *vice versa*. In this preliminary study, the decrease of both vessel' shape characteristics (LL and LW) was most common in the year after the landslide (2011) and LL decrease was slightly higher comparing to LW decrease. Due to the fact that LL ≥ LW, such a change leads just to isodiametricity increase, which was documented twice more than isodiametricity decrease. Similar character and trend of changes were documented on smaller statistical sample of seven birches scarred by debris-flow (Arbellay et al. 2010) – average observed LL decrease was 26% while LW decrease was 22%. Although landslides impact the tree with much less energy than fast motions of debris and inclination and scarring probably have partially different response in physiology and anatomy of the wood, these findings suggest that the vessels longer diameter (LL) of *B. pendula* species (which usually corresponds to approximate radial orientation; Figure 4) is more susceptible to disturbance-induced changes than the tangential diameter (LW). The same relationship between exogenous disturbance-induced changes in LL and LW were found also in other deciduous species – such as *Alnus glutinosa* (L.) Gaertn., *Fraxinus angustifolia* Vahl. and *Quercus pyrenaica* L. (Ballesteros et al. 2010).

The relatively low $ACI_{2010/11}$ values observed in the reference trees within our study, as well as similar levels of $ACI_{2009/2010}$ of selected disturbed trees, show, that in the case of trees whose growth was not affected by external disturbances or environmental changes annual change of ratio between LL and LW is less significant. This is consistent with the fact that proportions of reference trees with increasing/decreasing isodiametricity between years 2010 and 2011 are very similar. Because all levels of $ACI_{2009/10}$ of disturbed samples and $ACI_{2010/11}$ of reference trees are below 23%, we can conclude, that the level of ACI below approximately 20% can be in case of *B. pendula* (usually) driven by non-geomorphological causes (e.g., ageing, climate) or possible inaccuracy of measuring and statistical process. Conversely, $ACI_{2010/11}$ values significantly higher in the category of disturbed trees are probably direct consequence of inclination caused by mass-movement event. Some differences in $ACI_{2010/11}$ values were found also between individual disturbed groups (Figure 8). In general, tilted trees with exposed and damaged root system (T1er) show high fluctuation of $ACI_{2010/11}$ values in respective directions and in direction of slope disturbance, the values of $ACI_{2010/11}$ were overall some of the highest detected (58–84%). Similar situation is in the group of trees tilted from the vertical direction (T1) with the difference, that maximal values of found $ACI_{2010/11}$ did not reach 60%. The highest found $ACI_{2010/11}$ value as well as the highest $ACI_{2010/11}$ fluctuation was found in tree no. 2 (T3 – buried stem). $ACI_{2010/11}$ maximum (in direction B) was 85.3%, but we were able to prepare microsections only from one single tree from T3 group and therefore this value has character of unproven observation. Remarkable fact is that among disturbed trees there were found tree examples (nos. 1, 9 and 16 all from T2) with very low $ACI_{2010/11}$ values; rather similar to the reference group (Figure 8). These trees were slightly tilted from vertical direction (to 10°) with significant stem curvature (no. 1 – S-shape, no. 2 – "pistol" butted and no. 16 – "candelabra" form) and so it is obvious trees were only transported within the compact landslide block during the main movement activity. Macroscopic stem deformation, which was the main reason for inclusion of these trees into research, occurred before the landslide initiation more probably as a result of strong heliophilicity of birch or due to other disturbances. If we exclude these three trees from ACI analysis, calculated average values of $ACI_{2010/11}$ increase by 1 to 2.5% in A, C and D directions, but to 51% in direction B (Figure 7). This fully supports above mentioned results, that the landslide was significantly reflected by $ACI_{2010/11}$ in the direction similar to the slope disturbance.

5. Conclusion and future research needs

We tried to analyse suitability of birch in mass movement studies in this preliminary study. In total 67 microsections were prepared from 24 trees of *B. pendula* specie selected in the area of a landslide from January 2011. We focused on vessel parameters variations (LL – lumen length and LW – lumen width) between two years, the year before landslide (2010) and in the year of landslide event (2011). This relationship is expressed by the equation of regression line. Overall 8236 vessels were analysed and an annual change index (ACI) was calculated in order to describe percentage change in the slope of the regression line. ACI was calculated for each sample from each tree.

The results show that there is statistically significant change in vessel size parameters between the years 2010 and 2011. The highest values of $ACI_{2010/11}$ were calculated in samples B (direction similar to the slope distribution and side of reaction wood production), where the average value was higher than 43% which is twice more than values from other samples (directions A, C and D). Increase of isodiametricity (reduce of the asymmetry) was found at 65% of analysed disturbed samples (of total 49). No such trend was found at reference samples. ACI values are substantially lower for reference trees as well for group of disturbed trees between years 2009 and 2010. We suppose, that average annual value of ACI around 20%, which was typical for both reference group and $ACI_{2009/10}$, can't be interpreted as a direct consequence of landslide event but is more probably caused by (i) other natural influences or (ii) inexact measuring process. In both situations, great challenges for future research occur – either identifying non-geomorphological cause(s) of slight ACI change (weather?; tree ageing?) or improvement of the sampling, measurement and statistical evaluation. Highest values of $ACI_{2010/11}$ were found at the tress inclined from vertical and with exposed roots, which means in trees with strongest exogenous disturbance. For a more accurate assessment of the potential (in)dependence of exogenous disturbance (macroscopic defects) and ACI value it would be appropriate to analyse more samples from trees from different landslide affected localities. There is also an assumption that after disturbance of different severity vessel shape parameters will return to pre-landslide level with different lags. If we quantify these lags, we could be able to reconstruct additional information about intensity of old prehistoric landslides.

Acknowledgements

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REFERENCES

ALESTALO, J. (1971): Dendrochronological interpretation of geomorphic processes. Fennia 105, 140 p.
ARBELLAY, E., FONTI, P., STOFFEL, M. (2012): Duration and extension of anatomical changes in wood structure after cambial injury. Journal of Experimental Botany 63(8), 3271–3277.
ARBELLAY, E., STOFFEL, M., BOLLSCHWEILER, M. (2010): Dendrogeomorphic reconstruction of past debris flow activity using injured broad-leaved trees. Earth Surface Processes and Landforms 35, 399–406.
BALLESTEROS, J. A., STOFFEL, M., BOLLSCHWEILER, M., BODOQUE, J. M., DÍEZ-HERRERO, A. (2010): Flash-flood impacts cause changes in wood anatomy of *Alnus glutinosa*, *Fraxinus angustifolia* and *Quercus pyrenaica*. Tree Physiology 30, 773–781.
BOLLSCHWEILER, M., STOFFEL, M. (2007): Debris flows on forested cones – reconstruction and comparison of frequencies in two catchments in Val Ferret, Switzerland. Natural Hazards and Earth System Sciences 7, 207–218.
BOLLSCHWEILER, M., STOFFEL, M., EHMISCH, M., MONBARON, M. (2007): Reconstructing spatio-temporal patterns of debris-flow activity using dendrogeomorphological methods. Geomorphology 87, 337–351.
BOLLSCHWEILER, M., STOFFEL, M., VÁZQUEZ-SELEM, L., PALACIOS, D. (2010): Tree-ring reconstruction of past lahar activity at Popocatépetl volcano, México. The Holocene 20, 265–274.
BOLLSCHWEILER, M., STOFFEL, M., SCHLÄPPY, R. (2011): Debris-flood reconstruction in a pre-alpine catchment in Switzerland based on tree-ring records of coniferous and broadleaved trees. Geografiska Annaler Series 93, 1–15.
BRAAM, R. R., WEISS, E. J. J., BURROUGH, P. A. (1987): Spatial and temporal analysis of mass movement using dendrochronology. Catena 14, 573–584.
BURDA, J. (2010): Dendrogeomorfologická analýza dynamiky svahových pohybů v lokalitě Jezeří. Geografie 115, 440–460.
BURDA, J., HARTVICH, F., VALENTA, J., SMÍTKA, V., RYBÁŘ, J. (2013): Climate-induced landslide reactivation at the edge of the Most Basin (Czech Republic) – progress towards better landslide prediction. Nat. Hazards Earth Syst. Sci., 13, 361–374.
BURDA, J. (2012): Dynamics and spatial extension of recent landslides at the foot of Krušné Hory Mts. Dissertation thesis, Charles University in Prague, 173 p.
CASTELLER, A., STÖCKLI, V., VILLALBA, R., MAYER, A. C. (2007): An Evaluation of Dendroecological Indicators of Snow Avalanches in the Swiss Alps. Arctic, Antarctic and Alpine Research 39, 218–228.
CASTELLER, A., VILLALBA, R., ARANEO, D., STÖCKLI, V. (2011): Reconstructing temporal patterns of snow avalanches at Lago del Desierto, southern Patagonian Andes. Cold Regions Science and Technology 67, 68–78.
CORONA, CH., ROVÉRA, G., LOPEZ SAEZ, J., STOFFEL, M., PARFETTINI, P. (2010): Spatio-temporal reconstruction of snow avalanche activity using tree rings: Pierres Jean Jeanne avalanche talus, Massif de l'Oisans, France. Catena 83, 107–118.
DAŇHELKA, J. (2001): Dendrogeomorfologický výzkum sesuvné lokality u Čeřeniště. Geografie 106, 166–177.

DECAULNE, A., EGGERTSSON, Ó., SÆMUNDSSON, Þ. (2012): A first dendrogeomorphologic approach of snow avalanche magnitude–frequency in Northern Iceland. Geomorphology 167–168, 35–44.

DECAULNE, A., SÆMUNDSSON, Þ. (2008): Dendrogeomorphology as a tool to unravel snow-avalanche activity: Preliminary results from the Fnjóskadalur test site, Northern Iceland. Norwegian Journal of Geography 62, 55–65.

FANTUCCI, R., SORRISO-VALVO, M. (1999): Dendrogeomorphological analysis of a slope near Lago, Calabria (Italy). Geomorphology 30, 165–174.

GÄRTNER, H., HEINRICH, I. (2009): The Formation of Traumatic Rows of Resin Ducts in *Larix decidua* and *Picea abies* (Pinaceae) as a Result of Wounding Experiments in the Dormant Season. IAWA Journal 30, 199–215.

GEORGE, S. S. (2010): Dendrohydrology and Extreme Floods along the Red River, Canada. In: Stoffel, M., et al. (eds): Tree Rings and Natural Hazards: a state-of-art. Springer, 277–282.

HEINRICH, I., GÄRTNER, H. (2008): Variations in tension wood of two broad-leaved tree species in response to different mechanical treatments: implications for dendrochronology and mass movement studies. International Journal of Plant Sciences 169, 928–936.

HENDL, J. (2009): Přehled statistických metod zpracování dat. Portál, Praha, 696 p.

KAMES, S., TARDIF, J. C., BERGERON, Y. (2011): Anomalous earlywood vessel lumen area in black ash (*Fraxinus nigra* Marsh.) tree rings as a potential indicator of forest fires. Dendrochronologia 29, 109–114.

HITZ, O. M., GÄRTNER, H., HEINRICH, I., MONBARON, M. (2008): Wood anatomical changes in roots of European ash (*Fraxinus excelsior* L.) after exposure. Dendrochronologia 25, 145–152.

KÖSE, N., AYDIN, A., AKKEMIK, Ü., YURTSEVEN, H., GÜNER, T. (2010): Using tree-ring signals and numerical model to identify the snow avalanche tracks in Kastamonu, Turkey. Natural Hazards 54, 435–449.

KOZLOWSKI, T. T. (1997): Responses of woody plants to flooding and salinity. Tree Physiol. Monogr 1: 1–29.

LANG, A., MOYA, J., COROMINAS, J., SCHROTT, L., DIKAU, R. (1999): Classic and new dating methods for assessing the temporal occurrence of mass movements. Geomorphology 30, 33–52.

LIPSKÝ, Z. (2006): Proměna Kopistské výsypky na regionální biocentrum. Životné prostredie 40, 200–205.

LOPEZ SAEZ, J., CORONA, CH., STOFFEL, M., ASTRADE, L., BERGER, F., MALET, J.-F. (2011): Dendrogeomorphic reconstruction of past landslide reactivation with seasonal precision: the Bois Noir landslide, southeast French Alps. Landslides, 1–15.

MOYA, J., COROMINAS, J., PÉREZ ARCAS, J., BAEZA, C. (2010): Tree-ring based assessment of rockfall frequency on talus slopes at Solà d'Andorra, Eastern Pyrenees. Geomorphology 118, 393–408.

MUNTÁN, E., GARCÍA, C., OLLER, P., MARTÍ, G., GARCÍA, A., GUTIÉRREZ, E. (2009): Reconstructing snow avalanches in the Southeastern Pyrennes. Natural Hazards and Earth System Sciences 9, 1599–1612.

PERRET, S., STOFFEL, M., KIENHOLZ, H. (2006): Spatial and temporal rockfall activity in a forest stand in the Swiss Prealps – A dendorgeomorphological case study. Geomorphology 74, 219–231.

SANTILLI, M., PELFINI, M. (2002): Dendrogeomorphology and dating of debris flows in the Valle del Gallo, Central Alps, Italy. Dendrochronologia 20, 269–284.

SASS, U., ECKSTEIN, D. (1995): The variability of vessel size in beech (*Fagus sylvatica* L.) and its ecophysiological interpretation. Trees 9, 247–252.

SCHNEUWLY, D. M., STOFFEL, M. (2008): Spatial analysis of rockfall activity, bounce heights and geomorphic changes over the last 50 years – A case study using dendrogeomorphology. Geomorphology 102, 522–531.

SCHWEINGRUBER, F. H. (1996): Tree rings and Enviroment. Dendroecology. Biermersdorf, Swiss Federal Institute for Forest, Snow and Landscape Research. Berne, 609 p.

SCHWEINGRUBER, F. H., BÖRNER, A., SCHULZE, E.-D. (2008): Atlas of Woody Plant Stems. Evolution, Structure and Environmental Modifications. Springer Verlag, Berlin, Heidelberg, 229 p.

SORG, A., BUGMANN, H., BOLLSCHWEILER, M., STOFFEL, M. (2010): Debris-flow activity along a torrent in the Swiss Alps: Minimum frequency of events and implications for forest dynamics. Dendrochronologia 28, 215–223.

STEFANINI, M. C. (2004): Spatio-temporal analysis of a complex landslide in the Northern Apennines (Italy) by means of dendrochronology. Geomorphology 63, 191–202.

STOFFEL, M. (2008): Dating past geomorphic processes with tangencial rows of traumatic resin ducts. Dendrochronologia 26, 53–60.

STOFFEL, M., LIÈVRE, I., CONUS, D., GRICHTING, M. A., RAETZO, H., GÄRTNER, H. W., MONBARON, M. (2005a): 400 Years of Debris-Flow Activity and Triggering Weather Conditions: Ritigraben, Valais, Switzerland. Arctic, Antarctic, and Alpine Research 37, 387–395.

STOFFEL, M., SCHNEUWLY, D., BOLLSCHWEILER, M., LIÉVRE, I., DELALOYE, R., MYINT, M., MONBARON, M. (2005b): Analyzing rockfall activity (1600–2002) in a protection forest – a case study using dendrogeomorphology. Geomorphology 68, 224–241.

STRUNK, H. (1997): Dating of geomorphological processes using dendrogeomorphological methods. Catena 31, 137–151.

SZYMCZAK, S., BOLLSCHWEILER, M., STOFFEL, M., DIKAU, R. (2010): Debris-flow activity and snow avalanches in a steep watershed of the Valais Alps (Switzerland): dendrogeomorphic event reconstruction and identification of triggers. Geomorphology 116, 107–114.

ŠILHÁN, K. (2010): Dendrogeomorphology of spatio-temporal activity of rockfall in the flysh Carpathians: a case study on the western slope of Mt. Smrk, Moravskoslezské Beskydy Mts. (Czech Republic). Moravian Geographical Reports 18, 33–42.

ŠILHÁN, K., PÁNEK, T. (2008): Historická chronologie blokovobahenních proudů v Moravskoslezských Beskydech. Geomorphologia Slovaca et Bohemica 8, 82–94.

TARDIF, J. C., KAMES, S., BERGERON, Y. (2010): Spring Water Levels Reconstructed from Ice-Scarred Trees and Cross-Sectional Area of Earlywood Vessels in Tree Rings from Eastern Boreal Canada. In: Stoffel, M., et al. (eds): Tree Rings and Natural Hazards: a State-of-art. Springer, 257–261.

VAN DEN EECKHAUT, M., MUYS, B., VAN LOY, K., BEECKMAN, H. (2009): Evidence for repeated re-activation of old landslide under forest. Earth surface processes and landforms 34, 352–365.

YOSHIDA, K., KIKUCHI, S., NAKAMURA, F., NODA, M. (1997): Dendrochronological analysis of debris flow disturbance on Rishiri Island. Geomorphology 20, 135–145.

ŽÍŽALA, D., ZVELEBIL, J., VILÍMEK, V. (2010): Using dendrogeomorphology in research on a slope deformation in Běleč, Czech-Moravian Highland (Czech Republic). AUC Geographica 45, 79–96.

RÉSUMÉ

Změny tvarových parametrů cév břízy bělokoré (*Betula pendula* Roth.) vyvolané svahovými pohyby – Předběžná studie

Za účelem ověření vhodnosti břízy bělokoré pro dendrogeomorfologickou analýzu svahových pohybů bylo z prostoru lesního porostu poblíž Jezeří, poničeného sesuvem z ledna 2011, připraveno 67 trvalých preparátů z 24 vytipovaných stromů (15 disturbovaných a 9 referenčních). Pomocí softwaru WinCell Pro 2011a byly na detailních mikrosnímcích anatomické struktury naměřeny šířky (LW) a délky (LL) lumenů dohromady 8236 trachejí v letokruzích vytvořených v letech 2010, 2011 a (za účelem zhodnocení meziroční variability tvaru cév) u vybraných jedinců i v roce 2009. Typický tvar buňky v daném letokruhu byl popsán pomocí směrnice regresní přímky udávající závislost mezi LW a LL a následně byla vypočtena meziroční procentuální změna této směrnice v daném vzorku (Annual Change Index – ACI).

Průměrné hodnoty ACI se v případě referenčních a disturbovaných stromů rok před sesuvem (tj. mezi lety 2009 a 2010) pohybují pod hodnotou 23 %, což lze považovat za hranici udávající změny způsobené jinými než vysoce energetickými gravitačními procesy. V případě disturbovaných jedinců mezi lety 2010 a 2011 dosahuje ACI ve směrech A, B, C a D průměrných hodnot 21,1 %, 43,7 %, 21,7 % a 26,2 %. V případě trachejí na straně B (proti svahu, tedy místo působení tahu a tvorby tenzního dřeva) se hodnoty směrnice regresní přímky statisticky významně liší mezi lety 2010 a 2011 (doloženo Wilcoxonovým a Znaménkovým testem – obě p-hodnoty < 0,001) a hodnoty ACI jsou odlišné od hodnot v ostatních orientacích vzorkování u disturbovaných stromů (ANOVA p-hodnota = 0,0459 a následný post-hoc test). Nejvyšší hodnoty $ACI_{2010/11}$ byly obecně zaznamenány u jedinců s nejzávažnějším typem vnější deformace (např. zasypání báze kmene, exponované kořeny).

Závěry této předběžné studie dokládají, že naklonění a další externí deformace kmene břízy bělokoré nacházejí odezvu v tvarových parametrech jejích cév. Nabízí se tak možnost využití trachejí jako indikátoru svahových disturbancí v dalších oblastech antropogenního reliéfu Mostecka i celé ČR; stejně tak však vyvstávají další výzkumné otázky týkající se metody – hlavně pokud se jedná o příčiny nízkého (zhruba do 20 %) ACI zjištěného u referenčních jedinců a v letech bez svahové aktivity.

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