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Factors affecting windstorm damage at the stand level in hemiboreal forests in Latvia: case study of 2005 winter storm

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Highlights

- In hemiboreal forests in Latvia, dominant tree species, admixture of spruce in canopy-layer, mean height, timing of thinnings, upwind forest edges and wind gusts had significant effect on windstorm damage occurrence at stand-level.
- Stands on peat soils were more damaged than stands on mineral soils.
- Tree species composition of canopy-layer was not statistically significant in the model.

Abstract

In managed European hemiboreal forests, windstorms have a notable ecological and socio-economic impact. In this study, stand properties affecting windstorm damage occurrence at the stand-level were assessed using a Generalized Linear Mixed model. After 2005 windstorm, 5959 stands dominated by birch (*Betula* spp.), Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), with mean height > 10 m were inventoried. Windstorm damage was positively associated with spruce and pine-dominated stands, increasing mean height, fresh forest edges, decreasing time since the last thinning and stronger wind gusts. Tree species composition – mixed or monodominant – was not statistically significant in the model; while, the admixture of spruce in the canopy layer was positively associated with higher windstorm damage. Stands on peat soils were more damaged than stands on mineral soils. Birch stands were more damaged than pine stands. This information could be used in forest management planning, selection of silvicultural treatments to increase forest resilience to natural disturbances.

Keywords windstorm; hemiboreal; Norway spruce; natural disturbance
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1 Introduction

In a hemiboreal zone, natural forest disturbances substantially affect forest stand dynamics (Jõgiste et al. 2017), carbon cycling (Lindroth et al. 2009) and other ecosystem services (Millar and Stephenson 2015). However, in managed forests, natural disturbances have considerable negative economic impacts (Dale et al. 2001).

Between 1950 and 2000, wind damage accounted for more than half of all natural disturbances causing damage to European forests (Schelhaas et al. 2003). The amount of damage caused might increase due to increasing large-scale windstorm intensity, which has been observed over the last three decades, likely driven by climate change (Gregow et al. 2017). To mitigate the negative impacts of wind disturbance, forest ecosystem resilience should be increased by implementing sustainable forest management practices (Suvanto et al. 2016).

The probability of wind damage has regional differences, shaped by complex interactions between multiple factors e.g., wind climate, soil type, topography and silviculture practices (Albrecht et al. 2010; Lagergren et al. 2012; Díaz-Yáñez et al. 2017). Studies investigating such effects have been conducted in Fennoscandia (Valinger and Fridman 2011; Zubizarreta-Gerendiain et al. 2012) and Germany (Albrecht et al. 2010); in Baltic region such information is lacking. In Latvia, annual wind disturbance is the reason for 40 to 60% of all sanitary clearcuts, according to Latvian State Forest Service statistics (LSFS 2018). Therefore, the aim of this study was to identify significant effects of stand properties on windstorm damage occurrence.

2 Methods and materials

2.1 Study area

Latvia is located in the hemiboreal vegetation zone, which is characterized by a mixture of pure and mixed stands of deciduous and conifer tree species (Ahti et al. 1968). According to the National Forest Inventory, the dominant tree species are birch (*Betula* spp.), Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.), which occupy 28.2%, 26.9% and 18.3% of the total forest area, respectively (NFI 2017). The climatic conditions in Latvia are strongly influenced by the Baltic Sea, intensity of prevailing westerlies and large-scale weather systems, e.g., North Atlantic Oscillation (NAO) (Jaagus et al. 2010, 2014). NAO activity have been linked to winter storm frequency and intensity (Gregow et al. 2017).

In January 2005, the winter cyclonic windstorm Erwin (Gudrun) severely affected the territory of Latvia. It was the third severest windstorm since the 1960s, with maximal average wind speed of 29 m s^{-1} and with gusts of up to 40 m s^{-1}, according to the Latvian Environment, Geology and Meteorology Centre (LEGMC 2013). Approximately 11.1–15.6 million m^3 of wood were damaged (Donis et al. 2007).

2.2 Data Sampling

In total, 169 study plots of 1×1 km^2 (Fig. 1) were randomly scattered over the territory of Latvia (1–75, with the mean of 35 stands per plot). All forest stands within each plot were assessed by local LSFS foresters. Stand properties (tree species composition, mean height, relative stand density, mean stem diameter, soil type, timing of thinning) were obtained from an inventory, conducted prior the windstorm (Table 1). After the windstorm, damage (lost proportion of standing stock) and forest edge information was evaluated for each stand. Fieldwork was done in summer

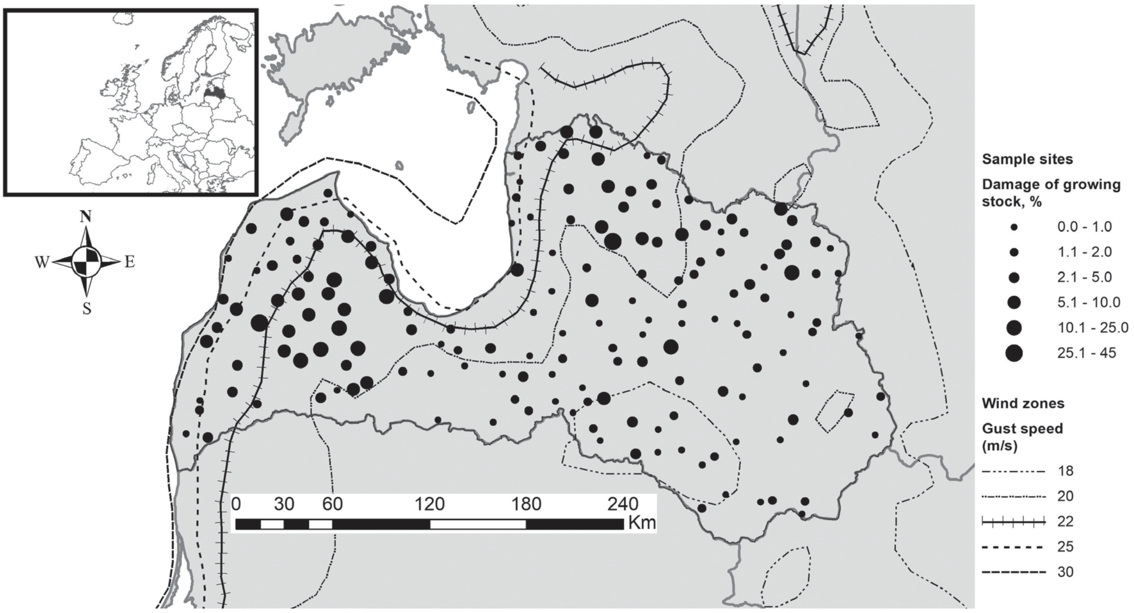

Fig. 1. Distribution of the study plots in the territory of Latvia.

2005. In total 5959 stands dominated by pine, spruce and birch with mean height >10 m were inventoried.

Map of maximal wind gust (m s^{-1}) at 10 m height were obtained from the Swedish Meteorological and Hydrological Institute (personal communication).

2.3 Data analysis

Effects of stand properties on windstorm damage (lost proportion of standing stock) were assessed by random intercept Generalized Linear Mixed model (GLMM) using maximum likelihood (Laplace Approximation) approach (Bates et al. 2015) and Gamma distribution with "log" link function. The study plot was used as a random factor. Dependant variables were added 0.1 to fit the Gamma distribution. All continuous variables (e.g. diameter) were scaled.

Multicollinearity between explanatory variables were assessed using Generalized Variance Inflation Factor (GVIF), variables with GVIF>5 were excluded from the model, in our case – mean stem diameter.

In the analysis, we compared two models: Model_1, which contained all factors retained after GVIF analysis and Model_2, adding to Model_1 interaction between the factors "dominant tree species" and "wind gust region" and "dominant tree species" and "timing of thinning".

For description of the model performance marginal and conditional pseudo-R^2 values were calculated using lognormal method. The selection of the best model was based on AIC (McGullagh and Nelder 1989).

All calculations were performed using R version 3.5.0 (R Core Team 2018) packages "car" (Fox and Weisberg 2011), "lme4" (Douglas et al. 2015).

Table 1. Description of explanatory variables tested in the model. Number of observations for categorical variables; mean ± standard deviation (SD) for continuous variables.

Abbreviation	Description	Classes	Number of observations / mean ± SD
st10	Dominant tree species (> 50 % of stand volume)	1 – birch	2010
		2 – pine	2854
		3 – spruce	1095
stand_str	Composition of canopy-layer	1 – mixed	3635
		2 – monodominant (≥ 75% of standing volume)	2324
mix_spruce	Admixture of spruce in canopy-layer		0.07 ± 0.11
storey_spruce	Admixture of spruce in understory	0 – no spruce	4918
		1 – spruce admixture	1041
dens_group	Relative stand density (calculated as ratio between basal area per hectare and the maximum stand basal area for a species and mean height)	1 – (≤ 0.4)	163
		2 – (0.5–0.8)	3544
		3 – (0.8–1.0)	2252
h10	Mean height of the dominant canopy trees (m)		21.27 ± 4.76
d10	Mean diameter of the dominant canopy trees (cm)		23.56 ± 6.73
h2d	Height^2/diameter ratio		19.58 ± 4.59
soil_group	Soil type (based on forest type group)	1 – dry mineral soil	1353
		2 – wet mineral soil	2752
		3 – peat soil	201
		4 – drained mineral soil	903
		5 – drained peat soil	750
thin_befk	Timing of thinning	1 – thinned more than 10 years ago or no information on thinning	4888
		2 – thinned within last 6 to 10 years	475
		3 – thinned within last 5 years	596
wind_dir	Adjacent upwind zone of the forest edge	BL – new forest edge (fresh clearcut/ young stand < 5 years)	190
		GL – old forest edge (young stand with mean tree height < 5 m / wetland / agriculture land)	840
		H – high-forest edge (forest stand with mean height > 5 m)	4929
gust_group	Wind gusts region	1 – (17–19 m s^{-1})	2830
		2 – (20–21 m s^{-1})	1502
		3 – (22–24 m s^{-1})	980
		4 – (25–30 m s^{-1})	647

3 Results

The Model_2 was chosen as the final model, based on lower AIC values, with conditional and marginal pseudo-R^2 values of 0.70 and 0.14, respectively. The final model had eleven statistically significant variables (shown in Table 2).

Windstorm damage was positively associated with spruce and pine-dominated stands, increasing admixture of spruce in canopy-layer, increasing mean stand height, higher wind gusts and fresh

Table 2. Parameter estimates of fitted model. (Df): degree of freedom, * – interaction between factors.

Explanatory variables	Chi-squared	Df	p-value
st10	296.6	2	<0.001
gust_group	44.8	3	<0.001
stand_str	1.4	1	0.22
mix_spruce	131.9	1	<0.001
storey_spruce	0.5	1	0.46
dens_group	44.6	2	<0.001
h10	49.6	1	<0.001
h2d	7.2	1	<0.01
thin_befk	266.7	2	<0.001
wind_dir	302.6	2	<0.001
soil_group	10.7	4	0.03
st10 * gust_group	13.1	6	0.04
st10 * thin_befk	16.4	4	<0.01

Random effects (study plot): variance 2.9; standard deviation 1.72

Table 3. Fixed effects parameter estimates of fitted model. (SE): standard error, * – interactions between factors.

Explanatory variables	Estimate	SE	t-value	p-value
Intercept	1.96	0.18	10.4	<0.001
st10: pine	0.16	0.07	2.1	<0.05
st10: spruce	1.03	0.08	11.7	<0.001
gust_group: 2	1.06	0.18	5.6	<0.001
gust_group: 3	1.06	0.22	4.8	<0.001
gust_group: 4	0.73	0.26	2.7	<0.01
stand_str: monodominant	0.05	0.04	1.2	0.22
mix_spruce	0.26	0.02	11.4	<0.001
storey_spruce: 1	0.04	0.05	0.7	0.45
dens_group: 2	–0.66	0.12	–5.5	<0.001
dens_group: 3	–0.79	0.12	–6.4	<0.001
h10	0.27	0.03	7	<0.001
h2d	–0.1	0.03	–2.6	<0.01
thin_befk: 2	0.53	0.13	4.1	<0.001
thin_befk: 4	0.93	0.12	7.3	<0.001
wind_dir: GL	–1.4	0.12	–11.6	<0.001
wind_dir: H	–1.83	0.11	–16.3	<0.001
soil_group: 2	–0.07	0.06	–1.1	0.25
soil_group: 3	0.2	0.07	2.5	<0.05
soil_group: 4	0.05	0.06	0.7	0.44
soil_group: 5	0.00008	0.07	0	0.99
st10: pine * gust_group: 2	–0.06	0.12	–0.5	0.58
st10: spruce * gust_group: 2	–0.1	0.13	–0.7	0.44
st10: pine * gust_group: 3	–0.21	0.13	–1.5	0.11
st10: spruce * gust_group: 3	0.08	0.16	0.5	0.61
st10: pine * gust_group: 4	–0.44	0.15	–2.8	<0.01
st10: spruce * gust_group: 4	–0.06	0.21	–0.3	0.75
st10: pine * Thin_befk: 2	–0.18	0.15	–1.1	0.24
st10: spruce * Thin_befk: 2	–0.57	0.21	–2.7	<0.01
st10: pine * Thin_befk: 4	0.07	0.15	0.4	0.63
st10: spruce * Thin_befk: 4	0.51	0.19	2.6	<0.01

forest edges. Windstorm damage was negatively associated with increasing stand relative density, increasing time since the last thinning and increasing h^2/d ratio (Table 3). The canopy-layer tree composition (mixed or monodominant) did not have statistically significant influence on damaged stock (Table 3). Stands on peat soils had significantly more damaged stock than stands on mineral soils. Pine-dominated stands in wind gusts region (25–30 m s^{-1}), had significantly less damaged stock than birch-dominated stands in the same wind gust region. Spruce-dominated stands which had been thinned within last 5 years had significantly more damaged stock than birch-dominated stands thinned within the same time period. While, spruce-dominated stands which were thinned in the last 6–10 years, had significantly less damaged stock than birch-dominated stands with the same timing of thinning (Table 3).

4 Discussion

This work summarizes the significant effects of stand properties on damaged standing volume, based on data collected throughout territory of Latvia after the windstorm of 2005. Our study results were in alignment with earlier studies carried out in southern Sweden (Valinger and Fridman 2011) and south-western Germany (Albrecht et al. 2010), where similarly spruce admixture, increasing mean stand height, fresh forest edges and recent thinnings increased stand susceptibility to windstorm damage.

Increasing windstorm damage with decreasing relative stand density is difficult to explain, as relative density did not correlate with timing of thinning, suggesting that vulnerability to wind damage might be related to historical forest stand management.

In our study, tree species composition was not statistically significant in the model. Although pure Norway spruce stands are considered the most vulnerable to windstorm damage (Valinger and Fridman 2011), also mixed stands are often damaged by wind and snow, and in some cases, even more than monodominant stands (Díaz-Yáñez et al. 2017).

Higher damages in stands on peat soils mostly likely is linked to shallow rooting, which affects tree stability (Nicoll and Ray 1996). Similar results have been obtained in Finland, where stands on peat soils had severe windstorm caused damages (Zubizarreta-Gerendiain et al. 2012). In 2005 windstorm, soils were unfrozen, under these conditions trees commonly are uprooted and birch has weaker resistance to uprooting than pine (Peltola et al. 2000), which might be the reason of larger damages in birch and in pine stands in wind zone (25–30 m s^{-1}).

Our results suggest that the vulnerability to windstorm damage could be addressed through silvicultural treatments. Wind resistance of individual trees could be improved by decreasing initial stand density (Gardiner and Quine 2000). In this way, the number of thinnings could be reduced. Lower initial stand density could benefit growth of a radial increment (Gardiner and Quine 2000), which might reduce the rotation period as target diameter could be reached faster, therefore minimizing the probability of windstorm damage. However, many uncertainties are linked to climate change and its various impacts on regional wind climate and forest growth (Blennow et al. 2010). General conclusions based on single storm events must be treated with caution (Albrecht et al. 2010; Valinger and Fridman 2011). Therefore, further studies could combine and analyse data of several windstorm events, to assess forest stand susceptibility to windstorm damages on broader perspective.

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Total of 26 references.