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Identifying the disturbance history over a large area of larch–spruce mountain forest in Central Europe

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ABSTRACT

It has been suggested that the frequency and intensity of extensive disturbances in European forests have increased in recent decades. To verify this, long-term data on past disturbance regimes over extensive areas should be delivered via dendroecological studies. The aim of our study was to identify the disturbance regime in mixed *Larix decidua–Picea abies* forests in the Tatras (Western Carpathians) over the last 200 years. We developed a method for determining forest disturbance regimes using data on reaction wood production, radial growth release and tree establishment. In 2004 the studied forests were struck by a strong windstorm over an area of 12,000 ha, which left most trees broken or uprooted. We wanted to find out whether such extensive disturbances can be regarded as typical, cyclic events in these forests. In a grid of plots in a 2000 ha area we collected cross sections from stumps representing the oldest trees. In the tree-ring series we noted the formation of compression wood and growth releases, which we took to be signs of past disturbances, and used the recruitment years of the sampled spruces and larches to date past gap formation. With these data we were able to reconstruct 200 years of disturbance history on a large spatial scale. In that period we distinguished 13 disturbance episodes. The temporal sequence of disturbance signals begins with the production of compression wood, followed by growth releases and finally by tree recruitment in gaps. This sequence suggests that wind-driven disturbances prevailed in the 19th and 20th centuries; they were more extensive in the 19th century but their frequency in the two centuries was similar. The intervals between severe events were long enough for dense stands to form, which were easily blown down over wide areas, but the intervals were short enough to enable light-demanding *L. decidua* to grow in stands of shade-tolerant *P. abies*. Our study demonstrates that including reaction wood in dendroecological studies can strengthen their explanatory power. Examining reaction wood along with other disturbance signals such as growth releases and tree recruitment improves the accuracy of disturbance event dating, and makes it possible to distinguish mechanical from biotic disturbance agents.

1. Introduction

In the last few decades, research on disturbance ecology has developed in boreal, temperate and tropical forests all over the world. It has become clear that sudden time-limited events influence the dynamics and structure of forest ecosystems, their biocenoses and populations. They also determine the species composition of forests. A new paradigm of unbalanced nature has displaced climax theory. According to this newer concept, fires, insect outbreaks and windthrows are widespread in forest ecosystems and are a key factor in their heterogeneity. Many of the differences between forests lie in the frequency, spatial extent, severity and other features of disturbances, and no forest is free of them (White, 1979; Pickett and White, 1985; Wu and Loucks, 1995; White and Jentsch, 2001; Frelich, 2002; Johnson and Miyanishi, 2007).

Though European ecology recognised the importance of disturbances for forest dynamics early on (Watt, 1947), since the 1950s most forest ecologists in Central and Western Europe have developed the conceptual framework of the forest developmental cycle without considering disturbances as a basic factor. They have been particularly interested in the structure of stands and their variability across developmental phases. They have focused their efforts on

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describing stand structure and changes in it, usually recorded in permanent plots, but they have paid less attention to the mechanisms behind the observed changes (Leibundgut, 1959; Korpeľ, 1982). While aware that tree death caused by different agents was responsible for shifts between successive phases of this cycle, they assumed gap-phase dynamics to be the main mortality process and the driver of recruitment of a new tree generation (Mayer and Ott, 1991; Korpeľ, 1995). Finally, they took no account of the possibility that extensive and abrupt disturbances could be important for the forests they studied. This view was strengthened by the phytosociological perspective that dominated forest vegetation studies in Europe (except in Great Britain and Scandinavia) for the greater part of the 20th century. Phytosociology methods were designed to sample the most typical vegetation patches, which were believed to remain in equilibrium with their environment (Becking, 1957). Disturbed patches were deliberately excluded from analyses as atypical. That approach was taken even in remnants of unmanaged forests under protection in national parks and nature reserves, with preferential sampling of phytocoenoses with high tree cover, excluding gaps and larger disturbed patches (Holeksa and Woźniak, 2005).

Such a methodology has led to the prevailing opinion that the severe disturbances affecting large forested areas in Central and Western Europe are mostly of anthropogenic origin or that anthropogenic factors were involved in their occurrence. Disturbances were usually seen as an effect of a forest management strategy that promoted conifer monocultures of uniform age, which are more susceptible to wind and to bark beetle attacks (Klimo et al., 2000; Hansen and Spiecker, 2004). Most of the stand diebacks of the 1970s to 1990s have been thought to be the result of environmental pollution. It has been suggested that pollution affected coniferous stands not only in industrialised regions but also in areas distant from those regions (Kandler and Innes, 1995). Another reason that extensive disturbances were not seen as a natural factor shaping forest ecosystems in Central and Western Europe was the rarity of stands left unmanaged during the last two centuries. Because they cover only a very small share of the landscape, the occurrence of severe disturbances in those places is less probable.

Schelhaas et al. (2003) suggested that the frequency and intensity of extensive disturbances in Europe has increased in the last fifty years as an effect of the expansion of forest areas and the increase of growing stock in managed forests. Some authors have posited the role of climate change in the recent intensification of disturbances: the spread of forest fires, the expansion of pathogens and pests, and the increase in wind velocity (Lindner et al., 2010; Milad et al., 2011). Both the frequency and intensity of all kinds of disturbances have been predicted to increase in the coming years (Dury et al., 2011).

Proposed models showing recent and future rises in the frequency and intensity of disturbances are based on records of wood volume damaged during past disturbances, among other data. The accuracy and completeness of these records is likely to diminish as they reach farther back in time, and this limits the soundness of the results. We need more field data for comparison over long periods and across large areas (Schelhaas et al., 2003).

Long-term data on past disturbances in large areas can be obtained using dendroecological methods by dating past disturbance episodes during the long life of trees (Splechtna et al., 2005; Nagel et al., 2007; Firm et al., 2009; Szewczyk et al., 2011; Svoboda et al., 2012, 2014; Balanda et al., 2013; Janda et al., 2014). Several types of disturbance signals are preserved in the sequences of annual rings in tree stems. The main signals include tree recruitment in gaps following the death of canopy trees, and growth rate acceleration due to release from the competitive pressure of neighbouring trees.

Another type of disturbance signal frequently present in tree boles is reaction wood, which is produced as a response to stem tilting. Stem tilting can result from hillslope geomorphological processes and from the force exerted by wind on a tree (Duncker and Spiecker, 2005; Stoffel and Bollschweiler, 2008). This signal can be used to distinguish disturbances caused by biotic factors, such as bark beetle outbreaks or pathogen infestation, from abiotic factors such as landslides and windstorms. The distinction is important in identifying the disturbance regimes that drive the dynamics of forest ecosystems. In most studies of disturbance regimes, however, reaction wood is not taken into account at all. Moreover, cores are taken in a way that avoids these growth anomalies (Rentch et al., 2010; Janda et al., 2014; Svoboda et al., 2014). The justification given for this practice is that compression wood makes crossdating of cores difficult (Zetterberg et al., 1995; Niklasson and Granström, 2000). Also, there is some difficulty in using this signal if samples have been collected with a Pressler increment borer, as the chance of finding reaction wood in narrow cores is small. Reaction wood becomes an important tool for detection of disturbances only if whole stem discs or wide sections of them are available.

The dearth of extensive old-growth forests for study in Central Europe imposes spatial limitations on research that employs dendroecological methods. It is difficult to find extensive areas with old trees that bear information over a long span of forest dynamics. Most of the recently acquired records of disturbances have been obtained by applying dendroecological methods to small remnants of montane old-growth mixed stands (Splechtna et al., 2005; Nagel and Diaci, 2006; Nagel et al., 2007; Nagel and Svoboda, 2008; Firm et al., 2009) and coniferous stands (Szewczyk et al., 2011; Svoboda et al., 2012, 2014; Janda et al., 2014) protected in nature reserves. Data from large areas covering at least a few hundred hectares of Central European forest are very rare.

One aim of our study was to identify the disturbance regime in mixed stands of European larch *Larix decidua* Mill and Norway spruce *Picea abies* L. (Karst) in the Slovakian Tatras (Western Carpathians). In 2004, a strong windstorm (wind speeds 30–50 m s^{-1}) struck these forests, affecting a 12,000 ha area and leaving most trees broken or uprooted. In this region, forests with a substantial share of European larch cover large areas and this forest type is unique for the Carpathians. We expected to find that extensive, severe disturbances were a frequent occurrence in the history of forests on the southern slopes of the Tatras. The basis of this hypothesis is the common occurrence of strongly light-demanding European larch in stands dominated by Norway spruce. Without disturbances to create large open areas in the forest canopy, larch would not regenerate and could be outcompeted by spruce. An earlier study found that it takes about 20 years for larch to regenerate after disturbances, with almost no recruitment between these narrow time-windows (Zielonka and Malcher, 2009).

Another aim was to improve the methodology employed to identify disturbance regimes in forest ecosystems, combining data on reaction wood with data on radial growth releases and tree establishment. We collected complete discs from all sampled trees because the tree boles, both broken and uprooted ones, had been cut and removed from the windthrow area. Having such a sample made it possible to use compression wood as a signal of past disturbances, along with the information on growth rate acceleration and tree recruitment.

2. Materials and methods

2.1. Study area

The study was conducted in coniferous mountain forests of the Slovakian High Tatras, protected since 1949 in Tatra National Park.