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Divergent response of European beech, silver fir and Norway spruce advance regeneration to increased light levels following natural disturbance

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ABSTRACT

A comparative study of young European beech, silver fir and Norway spruce in the Slovenian mixed forest stands was made at four locations, exposed to the rapid canopy disintegration after the severe ice storm in 2014. Nitrogen amount (N_{tot}), Leaf mass per area (LMA), maximal Assimilation response to light (A_{max}) and Quantum yield (Φ) were measured in three categories of different light intensities under closed canopy with Indirect Site Factor (ISF) < 15%, at the forest edge (15% < ISF < 25%) and in the open (ISF > 25%). Tree responses were compared between damaged plots – rapidly exposed to light and undamaged sites, where young trees gradually adapted to the light environment during two years (2015 and 2016) after the disturbance event.

Nitrogen content of all three species was within optimal range values, highest in the open and lowest under canopy conditions on every plot. Rapid exposure to increased light levels affected most directly fir in the category of forest edge and under open canopies. Contrary to fir, beech responded in a favourable way, while no differences in response were evident in spruce. Assimilation efficiency, where both fir and beech were equal shifted towards the shade in both years.

1. Introduction

Changes in climate and in natural disturbance regime will significantly influence future forest development (Usbeck et al., 2010). Especially disturbance severity is on the increase, with several Central European countries facing unprecedented events in the recorded history (Nagel et al., 2017). Forest restoration of large canopy openings created by the disturbances may be less challenging for countries with prevalent clear-cut silvicultural system and artificial regeneration, since the whole system of reforestation is well-established and trees are adapted to the micro-climate of the open areas. In many Central European countries, however, the clear-cut management is quite limited (Pommerening and Murphy, 2004; Schütz et al., 2016) and consequently the whole system of artificial regeneration is less developed as well. Moreover, target species for various silvicultural goals are predominantly shade tolerant, especially silver fir, Norway spruce and beech. Even after natural disturbances there is a strong emphasis on forest restoration based on natural regeneration and release of advance regeneration (Brang et al., 2015). However, insufficient attention has been paid to the ecological differences between regular management and disturbances. While the former is characterised by the gradual controlled canopy removal (i.e. selection system or irregular shelterwood system), natural disturbances cause instantaneous change of forest climate (Schütz et al., 2016). Since disturbances are often followed by the sanitary/salvage logging, the cumulative effect may lead to quite extreme environmental conditions in the short term. This can influence a decline in photosynthetic efficiency and productivity of established seedlings (Ruban, 2009), which may retard natural regeneration, lead to decline of shade tolerant species and contribute to poor decisions on the type of forest restoration.

In February 2014, larger area of Slovenian montane forests has been severely damaged by the ice-storm; ice in combination with wet snow damaged mostly forests at altitudes between 500 and 1.200 m in the southwestern and western parts of the country. According to the Slovenian Forestry Service, the damage estimate in April 2014 included conifers with more than 30% and broad-

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leaves with more than 60% of broken canopies within the damaged forest, a total of 9.3 million m^3 in the entire Slovenia (Slovenian Forest Service, 2014). Forest restoration on 51% of Slovenian forested area included sanitary and salvage logging and regeneration measures within damaged forest stands (Fig. 1), which is still in the progress. Sanitary harvests also mitigate the risk of invasive pest outbreaks, such as a bark beetle.

In uneven-aged stands with an intense mixture of height and diameter class composition, the susceptibility to damage was related more to the individual tree or groups of trees than whole stands. Total damage in forests, forest roads and forest infrastructure was estimated at 214 mio EUR or 50% of the total damage caused by sleet. Regeneration (both natural and artificial) measures were required on approximately 13,800 hectares (2% of damaged area) (Slovenian Forest Service, 2014). Slovenian forests are mixed and well structured, therefore natural regeneration is quite successful. On 900 ha of damaged area, however, artificial regeneration by planting was also necessary.

In instantly open canopies following disturbance and consequent post-disturbance harvest operations it is crucial to select and favour tree species, that are site-adapted and are also able to cope with conditions of rapid light climate change and ample light. The choice between natural or artificial regeneration depends on the abundance and the quality of advance regeneration. Response of saplings is strongly related to their crown development and with the time spent in the shelter of mature stand (Greene et al., 2000). Successful seedling development and their survival rate decreases with the time spent in the shaded environment; the response ability of different tree species varies and depends on several factors (Wright et al., 2000; Greene et al., 2000). Growth response of root system is immediate, while response of aboveground parts is delayed, slower, defined by the vitality, age, stand conditions and adaptive ability of the species (Kneeshaw et al., 2006; Metslaid et al., 2005).

In this study, a comparison between two conifer species and one deciduous species in Slovenian mixed mountain forest stands is presented; effectiveness/reaction of advance regeneration of beech, silver fir and spruce saplings to increase in light intensity caused by the rapid canopy release triggered by the ice storm was compared among three tree species (1). Light response in damaged stands for each species was compared with the response in comparable light conditions in undamaged stands, where young trees gradually adapted to the light environment (2).

2. Material and methods

2.1. Site location

At four locations (Fig. 1), where sleet damages were evident in 2014 on the mature canopy stand, three categories of different light intensities were defined based on the analysis of hemispherical photos: under closed canopy with Indirect Site Factor (ISF) < 15%, at the forest edge (15% < ISF < 25%) and in the open ISF > 25%. Assimilation response was measured in saplings of silver fir (hereafter fir), beech and Norway spruce (hereafter spruce) in June and July during two consecutive growing seasons (2015 and 2016). Age of saplings varied between 4 and 9 years. The light response of trees on damaged plots was compared with the response of trees in same light categories that were not exposed to the rapid increase of light. Control represented young trees from undamaged nearby stands, that were regularly managed. Thus, seedlings could gradually adapt to new environmental conditions within canopy openings during longer time periods (Table 1).

On each site, 8 saplings were measured in every light category (canopy, edge, open) for each species (beech, fir, spruce) on damaged and undamaged sites (2) - 144 measurements. During each growing season three replications were provided: from 2 to 13 June, 3 to 12 July and 21 to 31 July in 2015 and 4 to 12 June, 4 to 13 July and 20 to 29 July in 2016. In each growing season in total 440 measurements were performed on all tree species and categories.

2.2. Nitrogen content (N_{tot}) and leaf mass per area (LMA)

- Leaves and needles were sampled in the upper crown position of minimal eight trees per light category and location, then cool-stored in airtight conditions. Same trees were used for the assimilation response measurements. Nitrogen concentra-

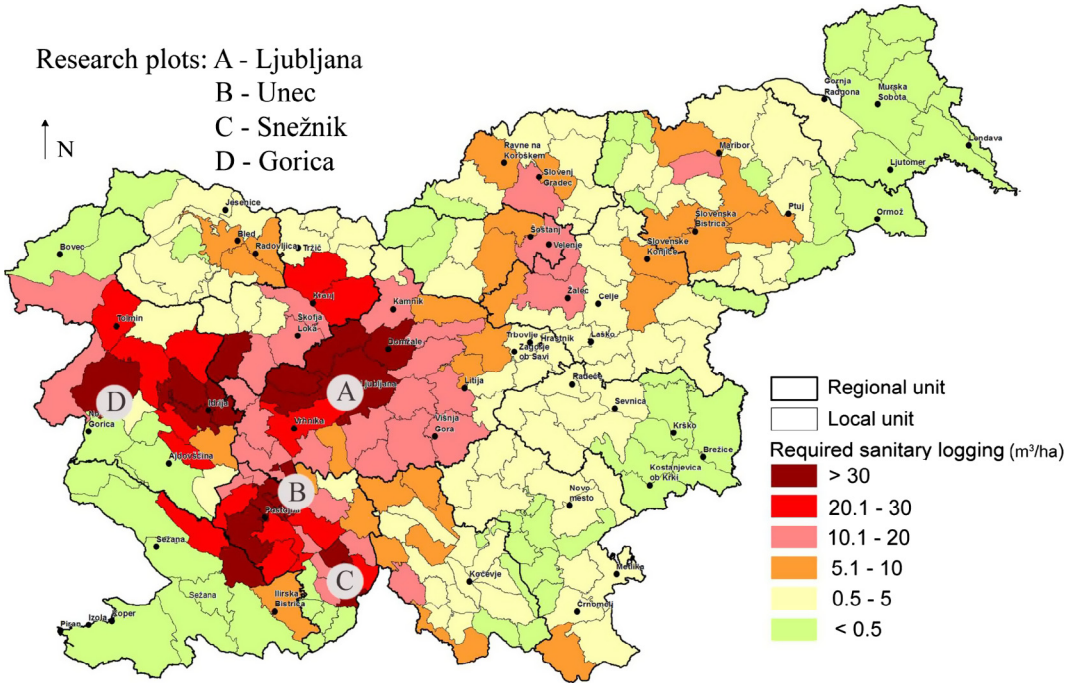

Fig. 1. Required sanitary logging (m^3/ha) (Slovenian Forestry Service, 2014) as a consequence of the ice storm in February 2014 and location of the research sites (A–D).