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Dynamics of windthrow events in a natural fir-beech forest in the Carpathian mountains

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ABSTRACT

The age of single windthrows (single uprooted trees and/or pit/mound microtopographical pairs) in a natural fir-beech forest was assessed in the flysch zone of the Outer Western Carpathians. The following characteristics were evaluated for all 1562 single windthrows occurring in a 10.8 ha area: dimensions; thickness of organic and upper mineral soil horizons both on mounds and in pits; and the presence of new trees taking root on the windthrows. For more recent windthrows, selected quantitative and qualitative characteristics of the uprooted trees were evaluated. A suppositional gradient of age (SGA) was constructed based on the windthrow characteristics using principal component analysis. A representative sample of windthrows was dated along the SGA with the use of dendroecological techniques and historic records from 1972 and 1995. For European beech (*Fagus sylvatica* L.) we were able to measure the actual threshold of release value – at 12% of growth change. The age of windthrows was determined in 37 of a total of 51 cases. The development of windthrow properties over time was studied. Age explained 33.7% of the variability in the measured windthrow characteristics ($F = 19.31$, $p = 0.0002$, measured characteristics see above). A multiple regression model ($R^2 = 0.844$, $F = 65.62$, $p < 1 \times 10^{-6}$) was constructed to evaluate the age of undated windthrows. The best predictors of age were: ordinal classification of trunk disintegration and thickness of F and A horizons on the mound.

In 2006, windthrows occupied 14.3% of the surface area of the studied locality, with a maximum windthrow age of 220 years. Approximately 1% of windthrows (1.5% of the windthrow area) were older than 150 years; 20% of windthrows (31% of the windthrow area) were older than 100 years, and 56% (78% of the area) were older than 50 years. The oldest windthrows with an uprooted trunk still present were 50–60 years old. The locality has not been affected by any high intensity (large scale) disturbances in the past. The period of direct soil turnover resulting from windthrows was about 1250 years. Compared with natural forests, the human caused long-term absence of windthrows in commercial forests may affect the course of soil formation. A single 100-year rotation period represents the absence of soil disturbance on 10% of the area.

1. Introduction

In the concept of disturbance ecology, disturbances are no longer understood as the “Nemesis of succession” as was wittily commented by Johnson and Miyanishi (2007), but are considered as an important part of plant communities dynamics. The most important type of disturbances in the temperate forests of Central Europe are blowdowns connected with the direct disturbance of soils (e.g. Schaetzl et al., 1989a,b; Ulanova, 2000). Mounds and pits created by windthrows represent ecologically unique microsites in forest stands, with a specific erosion-sedimentation regime (Armson and Fessenden, 1973; Beatty, 1984; Peterson and Pickett, 1990; Millikin and Drew, 1996; Clinton and Baker, 2000; Nachtergale et al., 2002) and essential impact on the terrain microtopography (Denny and Goodlett, 1956; Lyford and MacLean, 1966; Cremeans and Kalisz, 1988). Windthrows significantly affect the composition of both the herb layer and seedlings (Putz, 1983; Ilisson et al., 2007; von Oheimb et al., 2007), and at the same time, they influence the spatial variability of the forest floor and the diversity of decomposer communities (Nachtergale et al., 2002; Šamonil et al., 2008a,b). One of the most important effects of windthrows is through the influence on the rate and quality of soil formation processes (Lyford and MacLean, 1966; Stone, 1975; Skvorcova et al., 1983; Peterson et al., 1990; Schaetzl, 1990; Bormann et al., 1995; Vassenev and Targulian, 1995; Ulanova, 2000).

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In most of studies, the age of windthrows is established indirectly, based on the monitoring of their characteristics in time (Goodlett, 1954; Zeide, 1981; Schaetzl and Follmer, 1990). Even though the accuracy is low, this method can be applied to a wide range of windthrows, and can even be used to assess the role of windthrow dynamics at the level of the whole ecosystem. An alternative method for determining the age of windthrows is to search for direct evidence related to the moment of their occurrence. Dendroecological analyses can be used to analyze growth releases on trees around the windthrow and corresponding tree ring series on uprooted trunks. The high potential of these techniques, but also a number of limitations, were studied in Swedish boreal spruce forests by Dynesius and Jonsson (1990). A similar study for the fir-beech forests of Europe with a typically fine level of disturbance is so far lacking.

In spite of the many sophisticated methods used in the collection and analysis of dendroecological data, there are still a number of arbitrary decisions that constrain the general application of these procedures. Arbitrary decisions include not only the selection of sample trees or the choice of exact intervals for the calculation of growth change (e.g. Schweingruber et al., 1990; Nowacki and Abrams, 1997; Py et al., 2006), but also include the choice of the threshold of release, which serves as a limit value for the identification of disturbance events. The threshold of release is usually subjectively established at a certain level (20, 25, 50, 75, 100, 125 or 250%) of the growth change (e.g. Frelich and Lorimer, 1991; Rozas, 2001; Black and Abrams, 2003, 2004) and this essentially affects the evaluation of the disturbance regime (Rubino and McCarthy, 2004). Because of these facts, modified dendroecological techniques are advantageous in studies of windthrow age in natural fir-beech forests for the calibration of widely applicable indirect methods, and can improve their accuracy.

The objectives of this study are as follows:

- To establish a method for the formalized assessment of the age of windthrow events in natural temperate forests in Central Europe.
- To evaluate the windthrow dynamics of a natural fir-beech forest in the flysch zone of the Outer Western Carpathians.
- To discuss the possible effect of windthrow dynamics on the soil forming processes, and use this to assess forest management implications.

2. Materials and methods

2.1. Characterization of the locality

The survey took place in the Razula National Nature Reserve (hereafter Razula) in 2006. Razula is situated in the Outer Western Carpathians (Demek et al., 2006) on the state border between the Czech Republic and Slovakia. Razula, with an area of 23.5 ha, has been under protection since 1933. The bedrock is composed of flysch rocks of the Soláň system of layers (Menčík, 1979; Menčík and Tyráček, 1979), i.e. sandstones, claystones and argillaceous shales. Prevailing soils are Skeletic Cambisols and Haplic Cambisols (Driessen et al., 2001; Michéli and Schad, 2006; according to Soil Survey Staff (1999) there are Dystrudepts on N and NW slopes with an inclination of about 20°. The prevailing humus form is Moder (Green et al., 1993; Klinka et al., 1997). Soils are silt-loam or loam (rarely clay-loam) in Cambic horizon (Soil Survey Staff, 2006) with soil reaction between pH_{KCl} 3.3 and pH_{KCl} 3.8. Mean annual total precipitation amounts in this region are 1050–1370 mm, mean annual temperatures range from 5 to 6 °C (Tolasz et al., 2007).

Natural (Adam et al., 2008) forests prevailing in the region are mixed stands dominated by European beech (*Fagus sylvatica* L.), with a limited proportion of silver fir (*Abies alba* Mill.) and Norway Spruce (*Picea abies* (L.) Karsten). The forests usually belong to the *Dentario enneaphylli-Fagetum* and *Dentario glandulosae-Fagetum* associations (Ellenberg, 1996; Šamonil and Vrška, 2007).

2.2. Data collection

2.2.1. Windthrows in the locality and their measured characteristics

The field survey was conducted in 2006 and included all identifiable single windthrows (single uprooted trees and/or pit/mound microtopographical pairs) occurring in the geomorphologically homogeneous part of Razula (10.8 ha). The minimum height of a mound and/or depth of a pit (related to the contour line) were 0.05 m (windthrows with small dimensions) and 0.2 m (windthrows with bigger dimensions). This total number of 1562 windthrows represented 14.3% of the area (Šamonil et al., 2008c). Of this, 9.8% consisted of mounds and the remaining 4.5% of pits. Variables measured in the field for all windthrows were: ground slope; windthrow dimensions (width, length, height, depth); thickness of forest floor horizons (L – litter, F – fermented, H – humification horizons) on mounds and in pits (mm); thickness of upper mineral A horizon on mounds and in pits (mm); and the presence of new trees growing within the windthrow (on mound or in pit).

Younger windthrows still had uprooted trunks present, for which the following characteristics were assessed: tree species, stem diameter at breast height (DBH = 1.3 m), presence (classified as "absent/present = 0/1") of branches up to the second order of branching, branchlets from the third order of branching, leaves, bark, roots and bryophytes on the trunk. Additionally, the maximum penetration depth of a penetrometer into the fallen trunk was measured (mm) (a force of 185 N was applied five times on the upper side of the trunk). The loss in mass of the fallen trunk due to decomposition (%) was established by visual estimation.

All windthrows found in 2006 were identified in historic "tree maps" and their current condition was compared with the historic records. All standing and lying trees with a diameter at breast height (DBH) ≥10 cm were repeatedly (in 1972 and 1995) mapped throughout the entire area of Razula in "tree maps" (Průša, 1985; Vrška et al., 2001). Lying stems were visually classified by degree of decomposition into three classes – hard/partly rotten/rotten (e.g. Vrška et al., 2002) during each terrain survey.

The number of assessed characteristics was markedly higher in windthrows with trunks present than in those without. For this reason the development of disturbance events was first assessed on two sets of windthrows as follows: (i) windthrows with uprooted trunks, (ii) windthrows already without uprooted trunks.

2.2.2. Selection of windthrows for dendroecological dating

Windthrows for dendroecological surveys had to be appropriate for the application of dendroecological techniques (in particular, of sufficient dimension and with no shape anomalies). At the same time, we wanted to limit subjectivity during sample selection. Therefore, from the total set of 1562 windthrows, some samples were excluded from dendroecological analysis based on the following rules: (i) small windthrows of width <300 cm, (ii) windthrows on locally elevated sites – with a slope >30°, (iii) atypically shaped windthrows with no mounds or pits, (iv) windthrows with uprooted trees of species other than *F. sylvatica* with DBH ≥20 cm (in the case of windthrows with trunks present). The most severely limiting factor for the selection of windthrows was their size. The final set included 435 windthrows without uprooted trunks and 80 windthrows with trunks (totaling 33.0% of the number and 65.8% of the area of the total windthrows).

In order to effectively use the dendroecological survey over a wide set of windthrows, a suppositional gradient of age (SGA) was constructed on the basis of the directly measured characteristics,