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Western Carpathian mountain spruce forest after a windthrow: Natural regeneration in cleared and uncleared areas

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ABSTRACT

A catastrophic windstorm called "bora" occurred in The Tatra National Park in Slovakia in 2004 and destroyed an extensive area of mountain spruce forests. Part of the windthrow area was left uncleared for natural development, but most of the area was cleared. We analyzed natural regeneration in cleared and uncleared windthrows, and in reference closed canopy forest in 2007 and 2008 with the aim of assessing the regeneration capability of the windthrown forests and proposing the best method for their restoration.

The species composition and quantity of natural regeneration reflected the influence of the windthrow and tree extraction. The highest recruitment density was found in the reference area in closed canopy forest for both years (67,500 and 38,000 indiv./ha), while the lowest density was in cleared windthrow (3380 and 1210 indiv./ha). There were 8835 and 7225 indiv./ha in uncleared windthrow. Spruce was the predominant species in natural regeneration in both years in the reference forest and cleared windthrow. Larch, which forms an admixture in these forests, was found only rarely, and so we cannot make any conclusions regarding its regeneration. Pioneer species such as birch and willow became the most numerous in uncleared windthrow in 2008. There was a natural decrease of numbers of young spruce seedlings in all the plots and natural decrease of their numbers can still be expected in windthrown areas distant from seed sources. In uncleared windthrow, spruce was replaced by newly established birch and willow in areas that are still without vegetation and so suitable for seedling establishment. Birch and willow were rare in cleared windthrow, which was already covered by dense vegetation. If the total numbers in cleared windthrow will still decrease, then there will probably not be sufficient trees for forest regeneration and some management measures, such as planting or seeding, may be necessary. The numbers in uncleared windthrow are undoubtedly sufficient for successful regeneration of the forest. Moreover, future stands in uncleared windthrow will be more diverse and probably more resistant against disturbances. For these reasons, we recommend leaving the windthrown stands in the protected area without clearing as the best option for forest restoration.

1. Introduction

Natural disturbances represent the key factor in natural forest dynamics (e.g. Bonan and Shugart, 1989; Frelich, 2002). Their biological legacies, which include standing and lying dead wood, are known as being important for natural regeneration of tree species and providing critical habitats for particular species (Bouget and Duelli, 2004; Lindenmayer et al., 2008; Müller et al., 2008). The most important natural disturbances influencing the dynamics and structure of natural Norway spruce forests are windstorm events and subsequent bark beetle outbreaks on and also around the blowdown stands (Korpel, 1995). The extent of these disturbances can vary: the dynamics of boreal spruce forests is formed by disturbances of all extents, from small to large-scale (Ulanova, 2000); small-scale and intermediate disturbances are reported from mountain mixed (Splechtna et al., 2005; Nagel et al., 2006; Firm et al., 2009) and spruce forests (Holeksa and Cybulski, 2001). Large-scale disturbances are not usually considered to be a natural part of Central-European forest dynamics. They are supposed to be rather a result of decreased resistance of forests affected by air pollution and perhaps due to climate change (Ayres and Lombardero, 1999). Salvage logging has been the main traditional management technique in Europe to deal with the results of natural disturbances. However, recently the frequency and intensity of windstorms and bark beetle outbreaks have increased and caused large disturbances in many spruce forests in Central Europe (Schelhaas et al., 2003). Another increase in the frequency and intensity of disturbances can be expected due to

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global climatic changes (Dale et al., 2001; Fuhrer et al., 2006; Schlyter et al., 2006).

There is still a lack of information about the role of such large-scale disturbances in the natural dynamics of Central-European mountain spruce forests. One of the reasons can be the fact that most mountain spruce forests in Central Europe were altered to different extents by anthropogenic activities, marginalizing the role of disturbances (Kulakowski et al., 2006; Svoboda and Pouska, 2008). However, mountain spruce forests differ from all other Central-European forests; due to their special properties they are more similar to boreal forests. The latest studies reconstructing the disturbance history of these forests indicated the possibility of regular occurrence of large-scale storm events and bark beetle outbreaks contributing to heterogeneity at landscape scales even in Central-European mountain spruce forests (Kulakowski and Bebi, 2004; Holeksa et al., 2007; Zielonka et al., 2007). Recent studies also reported successful spontaneous regeneration of these forests after large-scale natural disturbances. An example of this is the approach of the Bavarian Forest National Park (Germany), where a large core area of the park was left to spontaneous development without forestry interventions after a storm event in 1984 and subsequent bark beetle outbreaks (Rall, 1995). Both windblown and bark beetle areas show successful regeneration (Heurich, 2001, 2009; Jehl, 2001). A similar development was described from the Bohemian Forest (Czech Republic) after a bark beetle outbreak in the 1990s (Jonášová and Prach, 2004; Ulbrichová et al., 2006) and from the Swiss Alps after the catastrophic storm Vivian (Wohlgemuth et al., 2002). Fischer et al. (2002) concluded that stand destruction by storm accelerates development from managed forests with homogenous structure to a structure characteristic for natural forests and can be seen as a chance for forest natural regeneration in national parks. By temporarily changing species composition in favor of broadleaved species after a windthrow, biodiversity increases and species, which are not able to survive under a closed canopy, are maintained in the ecosystem. Natural disturbances were found to positively effect biodiversity of plants (del Rio, 2006; Kreyer and Zerbe, 2006; Rixen et al., 2007) and insects (Müller et al., 2008). Pioneer broadleaved species, especially birch, improve soil through nutrient cycling (Perala and Alm, 1990), which is important for long-term functioning of spruce forests.

Successional processes after a natural disturbance are to a great extent determined by the numbers of surviving adult trees and natural regeneration (Rammig et al., 2006). A windthrow results in sudden changes to the ecosystem due to destruction of the tree canopy and part of the natural regeneration, and disturbance of the soil surface. After a large wind disturbance the number of surviving trees and rate of natural regeneration is usually smaller than in the case of bark beetle, which is the second most common disturbance in mountain spruce forests. Direct regeneration of spruce with only a temporary higher share of rowan was usually described after bark beetle outbreaks in Central Europe (Jonášová and Prach, 2004; Heurich, 2009). This is in contrast with the development after extensive wind storms, when a substantial part of natural regeneration is often formed by broadleaved species (Fischer et al., 2002; Wohlgemuth et al., 2002), which implies a large development cycle. This is probably due to disturbed soil surface, increase in light levels and easy dispersal of pioneer species seeds in extensive windthrow areas.

The presumption that mountain spruce forests affected by many stress factors have decreased resistance against the impact of natural disturbances, and a lowered ability to regenerate, led to a controversial enforcement of traditional forestry measures including salvage logging in areas affected by natural disturbances in some Central-European national parks (Solar and Galland, 2002; Grodzki et al., 2006). The effects of salvage logging are generally different from those of natural disturbances and forest ecosystems may be more strongly affected by post-disturbance logging than the initial disturbance (Lindenmayer and Noss, 2006; Lain et al., 2008; Lindenmayer et al., 2008). The most important consequences of salvage logging are reduction of natural regeneration and lack of dead wood as substrate for tree seedlings (Foster and Orwig, 2006). Other negative effects are disturbed soil surface, negative effects on species composition of the herb and moss layer (Mayer et al., 2004; Jonášová and Prach, 2008) and increased nutrient leaching in cleared areas (Bischoff et al., 2008).

A large-scale destruction of spruce forests by wind storm and consequent extensive salvage logging occurred in The Tatra Mts., Slovakia. The windstorm occurred on 19 November 2004, resulting in a windthrow area of 12,600 ha with wood volume of 2.3 mil m^3 at altitudes between 700 and 1350 m. The area is protected as a national park (Tatranský Národny Park, TANAP), thus it was decided to leave a part of the windblown area for natural development as a reference area, but most of the area was cleared (Fleischer, 2008a). Although this windstorm is viewed as an outstanding calamity silviculturally, this special wind called "bora" is typical for the region of The Tatra Mts. and its regular occurrence here has been documented (Zielonka et al., 2007). According to Holeksa et al. (2007), subalpine spruce forests in the Western Carpathians seem to be shaped by large-scale disturbances more than gapphase regeneration, and even over a large-spatial extent of several square kilometers do not reach a quasi-equilibrium state. However, except for small nature reserves, large areas of windblown forests had always been salvage logged and planted, so there is not enough information about the natural development of these forests after such an extensive wind storm if left without silvicultural interventions. Leaving part of the windblown area for spontaneous development created a unique opportunity for an extensive research of processes in the forest ecosystem after a large natural disturbance (Fleischer, 2008a). Salvage logging should be considered to be another type of disturbance, which can have far-reaching consequences for the restoration of affected forests. The aim of this study was to evaluate the development of natural regeneration in the windblown areas, both cleared and uncleared, and to propose the best method for restoration of windblown forests. For this purpose we evaluated the numbers of young individuals in cleared and uncleared windthrow, and the reference forest and determined their height and age (in the case of spruce) structure and occurrence in different microsites.

2. Methods

2.1. Study area

The study was performed in spruce forests on the south-east slopes of The Tatra Mts. at altitudes between 1060 and 1235 m. The area belongs to the cold climatic region with mean annual temperature 5.3 °C and mean annual precipitation 833 mm (Fleischer, 2008b). The bedrock is composed of fluvioglacial sediments, and the soil is podzolic cambisol. Soil granulity is clay to sand clay (Mičuda et al., 2005). The region is characterized by the regular occurrence of wind called "bora". The study of Zielonka et al. (2007), who reconstructed the disturbance history in the cleared windthrown area, revealed that the forest was extensively disturbed at least four times during the last 135 years. As a result of regular disturbance, a special geographical form of spruce forests has been formed in the Tatra region up to an altitude of 1200 m: larch-spruce forests (*Lariceto-Piceetum*) and pine-spruce forests (*Pineto-Piceetum*). The occurrence of light-demanding larch and pine is probably a result of the regular opening of the forests by "bora".