Dendrochronological record of soil creep and landslide activity – the comparison of tree-ring eccentricity and compression wood (examples from the Kamienne Mts., Poland)

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Abstract: Forested mountain slopes can be simultaneously affected by soil creep and landslide activity, both of which cause the tilting of tree stems, with the result that their dendrochronological record of tree-ring eccentricity and compression wood is potentially similar. There is a need to identify similarities and differences in these records and thus our research aimed to compare patterns of eccentricity and compression wood developed by trees under the impact of soil creep and landslides. We sampled trees growing on a landslide and creeping slopes in the Kamienne Mts., with 21 Norway spruce trees were sampled on each site. We found several main differences between the dendrochronological record of landslide activity and soil creep. On the landslide we found larger number of dendrochronological events, stronger and more variable eccentricity and a similar number of upslope and downslope events. On creeping slopes, upslope eccentricity events predominate, and the number of eccentricity events dated in all trees increases in time. We also compared the utility of eccentricity and compression wood for dating mass movements. They differ in their sensitivity to stem tilting. Thus, in analyses of landslide activity and soil creep activity, it is recommended to include both wood anatomy features.

Keywords: dendrochronology, landslide, soil creep, compression wood, tree-ring eccentricity

INTRODUCTION

Trees growing on slopes where landslides and soil creep occur are subject to stem deformations (Šilhán 2015). These two geomorphological processes differ in terms of their character and dynamics. Landslide activity can occur with the high magnitude and fast movement of material along slopes. Baroň et al. (2011), e.g., described how landslide colluvia were transported over 250 m within several hours. The speed of landslide activity can also be low: less than a centimetre per year in the case of slow-moving landslides (Noferini et al. 2007, Massey et al. 2013). Soil creep acts without abrupt accelerations which are common in the case of landslides. The intensity of soil creep can reach 100 cm^3/cm/yr (Pawlik & Šamonil 2018). However, in the temperate climatic zone, it usually reaches 5–30 cm^3/cm/yr (Saunders & Young 1983, Martin 2000). Landslides typically move along surfaces of rupture that divide mobile colluvia from the stable underlying material (Yuan et al. 2015). In the case of soil creep, it is impossible to determine a clear surface along which the movement occurs (Matsuura et al. 2003, Heimsath & Jungers 2013). Another difference between soil creep and landslides is the depth at which they occur. Deep-seated landslides move along surfaces of rupture located tens of meters below the ground surface (Petley & Allison 1997). On the other hand, shallow landslides only reach a few metres (Montrasio & Valentino 2007). However, soil creep involves an even thinner layer of soil cover on slopes (Culling 1963, Auzet & Ambroise 1996).

Despite the above-listed differences in their character and dynamics, both geomorphic processes can affect the growth of trees on slopes. Stems of trees are deformed under the impact of soil creep and landslides. However, the varying mechanisms of the two processes cause differences in the stem shapes of trees growing on creeping and sliding slopes. As a result of landslide activity, trees growing in the upper parts of slopes are usually tilted upslope, and trees growing in lower parts of slopes are usually tilted downslope, but stem bending is rare (Papadopulos et al. 2007, Wistuba et al. 2013). It is difficult to determine any regularities in stem deformations among trees affected by soil creep based on research published so far. Stems are deformed in various ways (Parizek & Woodruff 1957, Denneler & Schweingruber 1993). According to Alestalo (1971), soil creep causes both tilting and bending of tree stems in the downslope direction, contrary to shallow rotational landslides, which cause upslope stem tilting.

External deformations of tree stems are the basis for the dendrochronological dating of mass movements, including soil creep and landslides. Deflection of tree stem from the upright orientation by 1–2° is enough for the immediate development of detectable and datable disturbances of wood anatomy (Timell 1986, Wiedenhoeft 2013): eccentric tree rings and reaction wood. Among the coniferous trees, the former are rings wider on the lower side and narrower on the upper side of a tilted/bent tree stem (Braam et al. 1987). The latter, compression wood in conifers, is wood with intracellular spaces, thicker and more rounded cell walls and smaller cell lumens (Ruelle 2014).

Numerous papers have been published on the dendrochronological record of landslides. Landslides are most often dendrochronologically dated in order to determine the activity of landslide slopes (Stefanini 2004, Malik & Wistuba 2012, Wistuba et al. 2013, Migoń et al. 2014, Malik et al. 2016, Šilhán et al. 2019a), reconstruct landslide activity (Hong et al. 2012, Lopez-Saez et al. 2012b, 2017, Šilhán et al. 2018), assess landslide hazard and risk (Carrara et al. 2003), forecast future landslide activity (Wistuba et al. 2019), develop probability maps of landslide activation (Lopez-Saez et al. 2012a, Łuszczyńska et al. 2017, 2018), determine relations of landslide activity with other environmental phenomena (Lopez-Saez et al. 2013, Wistuba et al. 2015, 2018, Quesada-Román et al. 2019), determine magnitude and frequency of landslides (Corominas & Moya 2010), as well as to analyse triggering factors of landslides (Carrara & O'Neill 2003, Chigira et al. 2010, Papciak et al. 2015, Wistuba et al. 2021).

Thus far, soil creep has rarely been dated using dendrochronology, most likely because this geomorphological process does not cause catastrophes, i.e., building and road destruction and therefore soil creep is more rarely studied in comparison to landslides. Moreover, stem deformations attributed to soil creep, the phenomenon of low intensity, can also be caused by other environmental processes (Pawlik & Šamonil 2018). It is relatively easy to incorrectly attribute tree tilting to soil creep while, in fact, tilting results from phototropism, windthrows or snow creep (Carson & Kirkby 1972, Matsuzaki et al. 2006). This is a limitation that makes dendrochronological analyses of soil creep rare and focused mainly on identifying stem deformations caused by this process compared to other environmental processes (Parizek & Woodruff 1957, Harker 1996, Bollati et al. 2012) and on estimating the intensity of soil creep (Burda 2011, Sabir et al. 2016).

So far, dendrochronological records of landslide activity and soil creep have never been compared directly, despite potential similarities of growth disturbances caused by the two processes and recorded in tree-ring series (Šilhán 2017). The research problem of these similarities seems particularly important considering the accuracy of the dendrochronological dating of the two processes. It is even more important for landslide dating, which is more and more often applied for practical analyses of landslide hazard. The possibility of overlapping the two geomorphological processes on one slope and thus, in the dendrochronological record of one tree population is an additional issue in distinguishing between activity and soil creep (Imaizumi et al. 2013).

In the research presented here, we assume that differences between the character and dynamics of soil creep and landslide activity and their different influence on stem deformations can result in differences in their dendrochronological record. Thus, our research aimed to compare tree-ring patterns developed by trees growing under the impact of landslide activity and soil creep and determine differences in the development of features such as ring eccentricity and compression wood (1). We also aimed to compare the utility of ring eccentricity and compression wood for dating landslide activity and soil creep (2).

MATERIALS AND METHODS

Study area

Two study sites were analysed in the Kamienne Mts., Central Sudetes (SW Poland, Central Europe) (Fig. 1). The relief of the study area is structural, reflecting bedrock resistance to erosion. The terrain is dissected with deep V-shaped valleys separating long sinuous ridges and steep-sided conical hills. Relative differences in altitude can reach 350–450 m while mean slope angles range from 20° to 40° but can reach 60° (Malik et al. 2016). This area is known for its widespread landslide terrains (Migoń et al. 2010, 2014). One of them is the Garbatka study site (Fig. 1): a slow-moving flowslide descending from the northern slopes of the Garbatka Mt. (797 m a.s.l.) (Malik et al. 2016). The upper part of the landslide is a shallow slope hollow, below which an elongated colluvial package, probably up to 10 m thick, descends into the valley floor. The total length of the landslide is nearly 1 km. The Kopica study site (Fig. 1), where soil creep was studied, includes slopes on both sides of an elongated, eastern ridge of the Kopica Mt. (803 m a.s.l.). Both slopes at this study site are gentle, with a smooth surface undisturbed by landslides.

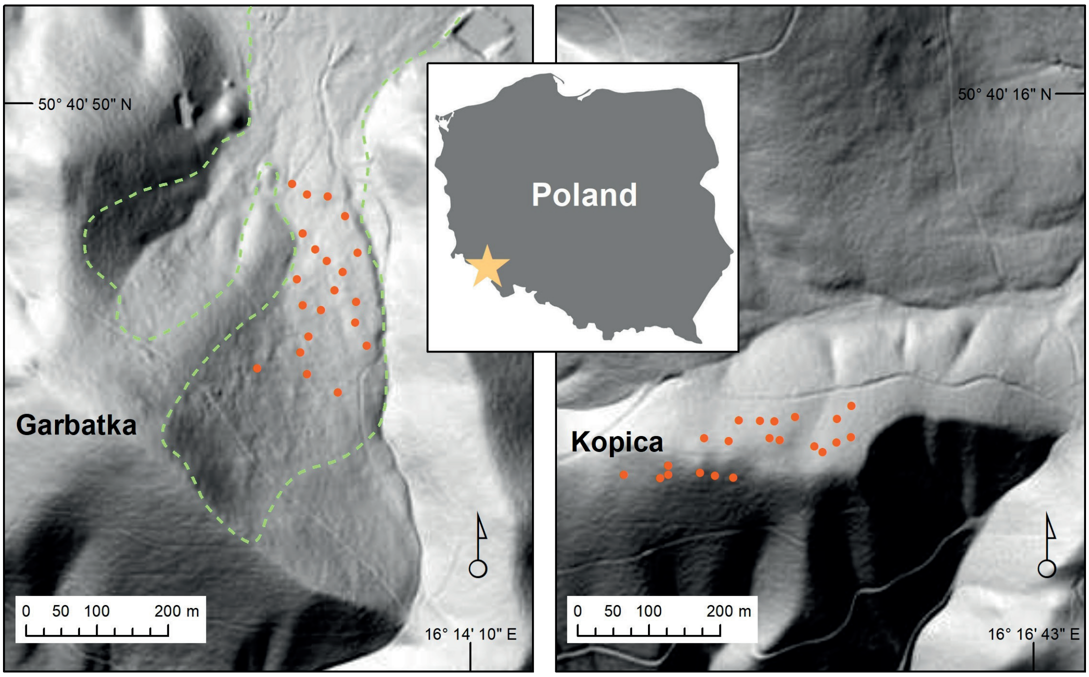

Fig. 1. *Location and relief of the study sites (green dotted line: extension of the Garbatka landslide). Location of sampled trees on the study sites (orange dots)*

The bedrock of the study area is composed of igneous and sedimentary rocks of late Carboniferous and early Permian age: rhyolites, trachyandesites, and rhyolitic tuffs, which overlie or intrude sandstones, mudstones and claystones (Awdankiewicz 1999). Bedrock at both study sites comprises rhyolitic tuffs prone to water oversaturation and gravitational mass movements, including landslides and soil creep.

The Kamienne Mts. are situated in the humid temperate zone, with a mean annual temperature around 5.5°C. The mean annual precipitation at the nearby weather station in Mieroszów was 776 mm (1977–2007), but annual rainfall totals can vary considerably (534–977 mm in 1977–2007) (Malik et al. 2016). The majority of precipitation falls within the summer season, and an absolute monthly maximum for 1977–2007 was recorded in July 1997 (344 mm) (Malik et al. 2016).

Natural vegetation in the Kamienne Mts. is a mixed forest, with European beech (*Fagus sylvatica* L.), Sycamore maple (*Acer pseudoplatanus*), hornbeam (*Carpinus betulus*) and Norway spruce (*Picea abies* Karst.). However, Norway spruce monocultures have replaced the natural forest composition after centuries of forest logging (Matuszkiewicz 2001).

Dendrochronological analysis of soil creep and landslide activity

For dating mass-movement activity, we sampled 21 Norway spruce trees (*Picea abies* Karst.) from the Garbatka study site and another 21 Norway spruce trees at the Kopica study site: 14 on the northern slope and 7 on the southern slope (Fig. 1). We found that trees growing on the two slopes with opposite aspects are all tilted upslope, i.e., stems of trees growing on the north-facing slope are tilted upslope, that is southward, and stems of trees growing on the south facing slope are also tilted upslope, that is northward. Thus, the factor which caused stem tilting was soil creep, not e.g., strong wind which would tilt trees growing on both slopes in one direction.

All of the dendrochronological samples were collected at chest height using Pressler borers. We sampled two cores from each tree: one from the upslope side and one from the downslope side of the stem. Cores were glued into wooden stands and sanded to reveal the wood structure. Upslope and downslope samples of every single tree were cross-dated with the Skeleton plot technique (Cropper 1979) to detect wedging rings and ensure correct dating of landslide activity. The wood anatomy in each sample has been checked ring by ring under the microscope in search of compression wood. We used criteria established by Yumoto et al. (1983) to date the first (the oldest) ring in each set of compression wood marking the time at which stem stability was disturbed by landslide reactivation.

We measured ring widths in all samples with the LinTAB measuring system (0.01 mm accuracy). We compared the measurements for each stem's upslope and downslope sides by calculating the eccentricity index and its annual variation according to the method of Malik and Wistuba (2012) and Wistuba et al. (2013). In the dating procedure, we used previously published data for a reference slope adjacent to the Garbatka study site. Thus, values of 56.52% and −51.40% were used as reference thresholds (Malik et al. 2016). In this standard method established by Wistuba et al. (2013), in samples taken on study sites, only years in which index variation exceeded the thresholds are considered events of landslide activity. However, the method was particularly developed to exclude the impact of soil creep from the record of landslide activity (Wistuba et al. 2013). The threshold values presented above, when applied to tree-ring data from creeping slopes of the Kopica study site, only yield 18 events of eccentricity compared to 127 events yielded on the landslide of the Garbatka study site. Thus, to compare eccentricity records of the two geomorphological processes, we divided the threshold values in half: 28.26% and −25.70%, allowing for comparable chronologies of eccentricity on both study sites.

Next, we calculated the total amount of trees disturbed annually by mass movements as a response index (Shroder Jr. 1978): the percentage of trees showing overall reaction (eccentricity or reaction wood or both) to landsliding and soil creep in each particular year in proportion to the total number of sampled trees already growing in the same year (sample depth value). If both eccentricity and compression wood were dated in the same tree ring, we recognised them as one single event of mass-movement activity. Finally, we calculated several statistical indicators, including arithmetical means, standard deviations, maximum and minimum values, to demonstrate similarities and differences between the dendrochronological record of landslide activity and soil creep.

RESULTS

Events of mass-movement activity dated from tree-ring eccentricity and compression wood

The total numbers of annual rings in populations of sampled trees differ slightly between the two study sites. For a landslide slope (the Garbatka study site), 1494 rings were found in 21 trees compared to 1550 rings in 21 trees on creeping slopes (the Kopica study site). The total number of mass-movement events dated from compression wood and ring eccentricity is 223 for the Kopica creeping slopes and 264 for the Garbatka landslide. These values constitute 14.39% and 17.71% of all tree rings found in all samples taken on each study site, respectively. Events dated solely from eccentricity and solely from compression wood are more frequent on the landslide slope than on creeping slopes (Tab. 1). The number of mass-movement events dated both from compression wood and eccentricity (i.e., two anatomical features were found in one tree ring) was again higher in the case of trees growing on the landslide slope compared to creeping slopes (Tab. 1). Events dated from both wood anatomy features found in the same tree rings constitute 11.74% of all events dated on the Garbatka landslide and 7.62% of all events dated on the Kopica creeping slopes.

On both study sites, and thus for both studied geomorphological processes, the number of events found on upslope sides of tilted stems of sampled trees predominates over events found on their downslope sides. This concerns both wood anatomy features: eccentricity and compression wood, when analysed separately (only eccentricity and only compression wood) and together (with the regard to the fact that both eccentricity and compression wood can occur in the same ring) (Tab. 2).

Table 1
The number of events dated from tree-ring eccentricity, compression wood and both wood anatomy features on the Garbatka landslide and Kopica creeping slopes

Study sites	Dated events from					
	tree-ring eccentricity		compression wood		both wood anatomy features	
	number of events	% of all tree rings	number of events	% of all tree rings	number of events	% of all tree rings
Garbatka	96	6.44	137	9.19	31	2.08
Kopica	86	5.55	120	7.74	17	1.10

Table 2
The number of events found on upslope and downslope sides of tilted stems of trees sampled on the Garbatka landslide and Kopica creeping slopes

Wood anatomy features	Events	Garbatka		Kopica	
		number of events	% of all tree rings	number of events	% of all tree rings
Only tree-ring eccentricity	upslope	91	6.10	88	5.68
	downslope	36	2.41	18	1.16
Only compression wood	upslope	121	8.12	103	6.65
	downslope	72	4.83	69	4.45
Both eccentricity and compression wood	upslope	212	12.54	191	11.23
	downslope	108	6.91	87	5.48

Eccentricity index and its yearly variation in sampled trees

Statistical parameters of eccentricity index values calculated for all annual rings in all trees sampled on each study site indicate that arithmetic mean and standard deviation are higher for the Garbatka landslide than for the Kopica creeping slopes (Tab. 3). This difference concerns mentioned statistical parameters calculated separately for both downslope and upslope eccentricity. Similarly, arithmetic mean and standard deviation calculated for yearly variation of eccentricity index values for all rings in all sampled trees are significantly higher for the Garbatka landslide than the Kopica creeping slopes (Tab. 3).

Table 3
Statistical parameters of eccentricity index values and index yearly variation values calculated for all annual rings in all trees sampled on each study site

Statistical parameters		Garbatka		Kopica	
		upslope	downslope	upslope	downslope
Eccentricity index	arithmetic mean	71.33	–32.87	52.31	–23.12
	standard deviation	95.79	37.41	55.76	30.16
Yearly variation	arithmetic mean	34.40	–34.04	29.26	–25.79
	standard deviation	48.02	45.70	34.22	27.64

Temporal variability of response index values

The oldest annual ring found in trees sampled on the Garbatka study site dates back to 1939, while the oldest on the Kopica study site dates back to 1935 (Fig. 2). The oldest events of mass movement activity on both study sites were found in 1942. On the Kopica creeping slopes, the highest activity of mass movements, represented by increased response index values (>30% of the sampled population of trees), was found in 1975, 1985, 1997, 2002, 2007, 2009, 2013 and 2014 (Fig. 2). The activity of soil creep was exceptionally high in 1997 and 2007 when the response index exceeded 50% of sampled trees (Fig. 2).

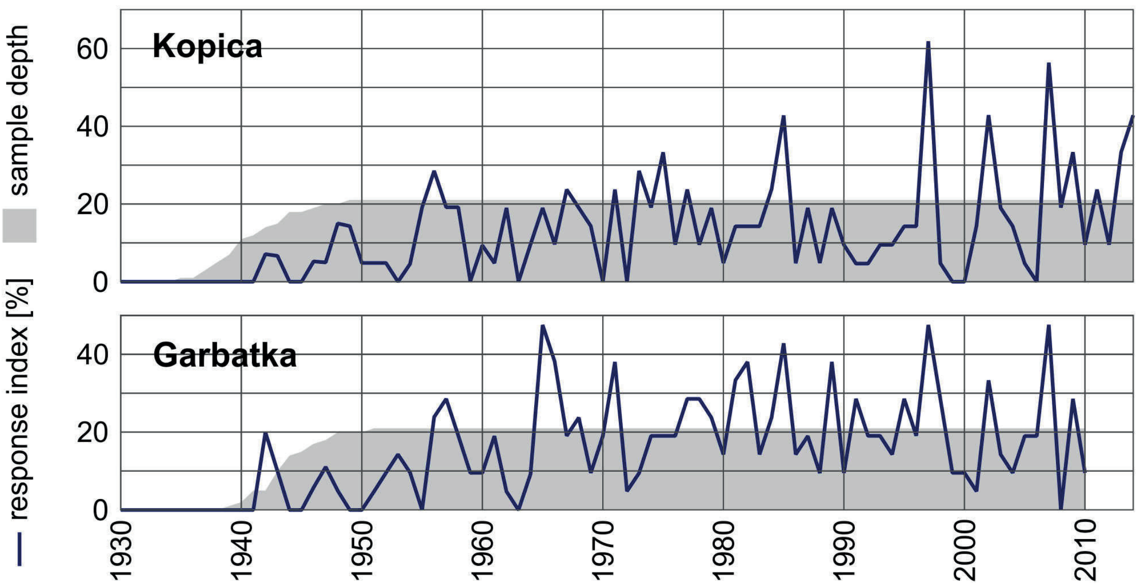

Fig. 2. *Temporal variability of response index values (based on both eccentricity and compression wood) and sample depth at the study sites*

On the other hand, the highest activity of the Garbatka landslide, represented by increased response index values (>30% of the sampled population of trees), was found in 1965, 1966, 1971, 1982, 1985, 1989, 1997, 1998, 2002, 2007 (Fig. 2). However, the response index for landslide activity does not reach as high as the values for soil creep, i.e. it does not exceed 50% in any year during the period under analysis. Increased activity of both soil creep on the Kopica study site and landsliding on the Garbatka study site coincided in 1985, 1997, 2002, and 2007 (response index >30% on both sites) (Fig. 2).

Considering the temporal variability of eccentricity and compression wood events separately (Figs. 3, 4), we found that the former are less dispersed in time than the latter, particularly on the creeping slope (Fig. 3). Moreover, on the creeping slope the number of eccentricity events increases over time (Fig. 3), and such a trend was not found for events based on compression wood. On both study slopes, events dated from compression wood are more or less equally divided between downslope and upslope sides of stems, while upslope events dominate among events dated from eccentricity (Figs. 5, 6).

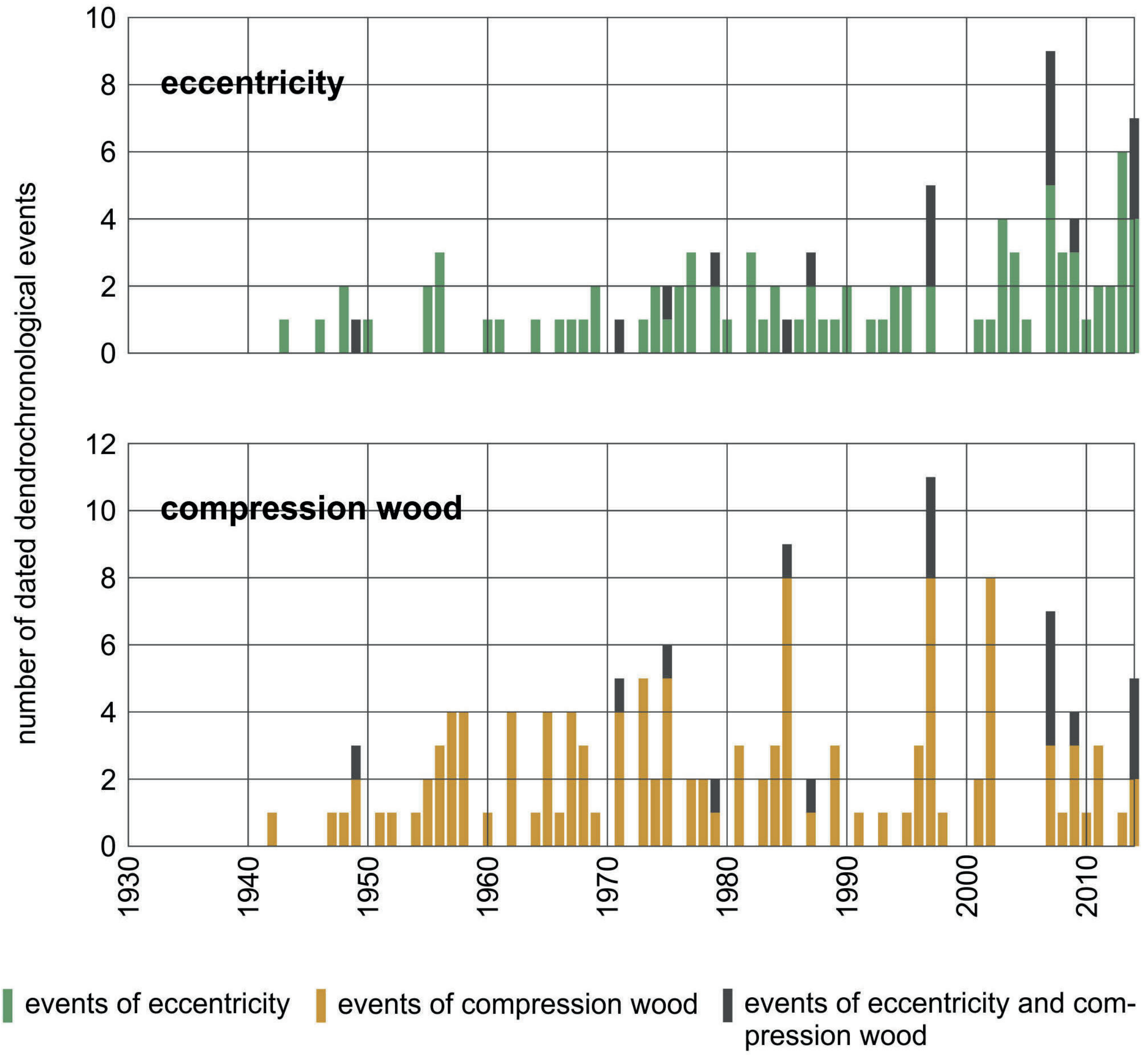

Fig. 3. *Eccentricity and compression wood record on the Kopica study site*

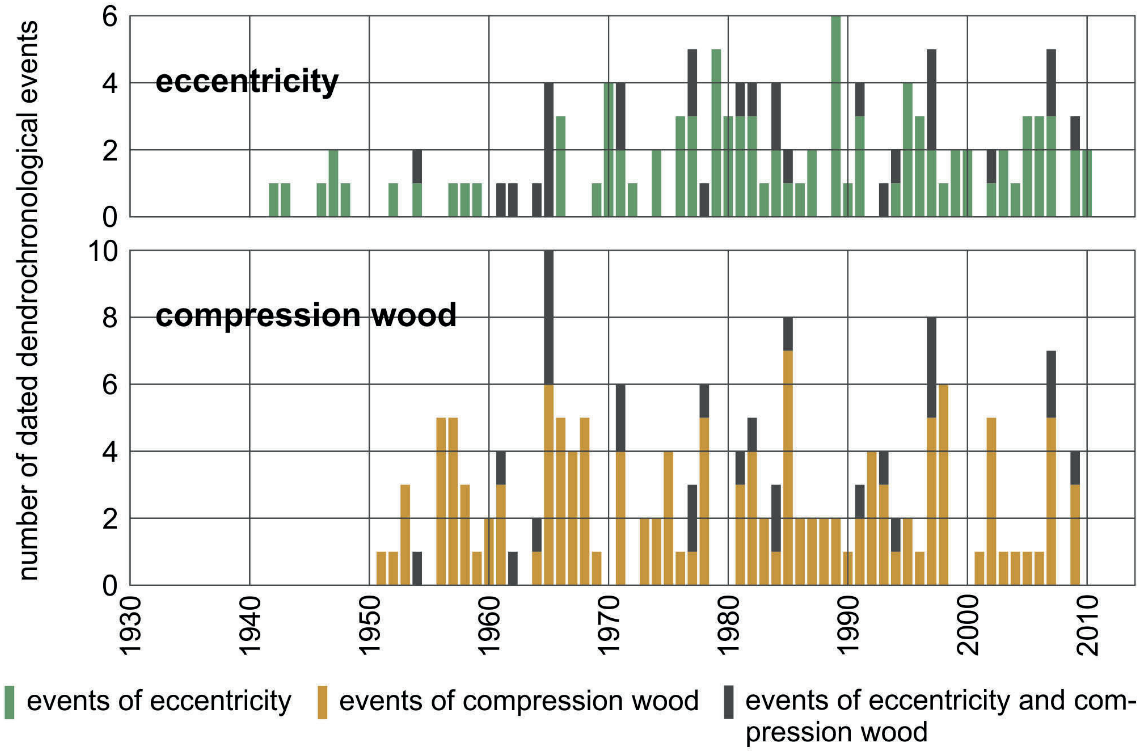

Fig. 4. Eccentricity and compression wood record on the Garbatka study site

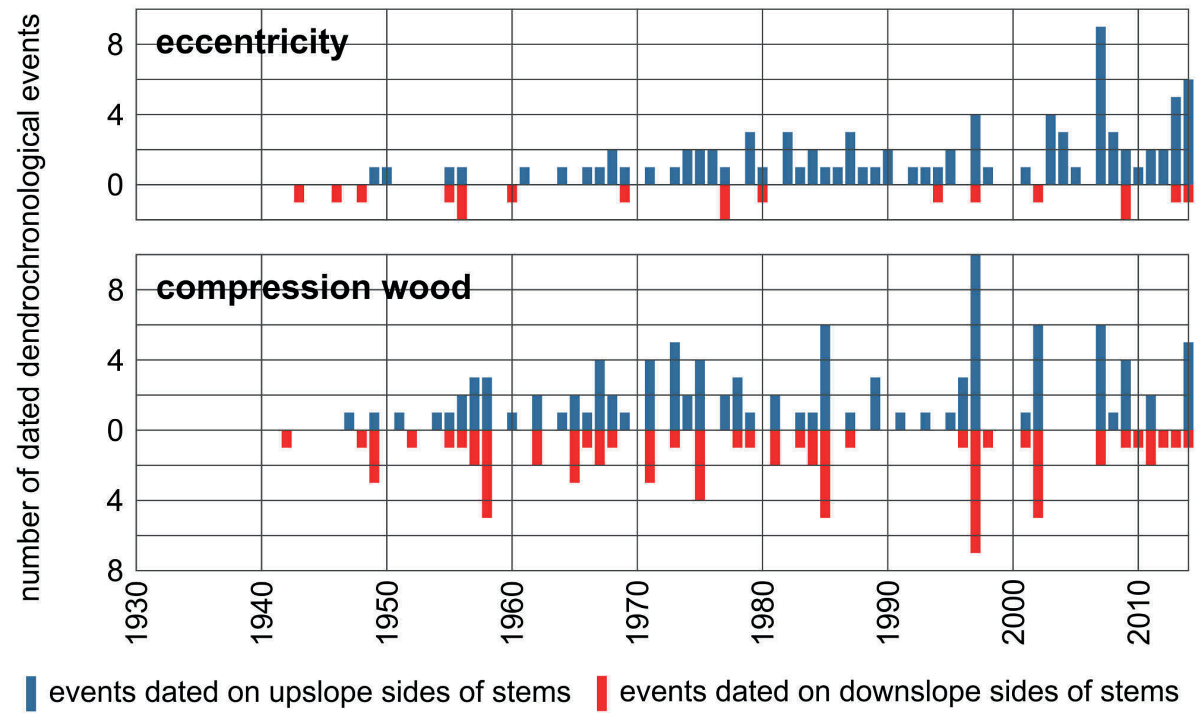

Fig. 5. Eccentricity and compression wood events recorded on upslope and downslope sides of stems at the Kopica study site

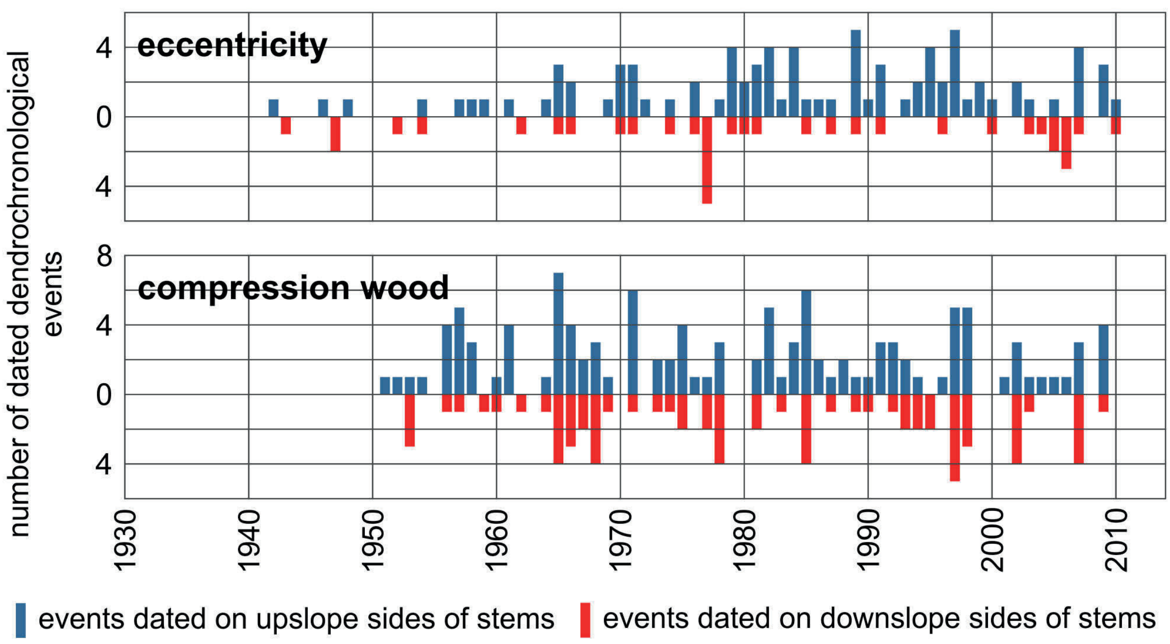

Fig. 6. *Eccentricity and compression wood events recorded on upslope and downslope sides of stems at the Garbatka study site*

DISCUSSION

The number of eccentricity and compression wood events identified on the Garbatka landslide exceeds the number of events found on the Kopica creeping slopes. This tendency is natural, considering higher dynamics of landslide activity as a geomorphic process compared to soil creep (Šilhán 2015, Sabir et al. 2016). Considering only eccentricity events, they are not only more frequent but also stronger on the landslide slope, which is clearly visible as higher arithmetic mean of the eccentricity index values from all rings in all sampled trees, compared to the same parameter on the creeping slope. The much higher standard deviation of the eccentricity index values from all rings in all sampled trees on the Garbatka study site, compared to Kopica, illustrates the higher temporal variability of slope activity on the landslide than on the creeping slope. Thus, it seems that with the use of dendrochronological data and simple statistical parameters such as arithmetic mean and standard deviation, we can assess relative strength and temporal variability of mass-movement activity on slopes. Using such parameters, we can obtain general knowledge on the differences in dynamics of selected, studied slopes. Such comparisons of slope dynamics can not only concern slopes affected by different geomorphological processes (here: landslide and soil creep); they can also be done between two or more landslides or two or more creeping slopes.

The fact that downslope eccentricity events are more frequent on the landslide slope than on creeping slopes is probably related to the greater depth and complexity of the landslide movement of slope materials. Landslide activity, including flowslides like Garbatka, typically produces hummocky topography with a significant number of small mounds and depressions where, during slope movement, trees are tilted in various directions (Booth et al. 2009). In the case of soil creep, upslope eccentricity events are clearly more frequent than downslope eccentricity events. Slopes affected by soil creep, including the Kopica study site, have smooth surfaces and topography less complex than landslide slopes (Saunders & Young 1983). A large number of upslope eccentricity events on the Kopica study site is related to the one-direction, shallow creeping movement of soil material. Such regularities are not as clear for compression wood compared to ring eccentricity, probably due to different sensitivity of those wood anatomy features to slope activity and tilting of tree stems (Łuszczyńska et al. 2018, Šilhán et al. 2019b).

In single trees affected by soil creep on the Kopica study site (Fig. 7), we found that ring eccentricity increased gradually over time. Eccentricity increased in sequences lasting several (up to 10) years. After each sequence, eccentricity decreased slightly but never again to previous lower values. Such periods of increased eccentricity probably reflect periods of more intensive soil creep caused by higher precipitation (Pawlik & Šamonil 2018). Eccentricity in trees affected by soil creep generally increases with tree age (Fig. 7). This can result from the increase in the weight of a tree while it is ageing and growing. The bigger and heavier a tree, the more sensitive it is to stem tilting and, thus, slope movements (Šilhán et al. 2019b). This is recorded as eccentricity increasing over time, both in single trees and in the whole sampled population (Figs. 3, 5). On the other hand, on the Garbatka landslide, events of slope activity are recorded as separate, severe escalations of tree-ring eccentricity (Fig. 7). These increases, related to events of landslide activity, appear suddenly and are rapidly suppressed back to the previous low level of eccentricity after 5–30 years.

There is a significant similarity of temporal variability of mass movements reconstructed from eccentricity and compression wood on both study sites. Periods of increased landslide activity and increased soil creep are much the same, i.e., there are numerous years when slope activity was dated on both study sites, including 1942, 1956, 1957, 1971, 1977, 1985, 1987, 1989, 1997, 2002 and 2007. This suggests that landslide activity on the Garbatka site and soil creep on the Kopica site are triggered simultaneously and, thus, depend on similar conditions. The Garbatka landslide is a flowslide. Such landslides are triggered by precipitation, a factor that also controls soil creep (Hungr et al. 2001, Malamud et al. 2004).

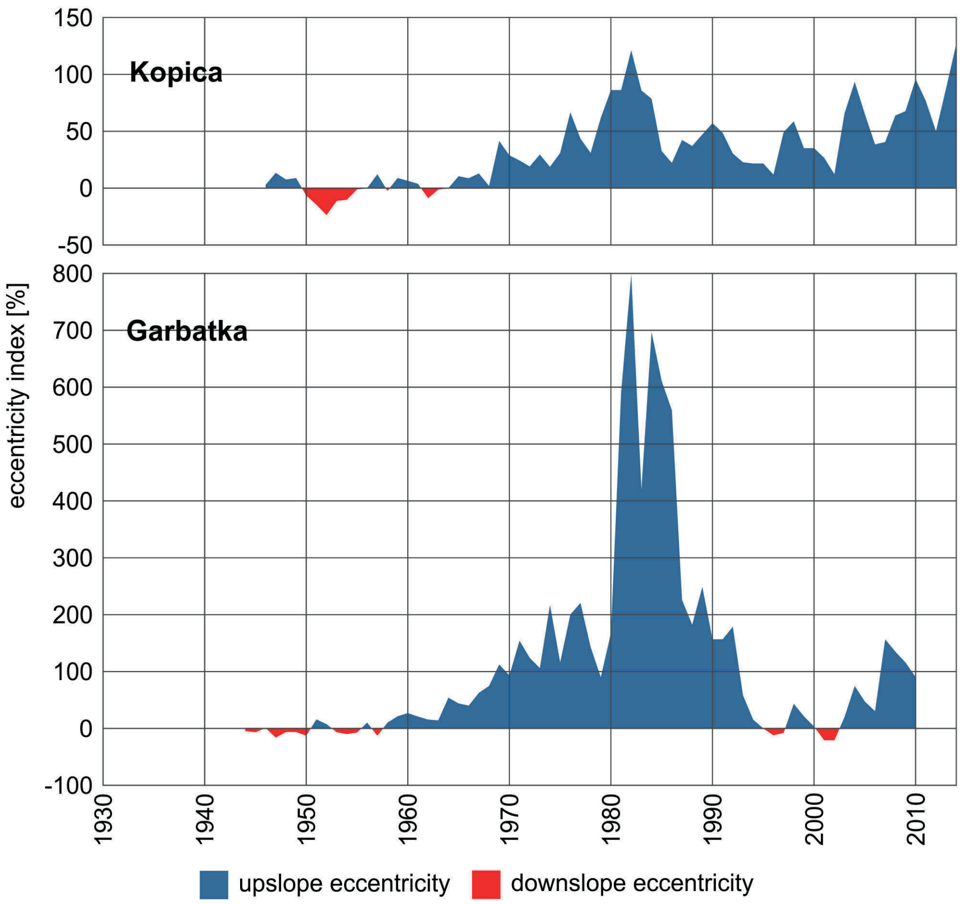

Fig. 7. *Examples of eccentricity index records in single trees sampled at both study sites (note the difference in vertical scales of two graphs)*

No strong earthquakes occur in the area under study that might have affected the activity of landslides and differentiate it from soil creep activity (which does not depend on earthquakes) (Li et al. 2013, Zhou et al. 2016). We would expect more distinct differences between dendrochronological records of landslide activity and soil creep in a seismic area (Malik et al. 2017).

Based on dendrochronological data, we have also identified years with high activity of the Garbatka landslide, but low activity of soil creep on the Kopica slopes, such as 1982, 1991 and 1995. The presence of such years either suggests slight differences in precipitation triggers of the two processes or the occurrence of non-precipitation triggers of landslide activity at Garbatka that do not affect soil creep at Kopica (Polemio & Petrucci 2000). Years 1989–1992, when significant activity was dated at the Garbatka landslide and low activity was found for soil creep at Kopica, were particularly dry (Malik et al. 2016, Pińskwar et al. 2019). Still, the activity of the study landslide was high. The lowest tip of the Garbatka landslide is undermined by stream erosion and dirt roads. Such factors often trigger landslide activity, but they do not trigger soil creep (Wistuba et al. 2015, Jaboyedoff et al. 2016). Therefore, it can be surmised that they might be responsible for the activity of the study landslide in dry years. We also cannot exclude the possibility that the low-magnitude earthquakes (M 4 and less) occurring in the study area might have led to small-scale landslide activity (e.g., Wistuba et al. 2018).

Results from both study sites indicate that eccentricity and compression wood events are rarely dated in the same calendar years. Tree rings that have both wood anatomy features constitute only 7.62% (Kopica) and 11.74% (Garbatka) of dated dendrochronological events of mass movement activity. This indicates that wood anatomy features applied in the study differ in their sensitivity to stem tilting and probably record events of slope activity that differ in strength. According to Kojs et al. (2012), slight tilting of a tree stem can be dendrochronologically recorded as eccentricity without compression wood. Medium tilting can be recorded with both growth disturbances, while strong tilting can produce only compression wood (Kojs et al. 2012). Such regularities show that both wood anatomy features should be analysed to assess the dynamics of landslides and creeping slopes thoroughly. However, our results indicate that eccentricity alone provides a more robust approach compared to analysing only compression wood. Tree-ring eccentricity, contrary to compression wood, can easily be measured and quantified. It can be recalculated into statistical parameters representing the whole data population, from simple arithmetic mean and standard deviation to more complex indicators. However, the record of eccentricity, contrary to compression wood, seems to be strongly affected by the increase in the weight of a tree over time. This impact is not significant on the dynamic landslide slope. However, it is evident for the gentler activity of soil creep. On the Kopica slopes, the number of dated eccentricity events increases with the age of sampled trees. This reflects that the sensitivity of trees to stem tilting by mass movements potentially increases with tree growth over the years. The bigger the size and weight of a tree, the stronger its reaction to the same degree of stem tilting.

CONCLUSIONS

1. On the Garbatka landslide and the Kopica creeping slopes, dendrochronological events recording slope activity frequently occur in the same calendar years. This is mainly because the two geomorphological processes are both controlled by precipitation. It seems that soil creep is more closely dependent on precipitation because the number of compression wood and eccentricity events decreases during dry years on the Kopica study site. On the other hand, landslide activity can be triggered by other factors, such as low-magnitude earthquakes and slope undermining by river or human activity, thus landslides can also be active during relatively dry years.
2. Among the main differences between the dendrochronological record of landslide activity and soil creep are:
   - the number of eccentricity events and compression wood events on the active landslide is larger compared to creeping slopes, where the slope dynamics is smaller;
   - the eccentricity, which represents slope activity, is also stronger and more variable year-by-year on the landslide, compared to creeping slopes;

- upslope eccentricity events dominate in the case of soil creep, which is particularly clear when analysing eccentricity, and less clear for compression wood; on a landslide slope, the number of upslope and downslope eccentricity events is similar;
- in the dendrochronological record from single trees affected by soil creep, eccentricity increases gradually over time in sequences lasting up to 10 years, after which it decreases but never to previous lower levels; in trees affected by landslide activity, severe and sudden increases of eccentricity are typical; they last 5–30 years, after which eccentricity rapidly returns to previous low values;
- the number of eccentricity events dated in the whole population of trees sampled on creeping slopes increases over time, while no such trend has been found on the landslide slope.

3. Tree-ring eccentricity and compression wood differ in their sensitivity to stem tilting. Thus, in analyses of landslide activity and soil creep activity, it is recommended to include both wood anatomy features. A more comprehensive assessment of slope activity is provided by eccentricity, which can easily be computed into objective mathematical data. Thus, eccentricity can also be statistically analysed and recalculated into statistical parameters such as arithmetical mean and standard deviation. However, contrary to compression wood, the record of eccentricity (on creeping slopes in particular) can be affected by the increase in the weight of a tree over time.

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