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Site factors are more important than salvage logging for tree regeneration after wind disturbance in Central European forests

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ABSTRACT

Wind disturbance is the main natural driver of forest dynamics in Central and Northern Europe, but little is known regarding the general patterns of tree regeneration following windthrow in this region. On the basis of 89 windthrow gaps, we quantified natural tree regeneration 10 and 20 years after wind disturbance, and identified the factors influencing tree regeneration dynamics, with a special emphasis on the post-storm management practices "salvage logging" and "no intervention". The sample encompasses gaps of ⩾3 ha and total overstory mortality caused by wind disturbance. The gaps date back to the two catastrophic storm events Vivian in 1990 and Lothar in 1999. Gaps covered an ecologically diverse region extending over 20,000 km^2 and ranging from 370 to 1780 m a.s.l. on the Central Plateau and in the Alps of Switzerland (Central Europe). Regeneration status was assessed on six circular sample plots per windthrow gap in 2010/2011. We recorded soil pH, organic layer, post-windthrow treatment, elevation, aspect, slope, browsing damage, and presence of predominant vegetation cover. We compared regeneration density and composition in gaps with and without salvage logging and elucidated the most important environmental factors influencing tree regeneration after wind disturbance using generalized linear models (GLMs). Ten and twenty years after wind disturbance, late-successional tree species such as beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) frequently dominated, independent of the post-storm treatment. Salvage logging did not negatively affect pre-storm regeneration and even positively influenced post-storm tree regeneration. GLMs revealed soil pH (+) and ground vegetation cover (−) to be the most important predictors of sapling density. The findings demonstrate that site factors have a stronger effect than post-storm treatment.

1. Introduction

Natural disturbances are key processes in most terrestrial ecosystems (Attiwill, 1994), with wind being one of the most important agents influencing forest stand dynamics (Lawton and Putz, 1988; Peterson, 2000; Ulanova, 2000). The severity of wind impact on forests depends on many factors, including the intensity of wind gusts, the duration of strong winds and current forest structure (e.g. Romme et al., 1998). Strong winds damage forest stands differently, ranging from scattered individual tree mortality across patterns of small canopy gaps to large openings (cf. Attiwill, 1994). Depending on the size of a canopy gap, the availability of resources such as light, water or nutrients may increase considerably. Microclimatic conditions are modified (Galhidy et al., 2006; Peterson et al., 1990) and plant diversity is promoted in the first few years after windthrow (Degen et al., 2005; von Oheimb et al., 2007). In mountain forests, severe wind disturbances often temporarily reduce the protective effect of forests against natural hazards such as avalanches or rockfall (Schönenberger, 2002). Therefore, and in the light of economic considerations, post-disturbance treatments usually aim at a quick restocking, often through artificial regeneration using late-successional species. In this context, an understanding of both the speed of natural regeneration and the factors driving tree regeneration are of considerable scientific and practical interest.

Managers commonly respond to natural disturbance in forests by salvage logging after fire (Ascoli et al., 2013; Beghin et al., 2010; Blake, 1982; Donato et al., 2006) or windthrow (Bottero et al., 2013; Lindenmayer et al., 2008). While salvage logging is usually practiced for economic reasons (Helms, 1998), it reduces structural heterogeneity with consequences for habitat diversity

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(Lindenmayer and Ough, 2006). Studies on salvage logging effects have focused chiefly on management after fire (e.g. Beschta et al., 2004; McIver and Starr, 2001). Here, three types of ecological impact may be identified: (i) impact on organisms and habitats, (ii) impact on key ecosystem processes such as nutrient cycling or soil formation, and (iii) impact on forest structure (Lindenmayer and Noss, 2006). Also after windthrow, salvage logging, since it consists of removing coarse woody debris, snags and living trees and subsequently diminishes pit-and-mound microtopography, considerably reduces the ecologically valuable structural heterogeneity (Bottero et al., 2013; Waldron et al., 2013). Management practices following forest disturbances modify numerous ecological legacies such as post-disturbance habitats, community composition, soil properties and nutrient levels, and hydrological regimes (Lindenmayer et al., 2008). Therefore, growth conditions may also be changed, thus possibly affecting successional pathways. Even without considering post-disturbance management practices, forest succession following different pathways has often been described in the literature. Romme et al. (2011), for example, reported fire damaged forests to be replaced by tree individuals of the same species, a process that has been described as "direct re-growth". According to the classical succession theory in temperate forests, however, tree species composition after disturbance starts by characteristic pioneer communities composed of early-successional tree species, which are subsequently replaced by late-successional species (e.g. Clements, 1936; Kimmins, 2004; Scherzinger, 1996).

Beyond management decisions, environmental factors such as soil pH (Peet et al., 2003) or elevation (Peterson and Pickett, 1990; van Mantgem et al., 2006) may have a strong influence on tree regeneration. In the present study, we aimed to quantify the impact of salvage logging compared to other environmental factors on the basis of a sample of 89 windthrow gaps located in Switzerland, in the lowlands (Central Plateau) and the Alps. We considered stands with total overstory mortality only (all trees windthrown in a gap), and assessed their regeneration status 20 and 10 years after the severe storm events Vivian (1990) and Lothar (1999). In particular, we aimed (i) to detect differences in natural tree regeneration between the two post-storm treatments "salvage logged" (SL treatment in this paper) and "no intervention" (windthrown trees were not removed; NI treatment in this paper), and (ii) to identify the most important environmental factors influencing tree regeneration after wind disturbance, with a focus on the post-storm treatments (SL vs. NI) and the different time periods since the disturbance events.

2. Materials and methods

2.1. Gap sample

The studied windthrow gaps in Switzerland, subsequently called 'gaps' as part of the 'gap sample', were caused by the winter storms Vivian, which occurred on February 27, 1990, and Lothar, which occurred on December 26, 1999 (Fig. 1 and Table 1). Gaps were selected from a geospatial database of windthrow patches all over Switzerland, derived from visual interpretations of post-disturbance aerial photographs (Vivian: Federal Office for the Environment FOEN; Lothar: Engineering Consultants H. U. Scherrer). Six criteria were applied for the selection: (1) gaps with total overstory mortality, (2) gaps $\geqslant$3 ha, (3) forest type in gaps belongs to one of the four most widespread forest types in Switzerland, i.e. beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.)-beech ('fir-beech' in this paper), silver fir-Norway spruce (*Picea abies* L.; 'fir-spruce' in this paper), or Norway spruce forest (Wohlgemuth et al., 2008b), (4) SL and NI treatments are evenly represented in gap samples

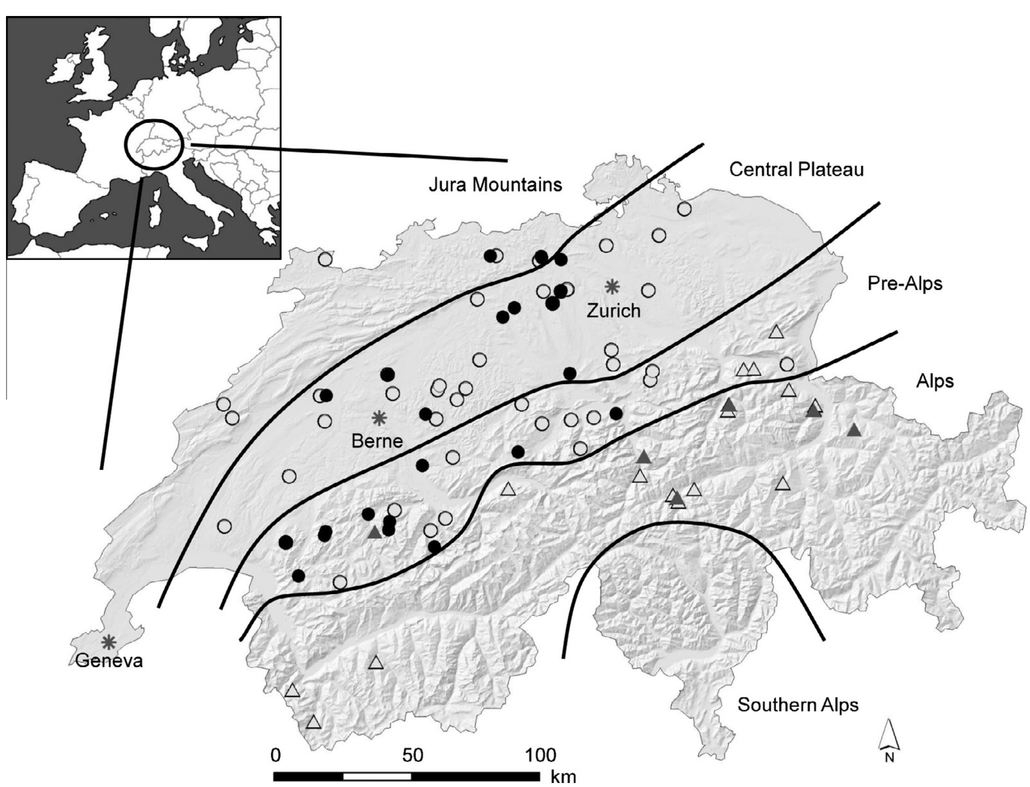

Fig. 1. Location of windthrow gaps in Switzerland. Vivian (1990): △ = salvage logged, ▲ = no intervention. Lothar (1999): ○ = salvage logged, ● = no intervention. Source of map: BFS GEOSTADT/Federal Office of Topography and Swiss Federal Institute for Forest, Snow and Landscape Research WSL.