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POST-STORM REGENERATION OF NORWAY SPRUCE

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Abstract
Impact of abiotic (wind, summer drought) and secondary (bark beetle (*Scolytinae*)) or primary (cervids (*Cervidae*)) biotic factors affect the survival of Norway spruce (*Picea abies* (L.) Karst.) that is an economically important tree species. Norway spruce is mostly regenerated via planting – thus with significant investment. Therefore it is important to improve the resistance of Norway spruce stands as much as possible. Aim of the study was to characterize damages in Norway spruce stands by cyclonic wind storm and the regeneration of the stands, destroyed by the storm. Data from 4491 Norway spruce dominated stand, destroyed by the storm of 2005, from State Forest service database were obtained. Areas of post-storm sanitary clearcuts ranged from 0.1 to 7.6, mean 0.9 ± 0.02 ha. Most of the clearcuts were larger than 0.5 ha, demonstrating a relatively large size of gaps created by this natural disturbance. Changes of dominant trees species after the storm were statistically significantly affected by the forest type and type of regeneration. Overall, it happened in 55% of the former Norway spruce areas and was predominantly in cases, where natural regeneration was practiced. No indications of measures to increase stability of future stands against wind damages were found.
Key words: salvage logging, *Pice abies*, wind storm, forest management, windfirm stands.

Introduction

Climate change, linked to a higher productivity of Norway spruce (*Picea abies* (L.) Karst.), has been happening in a number of countries in the Baltic sea region (Pretzsch *et al.*, 2014); similarly also improved forest management has increased the growth. One of such measures is fertilization that has a long-lasting impact on the growth (diameter increment) of Norway spruce (Jansons *et al.*, 2016a). Further capacity of trees to increase the growth can be possible (Katrevics *et al.*, 2018; Katrevičs *et al.*, 2018) both due to the changes in silviculture as well as longer growing period (Krišāns *et al.*, 2016). Continuous rapid changes in climate might lead to limits of phenotypic plasticity of adaptation (Schmidt-Vogt, 1977). It may also cause changes in limiting factors, e.g. increasing influence of summer drought (Jansons *et al.*, 2015b; Matisons *et al.*, 2017), as well as increasingly suitable conditions for damaging agents, e.g. dendrophagous insects (Bāders *et al.*, 2018). Main climatic factors influencing growth of trees have been analyzed and compared between species (Jansons *et al.*, 2016b). Not only growth, but also wood quality and potentially decay can be affected by the sudden climatic changes, causing drought crack (Burnevičа *et al.*, 2016; Zeltins *et al.*, 2016, 2018). Selection of fast-growing and robust provenances for particular sites (regions) is in the aims of forestry adaptation to climatic changes (Rieksts-Riekstins *et al.*, 2014; Matisons *et al.*, 2018). Long-term tree breeding has been developed for different commercially important tree species (Jansons, Gailis, & Donis, 2011), including *Picea abies*, and the potential for adaptation to climatic changes is considered in it (Jansons *et al.*, 2015a). Genotype x environment interaction evaluation is a crucial element in this approach (Jansons, 2008). Good regeneration of unmanaged Norway spruce stands also in larger gaps after the storm (without salvage logging) had been observed (Baders *et al.*, 2017), similar to that after clearcutting and planting. However, the advantage of planting is potential of further improvement (and ensured vitality, if rapid adaptation is of importance) due to application of progressive soil scarification methods and plants with high phenotypic and physiological (Haapanen *et al.*, 2015; Dzerina *et al.*, 2016; Celma *et al.*, 2018) characteristics. Overall, genetic gain of around 10% for stem volume growth by selecting a seed source can be achieved (Janson *et al.*, 2013), as well as increased the above-ground biomass (Lībiete-Zālīte & Jansons, 2011; Lībiete *et al.*, 2017).

Main causes of damages in European forests are fires, wind storms and bark beetles (*Scolytinae*). Their impact is expected to increase in future (Seidl *et al.*, 2014; Kitenberga *et al.*, 2018, 2019). It will influence the financial gain from forestry and tree species composition. Norway spruce can easily be affected by all of these factors. Fires mostly are human-caused, the climate change can only alter their size (Donis *et al.*, 2017). In contrast, the wind-storms are out of the anthropogenic control and have become increasingly more common, affecting large forest areas. Norway spruce is not stable due to superficial roots. Additionally, feeding damages by cervids (*Cervidae*) to the bark of the trees may be an important factor affecting spruces – both their growth and wind-resistance. Therefore, it is important to establish stands that are more stable than the current generation of trees.

The aim of the study was to characterize damages in Norway spruce stands by cyclonic wind storm and the regeneration of the stands, destroyed by the storm.

Materials and Methods

The study was carried out as an analysis of data on the most significant cyclone storm of recent decades, which took place on January 8-9, 2005.

Data regarding the regeneration of the damaged areas of storm in 2005, in which a salvage logging has been performed, have been obtained from a database of the State Forest Service, where information regarding the compartments prior to (2004) and after the storm (2018) can be found. Only forest compartments, where storm was noted as a primary cause of sanitary clearcut, have been selected and used for statistical analysis from the database, and a clearing after the storms of 2005 is checked when testing theaerophoto maps, provided that it is logically possible to connect them to the most recent database information on the same compartments. Overall, the analysis uses data from 4491 spruce stands, distributed evenly across Latvia. A binary logistical regression has been used to analyse the changes in the prevailing species (difference before and after regeneration): the variable is assigned a value of 0, where the dominant tree species have remained unchanged following the storm in the forest stand; and a value of 1 if the prevailing species has changed after the storm. It was further analysed how the prevailing species would change depending on the type and origin of the forest (planting or natural regeneration). Wind-damages were found in all forest types where Norway spruce dominated stands can be found in Latvia (Table 1).

Results and Discussion

Influence of the storm on Norway spruce stands is characterized by the size-distribution of sanitary clearcuts. The proportion of sanitary clearcuts with an area of not more than 0.3 ha represents 23% of the total number of sanitary clearcuts following the 2005 storm, those whose area does not exceed 0.5 ha – 41%, 1.0 ha – 71%, while the proportion of felling areas exceeding 1.0 ha is 28% of the total number of sanitary fellings after this storm. Absolute majority (76% both from number and total area) of all sanitary clearcuts are in Norway spruce stands on fertile mineral soil with normal moisture regime, even though in these areas, overall, only 49% are from Norway spruce stands (Latvian national forest inventory (NFI) data). Trees in such soils are expected to be more windfirm than in other. However, even though the storm happened in January, the ground was not frozen at the time – thus affecting the amount of damages. Also, in these conditions, trees have very good growth rates, potentially being higher than others – it would also affect (lower) their wind resistance. Such result indicates the necessity to pay special attention to the reduction of wind risks in stands very suitable for growth of Norway spruce, since the un-frozen soil during the winter will become more and more common due to global climate change. The result on the mean size of the area damaged to such an extent that sanitary clearcut (salvage logging)

Table 1

Post-storm regeneration of destroyed Norway spruce stands

Soil conditions	Forest types	Number of stands regenerated by						Proportion of spruce, %
		spruce (*Picea abies* (L.) Karst.)	birch (*Betula* spp.)	aspen (*Populus tremula* L.)	pine (*Pinus sylvestris* L.)	other species	all species	
Fertile dry mineral soil	*Hylocomiosa*	730	524	40	183	11	1488	49
	Oxalidosa	834	642	259	9	80	1824	46
	Aegopodiosa	23	45	15		5	88	26
Fertile wet mineral soil	*Myrtilloso-sphagnosa*	58	82	2	16	6	164	35
	Myrtilloso-polytrichosa	61	61	7		16	145	42
Fertile drained mineral soil	*Myrtillosa mel.*	132	102	7	25	4	270	49
	Mercurialosa mel.	79	67	22		11	179	44
Fertile drained peat soil	*Myrtillosa turf. mel.*	38	61	1	1	2	103	37
	Oxalidosa turf. mel.	35	82			14	131	27
Other	Other	24	46	2	18	9	99	24
Total	All	2014	1712	355	252	158	4491	45

Table 2

Parameter values of the model

Factor	χ^2 coefficient	Degrees of freedom	p-value
Forest type	434.96	16	< 0.001
Regeneration type	845.87	1	< 0.001

was necessary, was 0.9 ± 0.87 ha, minimum clearing area 0.1 ha, maximum clearing area 7.6 ha (Figure 1) Mean clearcut area is larger in stands on peat soils – they represent 5% of the total number of damaged stands and 8% of the total area. It is in accordance with earlier findings that more damages (as proportion on growing stock) can be found on peat soils (Donis *et al.*, 2018).

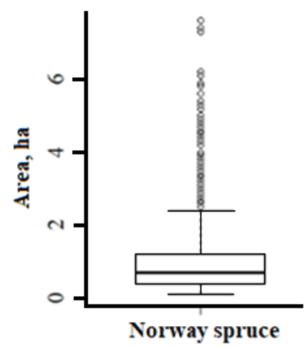

Figure 1. Distribution of size of sanitary clearcuts in Norway spruce stands after storm on January 8-9, 2005 (based on data from State Forest Service).

It demonstrates that the gap-dynamics, when only single trees or small groups of trees are falling, is not necessarily the only disturbance regime in Norway spruce forests. Combined with earlier findings on relatively successful post-storm regeneration of this species (Baders *et al.*, 2017), it leads to conclusion that close-to-nature silviculture for this tree species does not exclude a small size (as practiced in Latvia) clearcuts.

In a binary logistic analysis, it was found that the forest type, as well as regeneration type (planting or self-seeding) in sanitary clearcuts have a statistically significant impact (p<0.01) on the dominant species of trees 13 years after the storm (Table 2). However, in this case only 2 groups of forest types have been distinguished: on fertile soils and on poor soils (very seldom for Norway spruce stands, classified as 'other' in Table 1).

Natural regeneration in all forest type groups on fertile soils in most of the cases leads to dominance of species other than Norway spruce – mostly aspen and birch. From all naturally regenerated areas in such soil conditions only 19 – 21% are Norway spruce dominated (Figure 2). In general, this could increase the stability of future stands, since birch is more wind resistant (Donis *et al.*, 2018). However, it might negatively affect the productivity and thus the income for the forest owner (and economy as a whole). The highest share of natural regeneration (on average 50%) can be observed in forest types with peat soils: the sites, where the best productivity could

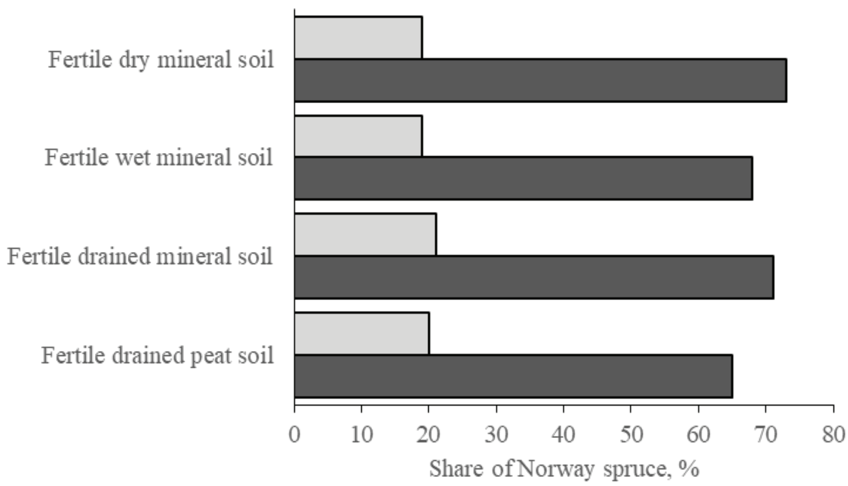

Figure 2. Share of Norway spruce in sites with fertile mineral or peat soils with differing moisture regime, depending on the regeneration method (based on data from State Forest Service): light grey – planting, dark grey – natural regeneration.

be achieved. Most of the Norway spruce young stands (78% on average) have formed after planting, and also most of planted areas (65 – 73%) are planted by Norway spruce. Thus – when the decision is made by the forest owner to invest in the forest regeneration, the less wind-resistant species is chosen. Such decision could be justified if the owners would also simultaneously apply measures to increase the wind-stability in stands, and/or apply it only on the very best soils, where other species grow notably slower than Norway spruce.

Conclusions

1. Wind-storm has created relatively large gaps in Norway spruce stands: 0.9 ± 0.02 ha; the openings in canopy cover due to storm impact, not exceeding 0.5 ha were 41% of the total number.
2. Majority (76% both from number and total area) of all sanitary clearcuts are in Norway spruce stands on fertile mineral soil; the proportion notably exceeded the share of these forest types in the total area of Norway spruce stands.
3. Changes of tree species after the storm happened in 55% of cases. Norway spruce had the highest share in the planted areas (78%), but lowest in naturally regenerated (19 – 21%) areas in forest types on fertile soils.

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