Disturbance Events in a Mixed Spruce – Larch Forest in the Tatra Mts., Western Carpathians – a Tentative Reconstruction

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Abstract

In this study paper we studied the effect of a severe and large scale windstorm which destroyed 12,000 ha of the *Lariceto – Piceetum* forest in the Slovakian High Tatra Mts. in 2004. Despite similar diameter and age structure of spruce and larch populations both species exhibited different resistance on the storm impact. Larch trees proved to be more resistant on heavy wind than spruce, and chances of survival of larch increased with its diameter. Spruce was almost totally eliminated from the stand. Irrespective of the species more trees died because of uprooting then because of breakage. The number of broken spruce stems increased with diameter compared with uprootings. Among thinnest diameter classes the number of breakages was more than twice lower than uprootings and among the thickest trees (exceeding diameter of 60 cm) most trees were broken. In case of larches most vulnerable on wind were thinner trees. Larch trees in diameter exceeding 40 cm had 50% survival chances while among stems below 40 cm only 17% remained intact after windstorm. The higher survival rate of larch probably resulted from their small crowns that were leafless in late fall when windstorm occurred. This shows a direct selective effect of a wind as a disturbance factor in the *Lariceto – Piceetum* forest in Tatra Mts. Tentative analyses of tree-rings based on 75 cross – sections from the oldest stumps of the damaged trees indicated abrupt changes in the growth pattern during the last two hundred years. The synchronized and strong release pulses in spruces and larches in the 19th century may indicate the occurrence of severe and infrequent disturbances in the past.

Key words: dendroecology, disturbance, *Larix decidua*, *Picea abies*, release signal, Tatra Mts

Introduction

European forests are influenced by different types of disturbances. Among disturbances of high severity fires seems to be the most important for Fenoscandia, while Central Europe is often affected by windthrows (Quine and Bell 1998, Ilisson et al. 2005). Insects' outbreaks may also result in a high timber loss and bark beetle has been responsible for considerable damages in Carpathian Mts. and Alps (Grodzki et al. 2006, Seidl et al. 2007). However, while fire and outbreaks can be controlled nowadays at least to some extend, windstorms are still outside a human control. It has been documented that heavy winds are responsible for serious damages in Europe. One of the most severe windthrows in last years took place in Slovakian High Tatras in 2004. During several hours bora wind destroyed 2.5 mln m^3 of timber on the area of 12,000 ha. The destruction of such scale has been never noted before in this region. Historical data from the 20th century indicate several windthrows in this area, however, of much less severity (Koren 2005).

The knowledge of forest history seems to be a main principle to understand processes occurring in forest stands. Disturbances influence tree mortality and regeneration, and finally they are responsible for the current structure of forest (Whittaker 1975). However, in many cases disturbances are hardly recognizable due to their specificity. They may occur with different frequency and varying intensity, what implicates problems when empirical observation is conducted directly. Studies in permanent plots are usually limited in time, and they are too short for the detection of disturbances, especially those which occur infrequently. For this reason the most of researchers focused only on descriptive studies which discriminate plant communities and temporary structure of forest. Forest ecologist from Central Europe most often based their models on the successive phases of growth of forest stands, which hardly produce a broad conception of forest dynamics, especially in terms of the role of disturbances (Korpel 1989). Therefore, the knowledge of a long time history covering at least the lifespan of tree generations may contribute significantly our understanding of forest dynamics. Among methodological tools for such reconstructions, dendrochronology seems to be the most suitable method (Bergeron et al. 2002). Information contained in tree rings enable a precise dating of different disturbance events like fires (Niklasson and Granström 2000), tree falls and uprootings (Storaunet and Rolstad 2004), insects outbreaks (Morin 1994), floods (Begin 2001, Zielonka et al. 2008) or landslides (Denneler and Schweingruber 1993). It is also possible to deduce from tree-rings about continuous processes like vegetation succession on decaying wood (Zielonka 2006, Zielonka and Piątek 2004) and the rate of dead wood decomposition (Holeksa et al. 2008). There is also a considerable number of publications which use dendrochronological methods to study the growth release as a direct result of past disturbances. An abrupt increase in the radial growth is usually caused by improvement of growth conditions related to the elimination of neighboring individuals. The moment of such event might be precisely cross-dated indicating the time when disturbance occurred (Lorimer and Frelich 1989, Black and Abrams 2003, Rubino and McCarthy 2004).

In this study, we aimed to determine the susceptibility of spruce and larch trees of different diameter to the windstorm damages. We also presented a tentative reconstruction of the history of mountain forest in the southern slopes of the High Tatras based on tree-ring analyses. Damages in 2004 have affected mixed spruce – larch stands belonging to the association of *Lariceto – Piceetum* (Zlatnik 1959). In Tatras, but also in the whole Carpathians the co-occurrence of the two species is rare. The presence of *Lariceto – Piceetum* in a spatial scale of thousands of hectares is limited to the area most seriously affected in 2004. These two species have different light requirements. Larch is much more light demanding species in comparison with spruce, so requires large openings for regeneration and juvenile growth, while spruce can regenerate in much smaller gaps or under canopy. Thus we hypothesize that spruce – larch stands in the High Tatras are a result of past disturbance regime. Because the historical information from before of the 20th century is lacking, we used tree-ring reconstruction of the oldest trees to date possible disturbances in the past.

Methods

Study site

The study site is located in the High Tatras in Slovakia in the area damaged by windthrow in 2004 (Figure 1). Spruce (*Picea abies* (L.) Karst) predominates among tree species. The other codominant species are: European larch (*Larix decidua* Mill), Scots pine (*Pinus silvestris* L.) and silver fir (*Abies alba* L.). Ground vegetation is dominated by *Vaccinium myrtillus*, *V. vitis-idaea*, *Calamagrostis villosa* and *Homogyne alpine*. The area of our study belongs to the Tatra National Park. We established a circular study plot of the radius of 60 m in the middle of 100 ha research plot, which was design for complex monitoring of the environmental changes after deforestation caused by wind. Thus, the 100 ha plot was chosen to be representative for the whole windthrow area. Soon after this event broken and uprooted trees were salvaged. Stumps were left in natural positions as well as single undamaged trees.

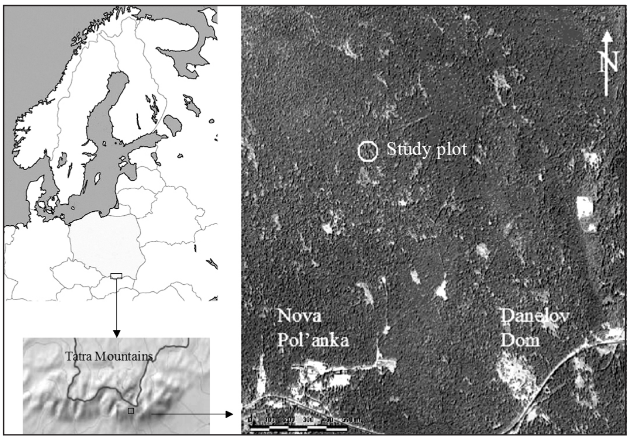

Figure 1. The study site. Aerial photo shows the structure of forest before the windthrow in 2004

Data collection

In 1 ha study plot the diameter of stumps was measured and the tree species was determined. Base diameter of living trees, which survived the windthrow was measured. For each stump we determined whether tree was broken or uprooted. Cross-sections from the oldest stumps of spruce and of larch were cut with a chain saw at the height of approximately 30 cm above the ground. Selection of the stumps was made by a rough estimation of the number of rings in the field. Wood samples were dried, polished with a belt sander and scanned with the resolution of 1200 dpi. The ring-width was measured with Win Dendro. The quality of measurements was checked with COFECHA (Holmes 1983). Further calculations were based on 50 ring-width series of spruce and 25 series of larch. To obtain the variability of growth during reconstructed period ring-width was averaged for decadal intervals for both species. Growth release to determine a release signal we calculated a percent growth change (PGC) (Nowacki and Abrams 1997):

$$PGC = [(M2 – M1)/M1] \times 100.$$

where: a PGC = percentage growth change between preceding and subsequent 10 years mean, M1 = preceding 10 years mean, M2 = subsequent 10 years mean.

PGC was calculated for each tree-ring of all collected series. The periods of possible past disturbances were determined using an average ring-width together with average PGC. Because the sampled trees belonged to approximately the same generation and are from the same plot we assumed that growth trend related with aging is similar for all trees (Schweingruber 1996), so comparison of time series was possible without detrending. Growth release is defined as an event when the percent growth change in a tree-ring series exceeds a given minimum threshold like 25%, 50% or 100%, which must be maintained for a certain length of time (5–10 years) (Black and Abrams 2004). Because we did not possess climatic data from the 19th century, we set a minimum threshold of PGC for 100% as an indication of growth release. Such a high threshold enabled the detection of only major releases related with more intensive disturbance events, while potential influence of climate was minimized.

Results

In the study plot 81% of trees were spruces, while the remaining trees were larches. Diameter distribution was similar for both species. The highest numbers of spruces and larches were found in the middle diameter class, between 30 and 40 cm (Figure 2). The largest trees of both species reached the diameter exceeding 60 cm at the base of stem. Larch trees exhibited higher resistance to the wind in 2004. As much as 26% of larches survived the windstorm intact, while all spruce individuals except one per 1 ha plot were damaged. Irrespective of the species more trees died because of uprooting than because of breakage. 38% of spruces were broken as well as 31% of larches. The number of broken spruce stems compared with uprootings increased with diameter. Among thinnest diameter classes the number of breakages was more than twice lower than uprootings and among the thickest trees (exceeding diameter of 60 cm) most trees were broken (Figure 3). In case of larches the most vulnerable to wind were

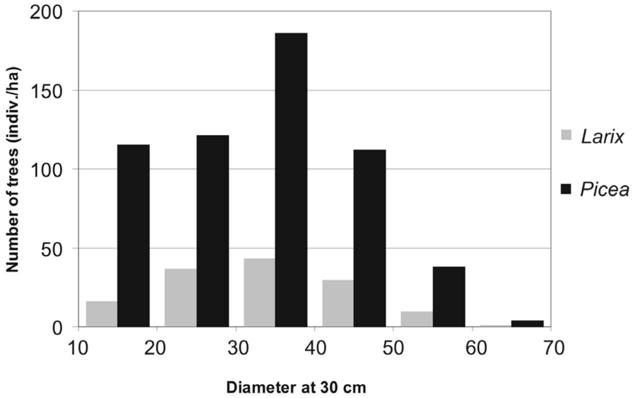

Figure 2. Diameter distribution of larch and spruce grouped in 10 cm classes. The diameter of stumps was measured at height of ca 30 cm

thinner trees. Larch trees in diameter exceeding 40 cm had 50% survival chances while among stems below 40 cm only 17% remained intact after windstorm. Breakages slightly prevailed in diameter class 20–29 cm, but in the remaining diameter spectrum the uprootings were more dominant, especially in thicker classes, where uprooted trees were very rare (Figure 3).

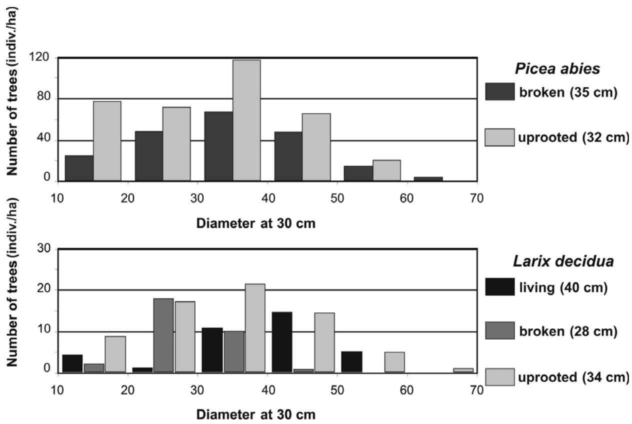

Figure 3. Number of trees which survived the windstorm, were broken and were uprooted grouped in diameter classes. Numbers in parenthesis show the average diameter for the category

The tree ring reconstruction went back to the end of the 18th century. The oldest tree-ring sample of spruce was cross-dated to 1770, and the pith year of the oldest larch was cross-dated to 1797. Spruce showed two dramatic changes in growth dynamics during the analyzed time span (Figure 4). The first abrupt acceleration of growth was visible at the end of the 18th century, and the second one started in ca. 1870. Both releases were preceded by strong depressions. Before the first released event, the average ring-width dropped to 0.15 mm. In 1860's an average growth

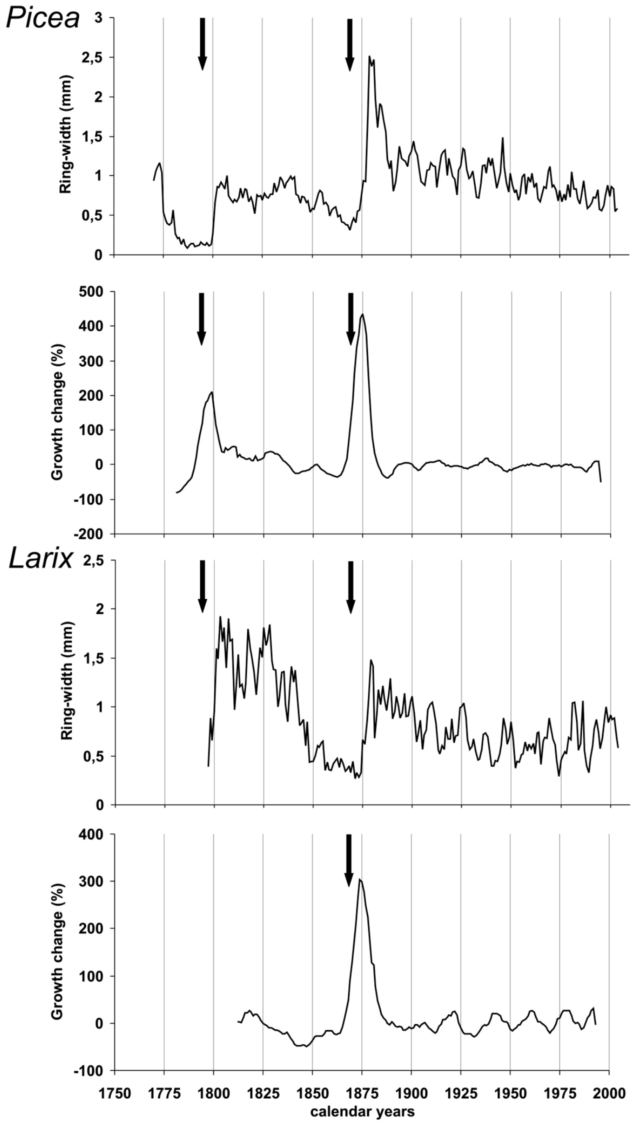

Figure 4. An average ring – width values and average PGC for two species. Arrows show an abrupt growth change, presumably severe disturbances

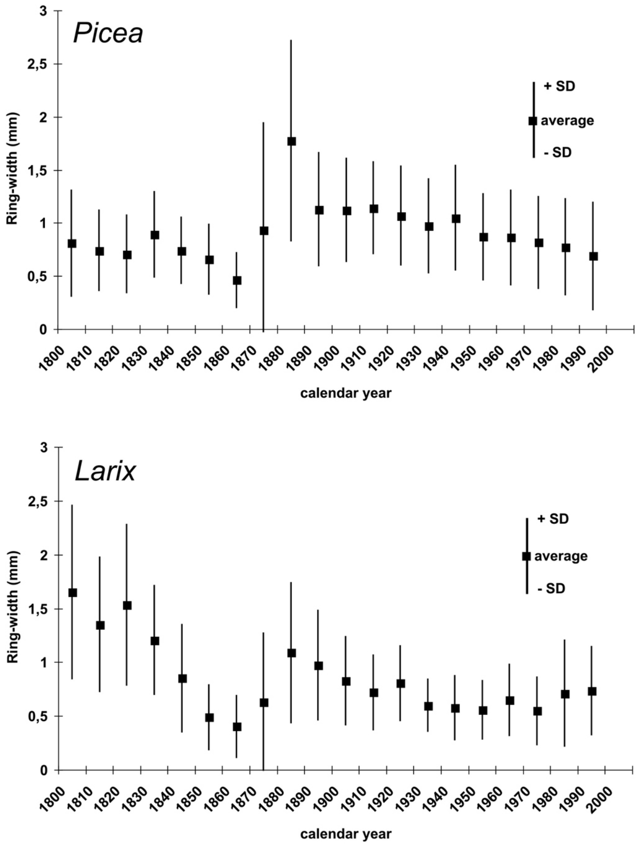

Figure 5. The average ring-width for decadal periods for both species

was around 0.4 mm and increased to over 2.5 mm in 1879. The same trend is visible in an average growth for decades (Figure 5). Two significant release events are also detected with PGC (Figure 4). Before 1800 an average percent growth change increased to over 200% and in 1870's growth change values for all spruces exceeded 400%. Growth dynamics of larch was similar to the growth trends of spruce (Figure 4, Figure 5). Larch similarly to spruce had a strong growth release around 1870. In this period an average ring-width increased from 0.3 mm to 1.4 mm in years 1870–1880. This release was also reflected in a strong increase of PGC values which approached to 300% (Figure 4). An average growth of larch also indicated an increasing trend beginning at the end of the 18th century but ring series of larch were too short to record a growth change. Detected release periods occurred in a large number of trees. Between 1866 and 1884 the highest percent of spruces – 94% and larches – 76% recorded a release reaction over 100% at the same time (Figure 6). Among two oldest spruces, both responded with release in the period 1792–1802. Additionally, 16% of spruces showed a strong reaction at the same time between 1820 and 1833. Out of these periods only single spruce and larch tree recorded short time releases over 100% of PGC.

Discussion

During the spacious windthrow in the High Tatras in 2004 larches seemed to be more resistant to heavy wind than spruce. Despite similar diameter and age structure of these two species one third of larches survived the windstorm, while all spruce individuals were eliminated from the stand. However, our empirical data come from one hectare plot; this regularity was observed all over the windthrow area. It seems that chances of survival of larches increased with its

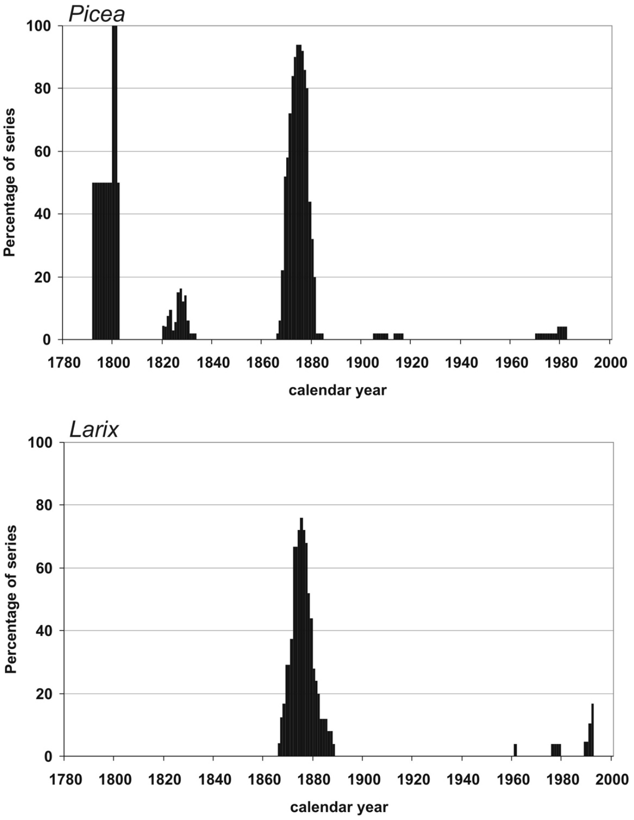

Figure 6. Percentage of tree-ring time series which showed value of PGC over 100% in a given calendar year, for both species

diameter. Thinner diameter classes were more vulnerable to breakages while thick larches were rather uprooted. Spruce trees exposed for a hurricane wind were damaged irrespective on their diameter. In both cases uprootings prevailed over the broken trees which can be explained by skeletal bedding and relatively flat root system produced by both species in thin layer of mineral soil. However, in contrast to larches, with increasing diameter the number of broken spruces increased slightly, especially, in the thickest diameter classes. Similar, increase of breakages in relation to uprootings in the thickest diameter classes (over 60 cm) was observed by Holeksa (1998) in spruce subalpine forest in Babia Góra. Also, Nagel and Diaci (2006) showed that among wind-killed spruces the mean DBH of snapped trees was significantly larger than the mean DBH of uprooted trees. This regularity was different from the other studies of the type of wind damages of Norway spruce in Estonia, where stem breakages dominated among smaller trees, while uprootings were more typical of larger individuals (Ilisson et al. 2005). We may only speculate that in case of sudden and the strongest storm gusts the momentary tension a stem cannot be compensated by root system fast enough and the stem might be broken before the extraction of a root plate. The higher survival rate of larch probably resulted from their small crowns that were leafless in the time of the windthrow.

There are historical data about severe windthrows affecting the Slovakian High Tatras in the 20th century (Koren 2005). However, accessible estimations of loss in timber suggest that none of them could match with the enormous scale of the last windthrow. These historical data suggest that windstorms are the main disturbance factors and they are responsible for the highest losses in the timber in this area. Our tree-ring reconstruction indicates two severe disturbances from before the 20th century. Strong release reaction present in most spruce trees and prevailing number of larches in the 1860s/70s indicates a severe disturbance event in this time. Another, previous one occurred at the end of the 18th century. Tree-ring pattern of studied trees indicates that during these two disturbance events the stand was greatly thinned, what implicated a significant improvement of growth condition for survival trees. Such disturbance events might selectively promote larch through larger damages to spruce, like during windthrow in 2004. Produced openings may have also led to the abundant larch regeneration. In our study, the first disturbance event in the end of the 18th century recorded by the tree-rings of the oldest spruce individuals overlaps in time with the regeneration of larch trees (Figure 4). Spruces regenerated under canopy and experienced a severe suppression in the period preceding the first disturbance event. At the beginning of the 19th century both species – suppressed spruces and new larch recruitment exhibited intensive growth. Selective influence of windstorms has been observed in the other mixed forests (Poulson and Platt 1996, Meunier et al. 2002, Ruel and Pineau 2002) including also *Picea – Larix* stands (Liu 1997). Those events influenced not only the species composition in tree layer but also the structural heterogeneity of forest (Hanson and Lorimer 2007).

Growth release in trees observed in our study might be caused by different factors. Release pulse is associated rather with an abrupt change in the environment than a specific disturbance agent (Lorimer and Frelich 1989). According to the historical sources we may rather exclude the influence of artificial thinning as human activity in this region especially before the 20th century was not intensive (Koren 2005). Insect outbreaks may also cause a selective thinning of forest stand, what results in a growth reaction of surviving trees (Berg et al. 2006). *Ips typographus* is an important disturbance agent in the Tatras spruce forests (Grodzki et al. 2006, Seidl et al. 2007) and we cannot entirely exclude that reconstructed disturbance events were caused by outbreak of this bark beetle. However, at least in the 20th century large scale bark beetle infestations followed directly reported windstorm damages as a secondary factor of spruce mortality (Koren 2005). Thus, we assumed that past windstorms, similar to this one in 2004 might explain the disturbances detected in our study. The windstorms were responsible for the disturbances also in the other Central European forest. In these studies in mixed *Fagus – Picea – Abies* forests (Splechtna et al. 2005, Nagel and Diaci 2006, Nagel et al. 2007) prevailed wind disturbances of higher frequency and lower severity than reconstructed in our stand in the Tatras.

Concluding, we assume that the occurrence of severe and infrequent disturbances may promote larch in spruce stands of *Lariceto – Piceetum* in the southern slopes of the Tatra Mountains. Presence of larch in spruce forest in the High Tatras was explained yet by influence of a continental climate, which is more suitable for larch (Balaz and Mindas 2004, Zlatnik 1959), but the past disturbance scenario was rather not taken into consideration. Our results should be supported in further research conducted in a larger spatial scale. Dendroecological reconstructions may significantly advance our knowledge on forest history, especially in the past centuries.

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СЛУЧАИ ЛЕСОНАРУШЕНИЯ В СМЕШАННОМ *LARIX DECIDUA – PICEA ABIES* ЛЕСУ В ТАТРАХ, ЗАПАДНЫЕ КАРПАТЫ – ПРЕДВАРИТЕЛЬНАЯ РЕКОНСТРУКЦИЯ

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Резюме

В данном исследовании мы изучили эффект серьезной и крупномасштабной бури, которая в 2004 году разрушила 12 000 га хвойного леса *Lariceto – Piceetum* в Словацких Высоких Татрах. Несмотря на аналогичный диаметр ствола и возрастную структуру ели и лиственницы, эти два вида деревьев проявили различное сопротивление при штормовом воздействии. Как оказалось, деревья лиственницы были более стойкими по отношению к тяжелому ветру, чем ель, и возможности выживания лиственницы увеличивались с ее диаметром. Ель в лесу была почти полностью уничтожена. Независимо от разновидностей, из-за ветровала погибло больше деревьев, чем из-за бурелома. По сравнению с повалами, количество сломанных елей увеличивалось соответственно их диаметру. Среди самых тонких классов диаметра число поломов было более чем в два раза ниже, чем повалов, и среди самых толстых деревьев (превышающий диаметр 60 см) большинство их было сломано. В случае лиственницы, более тонкие деревья были самые уязвимые на ветру. Деревья лиственницы, превышающие 40 см в диаметре, имели 50%-ую возможность выживания, в то время среди стволов диаметром ниже 40 см, только 17% оставались неповрежденными после бури. Более высокая норма выживания лиственницы, вероятно, была следствием их маленьких крон, которые поздней осенью во время бури были уже без иголок. Это указывает на прямое отборное влияние ветра в *Lariceto – Piceetum* лесу в Татрах. Предварительные исследования колец деревьев по 75 образцам из самых старых пней поврежденных деревьев, указали на резкие изменения в их росте в течении прошлых двухсот лет. Синхронизированное и резкое освобождение радиального прироста в елях и лиственницах в 19-ом столетии может указать на возникновение серьезных и нечастых нарушений в прошлом.

Ключевые слова: дендроэкология, нарушения, *Larix decidua*, *Picea abies*, сигнал освобождения, Высокие Татры