TREE DAMAGES BY ICING IN SCOTS PINE (*PINUS SYLVESTRIS* L.) STANDS AND FACTORS AFFECTING THEM

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Abstract

Icing notably increases the mass of a tree crown, causing damage to the tree. So far, a very limited number of studies have assessed the icing influence on coniferous trees, none of them in Latvia. The aim of the study was to assess the influence of tree parameters and recent thinning on the proportion of damaged trees and the type of damage in Scots pine stands. The study sites were located in the eastern part of Latvia, damaged in December 2012. In total, 98 pine dominated stands of different age were selected randomly. Eight (mean) plots per stand were established; in each plot, all trees larger than 2.1 cm were measured and the type of damage assessed. The above-ground biomass from 12 randomly selected stands (57 dominant trees) of different age was weighted with and without icing. The biomass of pine with icing exceeded that without 1.5 ± 0.27 times. The mean proportion of damaged trees in pine dominated stands was 26%; the proportion of broken trees peaked in the middle-aged stands (41 – 70 years old), but the largest proportion of pooled bent and uprooted trees was found in the young (11 – 20 years old) stands. The proportion of damaged dominant trees was affected by the slenderness coefficient – a higher proportion of such trees was found among more slender trees. The results suggest that the risk of icing damage could be reduced by silvicultural measures boosting individual tree stability.

Key words: natural disturbance, stem breakage, stem bending.

Introduction

The freezing rain, i.e. phenomena when liquid precipitation freezes on a cooled surface, causes icing (Drage, 2005). In Latvia, favourable conditions for occurrence of freezing rain are caused by the dominant western wind direction, which moves the cyclones of the North Atlantic Ocean (Jordi & Sultan, 2009), as well as by increasing continentality from west to east (Draveniece, 2007). Historically, freezing rain has been more frequently observed in the eastern part of Latvia, and it is not expected to decrease due to climatic changes. For instance, in Germany the damage of trees caused by snow and icing occurs after each 3 – 7 years (Rottmann, 1985), but in Sweden notable damage (from 100 thousand to 1 million m^3 wood) has been caused by ten snow storms at the end of the last century (Schroeder & Eidmann, 1993). In contrast to some other natural disasters, e.g. forest fire which affects the survival and regeneration of pines (Zadiņa, Donis, & Jansons, 2015), the icing cannot be prevented. A number of studies have been done to understand the regional differences of the formation of freezing rain (Carrière *et al*., 2000; Makkonen & Ahti, 1995). However, the monitoring of icing is mainly related to increased loading to infrastructure, e.g. power lines. The effect of icing on forest stands has been studied less and includes the combination with other factors, mainly snow and wind. Icing increases loading on the tree stem and crown, causing mechanical deformation or irreversible damage. The layer of 1 – 2 cm thick icing is believed to cause notable damage of branches (Greene, Jones, & Proulx, 2007). However, the individual stem integrity depends on many factors, among which the main are physically-mechanical properties of wood, the accumulated amount of ice, additional loading of snow load, duration of loading and wind speed (Bragg, Shelton, & Zeide, 2003). The type (Croxton, 1939; Irland, 2000) and severity of damage differs between the stands due to the differences of tree species composition, age structure, density, spatial distribution of crowns (Turcotte et al., 2012), as well as between individual trees due to the differences of stem straightness, branching symmetry and structure, root vitality (Bragg, Shelton, & Zeide, 2003; Hauer, Werner, & Dawson, 2008; Päätalo, Peltola, & Kellomäki, 1999); thus information of precise thresholds is missing. Nevertheless, most of these characteristics can be altered by silvicultural measures (Goodnow, Sullivan, & Amacher, 2008). Therefore, the aim of the study was to assess the influence of tree parameters and recent thinning on the proportion of damaged trees and the type of damage in Scots pine dominated stands.

Materials and Methods

The Scots pine (*Pinus sylvestris* L.) dominated stands were assessed in the eastern part of Latvia (Rēzekne, Baltinava, Balvi and Kārsava municipalities) after the icing event in December 2012. In 12 pine stands of different age classes, 55 broken and bent dominant pines representing diameter at breast height from 2 to 17 cm were randomly selected and cut. The above-ground biomass with icing was weighted using KERN HCB scales (*precision* 200 g). The tree biomass was measured repeatedly after the icing melted.

The icing damage was assessed in randomly selected 98 pine dominated (at least 70% from standing volume) stands with the minimum area of

Table 1

The characteristics of the studied stands

Age, years	N	G, m^2 ha^{-1}	DBH, cm	H, m	Number of measured trees	Proportion of damaged trees, %
11 – 20	12 (12)	5	8	6	3506	32
31 – 40	7 (7)	17	14	14	179	42
41 – 50	4 (1)	24	18	19	1867	29
51 – 60	19 (16)	26	20	21	2110	26
61 – 70	2 (1)	19	25	22	129	36
71 – 80	15 (7)	29	26	24	2462	23
91 – 100	18 (6)	33	28	26	488	37
>101	21 (3)	31	28	24	1902	24

N – total number of stands (number of stands thinned during the last 3 years); G – stand basal area; DBH – mean diameter at breast height; H – mean height.

0.8 ha; according to the stand inventory data, the age of the stands was 12–123 years. The stands were evenly distributed across the study area and were located on dry mineral soils (forest types according to Bušs (1976): sandy and loamy automorphic soils (*Cladinoso–callunosa*, *Vacciniosa*, *Myrtillosa*, *Hylocomiosa*), wet mineral soils (*Vaccinioso–sphagnosa*, *Myrtilloso–sphagnosa*), poor peat soils (*Caricoso–phragmitosa*), as well as on drained mineral and peat soils (*Myrtillosa mel*. and *Myrtillosa turf.mel*.), respectively. In each stand, eight (mean) sample plots of 200 m^2 area were established. Sample plots were evenly distributed within the stand, located at least 10 m from its edges. For each tree, the type of icing damage (not damaged, bent, broken or uprooted) was denoted, and the height and diameter at breast height (DBH) was measured (Table 1). Trees smaller than 2.1 cm DBH were not included in the study. Trees were classified as 'bent' if the stem deviation form vertical axis exceeded 15°, including trees with bent top; if the stem deviation exceeded 85° (including fallen trees), the tree was classified as 'uprooted'. During the analysis, 'bent' trees were pooled with 'uprooted' trees due to the low number of the latter trees; further named as 'bent/uprooted' trees. In total, data of 12,643 trees were analysed. The slenderness coefficients, defined as the ratio of tree height to DBH, were calculated from individual tree data. Stands are especially prone to ice and snow caused damages in the first years after thinning (Bragg, Shelton, & Zeide, 2003). Therefore, the influence of thinning was assessed between the 'recently' thinned, i.e. during the last 3 years and the 'other' stands – not thinned or thinned more than 3 years ago.

The normality of data was assessed by Shapiro-Wilk test. The relationship between the tree above-ground biomass with and without icing and the relationship between the proportion of broken and bent/uprooted trees and stem DBH were assessed by the linear model. The one-way analysis of variance was used to assess the differences of the proportion of broken and bent/uprooted trees between the stands of different age and the differences of the proportion of damaged trees in the recently thinned and the other stands between the stands of different age.

Results and Discussion

The weight of the dominant pines with icing 1.5 ± 0.27 times exceeded that without ice in the naturally moist condition. The biomass of pine and weight of icing on it were significantly and tightly related ($r=0.71$; $p<0.01$) (Fig. 1). However, notable variation of the icing weight for pines of different sizes was noted, presumably caused by the asymmetry of a tree crown or influenced by wind. The information of threshold of icing mass or layer beyond which the tree broke is missing; some authors have reported the threshold of layer thickness 1.0 – 2.5 cm (Greene, Jones, & Proulx, 2007; Hauer, Werner, & Dawson, 2008).

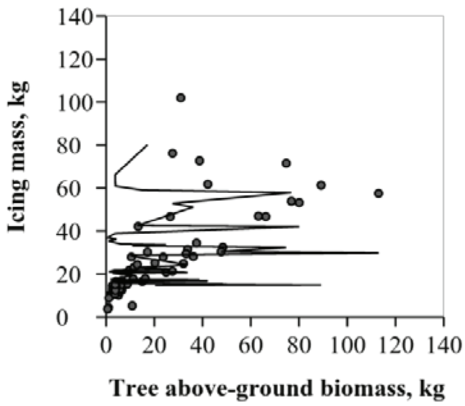

Figure 1. The relation between the tree biomass and icing mass.

In the studied stands, the proportion of damaged spruces, pines and birches was 20, 26 and 32%, respectively; in total 26% of all trees. A higher proportion of trees were broken than bent/uprooted: 18 and 7%, respectively. During the icing event, the soil was unfrozen, presumably increasing the proportion of the bent and uprooted pines. The effect of soil conditions on the type of damage has been reported (Gregow, 2013; Peltola *et al*., 1999). For instance, on frozen soil a higher number of pines are broken or bent, while on unfrozen soil the uprooting is more common, especially for spruce due to its shallow root system (Gregow, 2013). Also the interaction between abiotic factors affects the type of damage. For instance, the snow loading of at least 20 kg m^{-2} with simultaneously increasing wind force will more likely cause stem breakage than uprooting (Gregow, 2013). The assessment of such interaction was not possible in our study since the icing affects a certain discrete location and no meteorological station was located in it.

The proportion of damaged trees was significantly ($p<0.05$) affected by the stand age (Fig. 2). The lowest proportion (6%) of the broken trees was in the youngest stands; it peaked (26 – 35%) at the middle-aged stands, significantly exceeding the proportion of broken trees at the other age classes. Among the older stands, the proportion of broken trees was 14 – 21%. The proportion of bent/uprooted trees showed an opposite pattern: the highest proportion (22%) of such trees was found at the age of 11 – 20 years, and the lowest (4%) – at the age of 71 – 80 years. In the older stands, the proportion of bent/uprooted trees slightly increased; a high proportion (18%) of such was obtained at the age of 100 – 110 years, which was represented by only one stand. Similar observations were done in Finland (Nykänen *et al*., 1997), indicating that the snow accumulation has a

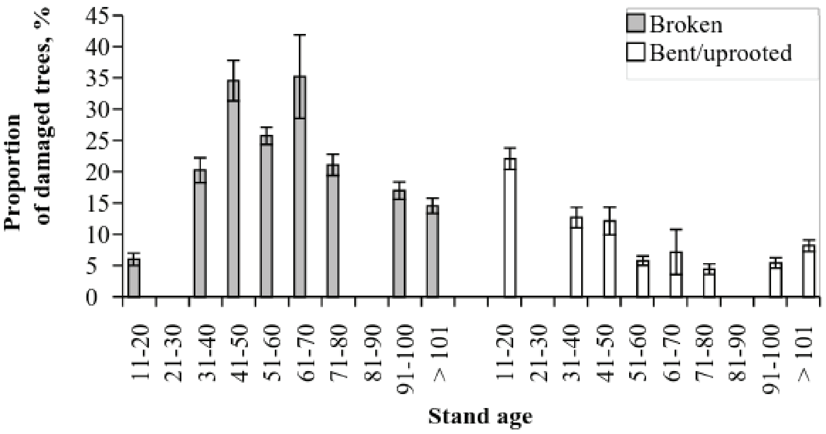

Figure 2. The proportion of broken and bent/uprooted trees in pine dominated stands according to the stand age. The error bars denote 95% confidence interval.

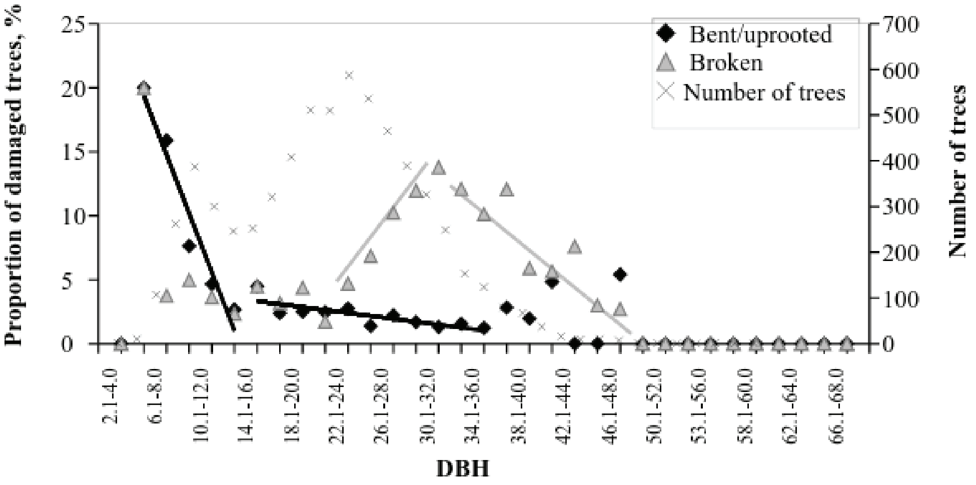

Figure 3. The proportion of the damaged dominant pines according to the diameter at breast height (DBH). The significant ($p<0.05$) trends are denoted by lines: grey – broken trees; black – bent/uprooted trees.

Table 2

The coefficients of equations () of the proportion of damaged dominant pines according to the diameter at breast height (DBH) classes

Type of damage	DBH classes, cm	Coefficients	R^2	p-value	
		b_0	b_1		
Bent/uprooted	4-12	0.28529195^{**}	-0.0459033^{**}	0.94	0.005
	14-34	0.0492392^{***}	-0.0022955^{**}	0.66	0.002
Broken	6-20	0.04812071^{**}	-0.0019466	0.19	0.285
	22-30	-0.2067749^{**}	0.02321109^{**}	0.99	0.001
	32-48	0.35563495^{***}	-0.0145005^{***}	0.86	0.000

* p<0.05; ** p<0.01; ** p<0.001.

high probability of uprooting tree groups in young, dense stands (slender trees with short, asymmetric crown) but the stem breakage more frequently occurs in the middle-aged and mature stands.

The proportion of bent/uprooted dominant pines had a significant negative relation to the tree DBH: it decreased rapidly for trees 4.1-14.0 cm DBH (Fig. 3; Table 2) and continued to decrease gradually for pines of 14.1 to 36.0 cm DBH. For larger pines (DBH 36.1-48.0 cm), the proportion of bent/uprooted pines fluctuated. In contrast, the proportion of broken pines had a significant positive relation to the tree DBH for trees 22.1-32.0 cm, peaking at 15.1%. After the peak, the proportion of broken pines decreased (DBH 32.1-50.0 cm) with a slight fluctuation. These results are consistent with the observation in the mature spruce-beech stands, where the proportion of the broken trees caused by the snow loading showed a positive relationship to the tree DBH until the peak of ca. 15% for trees with DBH 18 – 20 cm, followed by a gradual decrease for larger trees (Hlásny *et al*., 2011). Stem breaks if its bending resistance is lower than the strength of roots; for instance, for spruce the stem resistance to breakage has a tight relation to the tree diameter and can be described by the function DBH^3 (Nykänen *et al*., 1997; Petty &Worrell, 1981). In contrast, the uprooting occurs if the accumulated snow and ice loading exceeds the strength of roots (Valinger, Lundqvist, & Bondesson, 1993) – that is more likely to happen to older (mature or over-mature) trees with a relatively large DBH and crown (Peltola *et al*., 1999), but is also observed in young, thinned stands (Hlásny *et al*., 2011). The root resistance to uprooting can be described by the function $H \times DBH^2$, indicating a substantially larger importance of tree DBH than height (H) on the uprooting probability (Peltola *et al*., 1999), presumably due to larger root biomass for trees with larger DBH, as determined in empirical studies in young Scots pine stands (Bārdulis, Jansons, & Liepa, 2011, 2012).

In our study, the damaged trees had a larger stem slenderness coefficient than undamaged trees, regardless of the thinning: in the recently thinned stands it was 1.07 and 0.93 and in the other stands 1.01 and 0.94, respectively. This trend remained in the assessment of the diameter classes and slenderness groups of the pines (Fig. 4). Likewise, other studies also have confirmed that the slenderness has a significant effect on the wind and snow caused damage in pine stands (Päätalo, Peltola, & Kellomäki, 1999). For instance, under the snow load of 60 kg m^{-2} simultaneously with 9 m s^{-1} wind, slender trees (tree height 12 – 24 m, slenderness coefficient >0.83) had a higher probability of stem breakage; and the

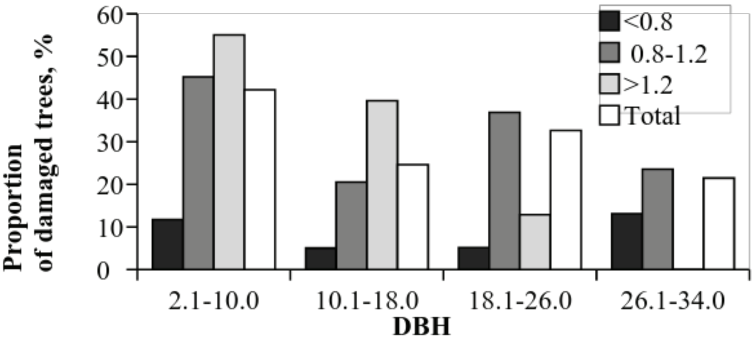

Figure 4. The proportion of the damaged pines according to the diameter at breast height (DBH) class and slenderness coefficients.

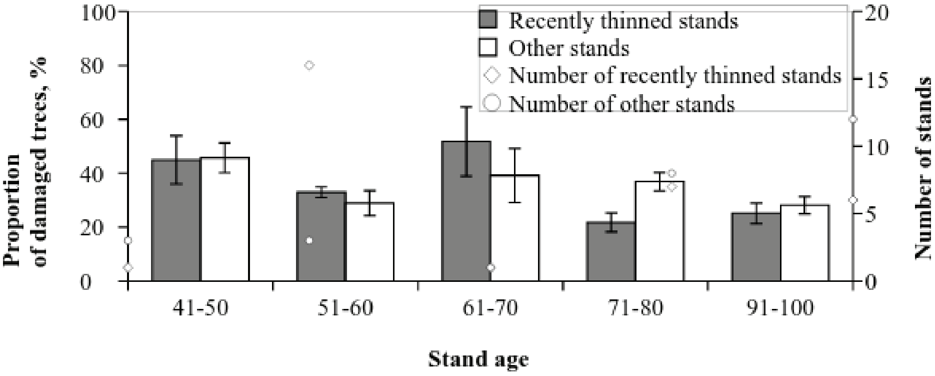

Figure 5. The proportion of damaged dominant trees according to the stand age in the recently thinned stands (i.e. thinned during the last 3 years) and in the other (i.e. thinned earlier or not thinned) pine dominated stands. The error bars denote 95% confidence interval.

proportion of broken trees decreased with decreasing slenderness coefficient of a tree. Also, the icing damage is more likely for the relatively slender trees; the reported threshold 0.9 – 1.0 (Bragg, Shelton, & Zeide, 2003; Cannell & Morgan, 1989; Nykänen *et al.*, 1997). Tree breeding as a financially viable activity is practised in a number of countries in the Baltic Sea region, including Latvia (Gailis & Jansons, 2010; Jansons, Gailis, & Donis, 2011; Jansons *et al.*, 2015a) and it has showed a notable effect on the growth traits of Scots pine (Jansons, 2005; Jansons *et al.*, 2006). It has been demonstrated, that genetics has a notable influence on the tree slenderness (Kroon, Andersson, & Mullin, 2008) and, therefore, genetics can affect the probability of icing caused damages. Also genotype x environment interaction (Jansons, 2008) might be of importance. For instance, changing climate will affect both height and diameter growth of pines (Jansons *et al.*, 2013a; Jansons *et al.*, 2013b; Jansons *et al.*, 2015b), but not to the same extent, presumably altering the slenderness of trees (Salminen, Jalkanen, & Lindholm, 2009). The influence of genetics (provenance) was a significant factor affecting reaction of Scots pine to different climatic conditions (Rieksts-Riekstiņš *et al.*, 2014), supporting the assumption that genetics might modify the effect of climatic changes on the tree slenderness coefficient. Nevertheless, genetics (both at clone and provenance level) can have a significant influence also on the biomass distribution, including the height of the mass point, and crown properties of young (25 - 39 years) coniferous trees. However, these differences were related to the influence of genetics on growth traits that tightly correlated with the particular crown traits, but not due to 'direct' genetic influence (Jansons *et al.*, 2014; Lībiete-Zālīte & Jansons, 2011).

In the recently thinned stands, the proportion of the damaged (pooled all types of damages) dominant trees were similar to that in the other stands: 25 and 26%, respectively. However, no clear relation of the proportion of damaged trees was found according to the DBH groups or age decades (Fig. 5). Significant differences were found only within the age class of 71 – 80 years: the proportion of the damaged dominant trees in the recently thinned stands was lower ($p<0.05$) than in the other stands. Presumably, the level of damage caused by icing was affected not simply by the timing of thinning but, in particular, by the applied management, represented as the noted influence of the slenderness on the proportion of damaged trees. This assumption is supported by results from dense, unthinned stands, where trees with a high slenderness coefficient and asymmetric, small crowns are prone to wind, snow and icing, moreover – mainly the dominant trees are damaged (Nykänen *et al.*, 1997). Similar results were obtained when 30 – 100 years old managed stands were compared with similar age, unmanaged (delayed or no thinning, very slender trees) stands. In the latter, the threshold of tree breakage and uprooting is notably lower than in the managed stands: the stem broke under the snow load of 10 – 25 kg m^{-2} and 54 – 60 kg m^{-2} (Päätalo, 2000; Peltola *et al.*, 1999), but uprooting occurred under the snow load of 10 – 23 kg m^{-2} and 17 – 53 kg m^{-2}, respectively (Päätalo, 2000). In the long term, thinning may decrease the probability of damage by 40% (Valinger, Lundqvist, & Bondesson, 1993) but the recently thinned stands are especially prone to icing (Bragg, Shelton, & Zeide, 2003). The possible cause of these differences from our results is, that the timing of the thinning (age of stand) or the proportion of the removed stand basal area could have a stronger effect than the time passed after the thinning itself. Trees need to adjust to the altered conditions, i.e. to increase stem diameter (and taper) and anchor the root system, and this time is reported to be from three (Zubizarreta-Gerendiain *et al.*, 2012) to eight (Nykänen *et al.*, 1997) years.

Conclusions

In the area where the icing weight was 50% of the above-ground biomass of Scots pine in the naturally moist condition on unfrozen soils, the proportion of the damaged trees in the pine dominated stands was 26%. The type of damage was related to the stand maturity: the highest proportion of broken pines was found in the middle-aged stands, but the highest proportion of bent pines – in the young stands. The recently thinned stands had no clear differences of the proportion of the damaged dominant trees in comparison to the other stands. However, the applied management influenced the proportion of damaged trees, as indicated by more frequent damages to pines with a higher slenderness coefficient. Therefore, the results suggest that the risk of icing damage of Scots pine could be reduced by silvicultural measures to increase the individual tree stability.

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