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Research paper

Wind-induced stem breakage height effect on potentially recovered timber value: case study of the Scots pine (*Pinus sylvestris* L.) in Latvia

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Abstract. In Europe, salvage-logging is a common management activity to partially recover economic value from wind disturbed forests. In the near future, wind damage to forests is predicted to increase due to climate change. Therefore, an economic assessment of wind damage effects on recovered timber value is useful information in the decision-making process. In this study, we aim to assess the influence of different stem damage heights on the monetary value of recovered timber. We simulated stem breakage at three heights for the Scots pine (*Pinus sylvestris* L.): 3, 5, and 7 m. For comparison, we used an uprooted tree without stem breakage. Our results revealed that the most negative influence on the recovered timber value was stem breakage at 3 m, which decreased the monetary value by 35%. The stem breakage at 5 and 7 m decreased the recovered timber value by 9–10%. Over the analysed period (2006–2017), no significant differences in the monetary value of the recovered timber were found between uprooted lumber and stems with breakage at 5 and 7 m. The price fluctuations in the market have a significant influence on the recovered timber value, which might cause a larger decrease in monetary value than stem breakage.

Key words: forest disturbance, wind damage, post-disturbance management, salvage logging, timber value.

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Introduction

Wind is the key disturbance agent in European forests, accounting for more than 50% of damage over the second half of the twentieth century (Schelhaas *et al.*, 2003). Winter storms, which originate over the North Atlantic Ocean, cause the most severe damage to European forests and infrastructure (Gardiner *et al.*, 2010). By 2085, the insurance loss caused by winter storms could reach 3.5 billion euros (Schwierz *et al.*, 2010). Over the Baltic States, northern Germany, and Poland, an increase in extreme wind gusts due to climate change has been predicted (Schwierz *et al.*, 2010). During winter seasons in the Baltic countries, intensification of the westerlies has already been observed (Jaagus & Kull, 2011), suggesting that an increase in wind damage to forests could be expected in the near future in Latvia.

In northern Europe, the Scots pine (*Pinus sylvestris* L.) has a higher resistance bending moment for uprooting than the Norway spruce (*Picea abies* (L.) Karst.) and

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silver birch (*Betula pendula* Roth.) (Peltola *et al.*, 1999; 2000), but tree species' sensitivity to wind damage greatly varies depending on forest management history, climate, ecological conditions, and windstorm characteristics (Dhôte, 2005; Quine & Gardiner, 2007; Gardiner *et al.*, 2016; Donis *et al.*, 2018). During winter storms, conifers are more vulnerable to damage than leafless broadleaved trees due to higher drag (Peltola *et al.*, 2013), which was also observed after the January 2005 wind storm in Latvia (Donis *et al.*, 2018). In north-eastern Poland, during summer wind storms, the Scots pine suffered a higher mortality rate than other tree species (black alder (*Alnus glutinosa* (L.) Gaertn.) and Norway spruce), yet direct causal factors that affect damage severity were not clearly identified (Szwagrzyk *et al.*, 2017).

Wind damages trees when the maximum applied bending moment is greater than the resistive bending moment, which is determined by the root system and tree stem (Peltola *et al.*, 1999; 2013). When wind gusts are stronger than root anchorage, trees are uprooted, but when the wind gusts are stronger than the stem wood, trees break (Peltola *et al.*, 1999; Gardiner *et al.*, 2016). Saturated soils increase the risk of tree uprooting (Quine & Gardiner, 2007). When soils are frozen, the risk of uprooting decreases; however, the risk of stem breakage increases, especially for the Scots pine (Peltola *et al.*, 2013). Scots pine breakage has also been observed during summer, when wind speeds are exceptionally strong at 170 km/h (Szwagrzyk *et al.*, 2017). It has been observed that, for the Scots pine, breakage usually occurs in the lowest third of the tree height; however, it has not been investigated systematically (Gardiner *et al.*, 2016). As more severe storms occur during winter (Gardiner *et al.*, 2010), stem breakage for the Scots pine could be damage more common than uprooting.

Similarly, in Latvia, wind is the main natural disturbance agent, causing the majority of annual natural disturbance damage to forests, according to the Latvian State Forest Service (LSFS, 2018). The last severe winter cyclonic windstorm Erwin (Gudrun) severely affected the territory of Latvia in January 2005, damaging 11.1–15.6 million m^3 of wood (Donis *et al.*, 2007). The increasing risks of future windstorm damage in northern Europe (Schwierz *et al.*, 2010) will lead to increased economic loss. Salvage-logging after windstorms is widely practised in managed forests to recover at least the partial economic value of damaged forests and to decrease the probability of a secondary disturbance (e.g. a bark beetle outbreak; Havašová *et al.*, 2017).

By improving the post-disturbance management decision-making process, the negative effects of windstorms could be minimised. Research shows that a stem breakage greater than 10 m has the most negative economic effect (Gardiner *et al.*, 2010); however, a more detailed assessment of the influence of stem breakage height on the recovered assortment volume is lacking. Therefore, the aim of this work is to evaluate the influence of stem breakage height on potential timber assortment recovery for the Scots pine. We hypothesise that decreasing the stem breakage height decreases the value recovery. In this research, we selected the Scots pine because it has a significant ecological and socio-economical value and an important carbon sequestration role (Jansons *et al.*, 2017; Kenina *et al.*, 2018). It is the most common tree species in Latvia, accounting for 225 million m^3 of yield, according to data from the National Forest Inventory (NFI, 2017).

Material and Methods

In this study, we simulated the wind damage effects on the potential timber assortment recovery. We tested stem breakage at three heights (from stump height): 3, 5, and 7 m. The stem without breakage represents an uprooted tree. For simulation, we selected eight different tree diameters at breast height (DBH): 8, 12, 16, 20, 24, 28, 32, and 36 cm. The tree height for each DBH class was obtained from the NFI (2017), based on the mean height of the pine growing in the *Hylocominosa* forest type (Bušs, 1976), which represents common and optimal growth conditions for pine forests in Latvia. The stem volume of the sample trees was calculated using taper curve equations as a function of the tree height and DBH (Ozolins, 2002). The bucking algorithm based on stem volumes and pre-defined timber assortments generated optimal cuts to maximise the value of the stem (Ozolins, 2002; Donis, 2014).

In calculations, we used four pre-defined timber assortments based on DBH: 1) saw log (DBH >14 cm), 2) saw log (DBH 10–14 cm), 3) pulpwood (DBH 6–10 cm), and 4) energy wood (DBH < 6 cm). The length of the potential timber assortments was obtained from the Joint Stock Company's 'Latvia's State Forests' wood procurement specifications. The length for different timber assortments varied from 3 to 6 m (LVM, 2019). Measurements 1 m above and 30 cm below the stem breakage height were counted as an energy wood assortment. The values (€/m^3) of the timber assortments were obtained from the Central Statistical Bureau of Latvia over the last 10 years. The price of timber has varied considerably in Latvia (Figure 1). The lowest price was recorded in 2009 during the global financial crisis, when it dropped by 35% in comparison to earlier periods. Over the years after 2009, the price of timber steadily rose; however, it did not reach the highest price level, which was recorded in 2007.

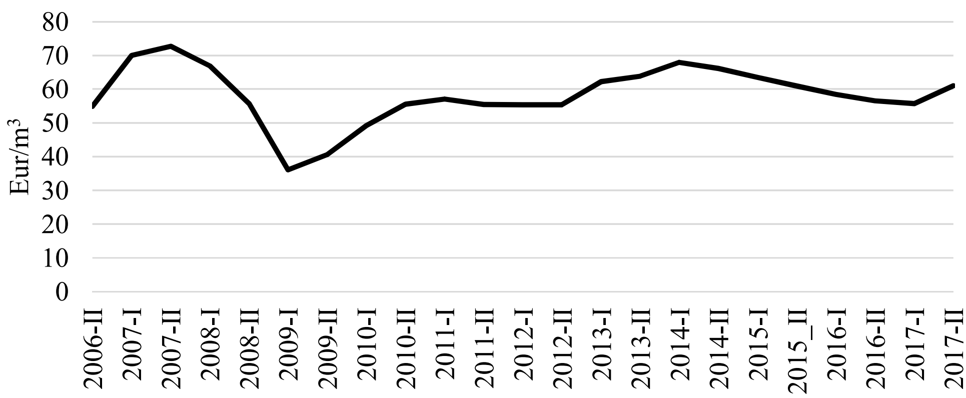

Figure 1. Mean price of timber assortments per m^3 in 2006–2017 in Latvia.

We used the Pearson chi-square independence test to assess the significant differences between the two groups. All calculations were done using R (v. 3.5.1; R Core Team, 2018).

Results

In the group with DBH at 8 cm, no significant differences between different groups (uprooted and 3, 5, and 7 m) in the proportional distributions of the log assortments were observed using the chi-square test (Figure 2). In the DBH group at 12 cm, significant differences were found between uprooted and all stem breakage heights (3, 5, and 7 m), with a *p*-value of < 0.05 in all cases (Table 1). In the groups with a DBH of 16 or 20 cm, significant differences were found between the 3 m breakage height and all other groups (uprooted and 5 and 7 m), and between the 7 m breakage height and the uprooted stem, with a *p*-value of < 0.05 in all cases (Table 1). In the groups with a DBH of 24, 28, 32, or 36 cm, significant differences were found between the 3 m breakage height and all other groups (uprooted and 5 and 7 m), with a *p*-value of < 0.05 in all cases. In the group with a DBH of 28 cm, significant differences were found between the 7 m breakage height and the uprooted stem, with a *p*-value of < 0.05. In the group with a DBH of 36 cm, significant differences were found between the 5 m breakage height and the uprooted stem, with a *p*-value of < 0.05 (Table 1).

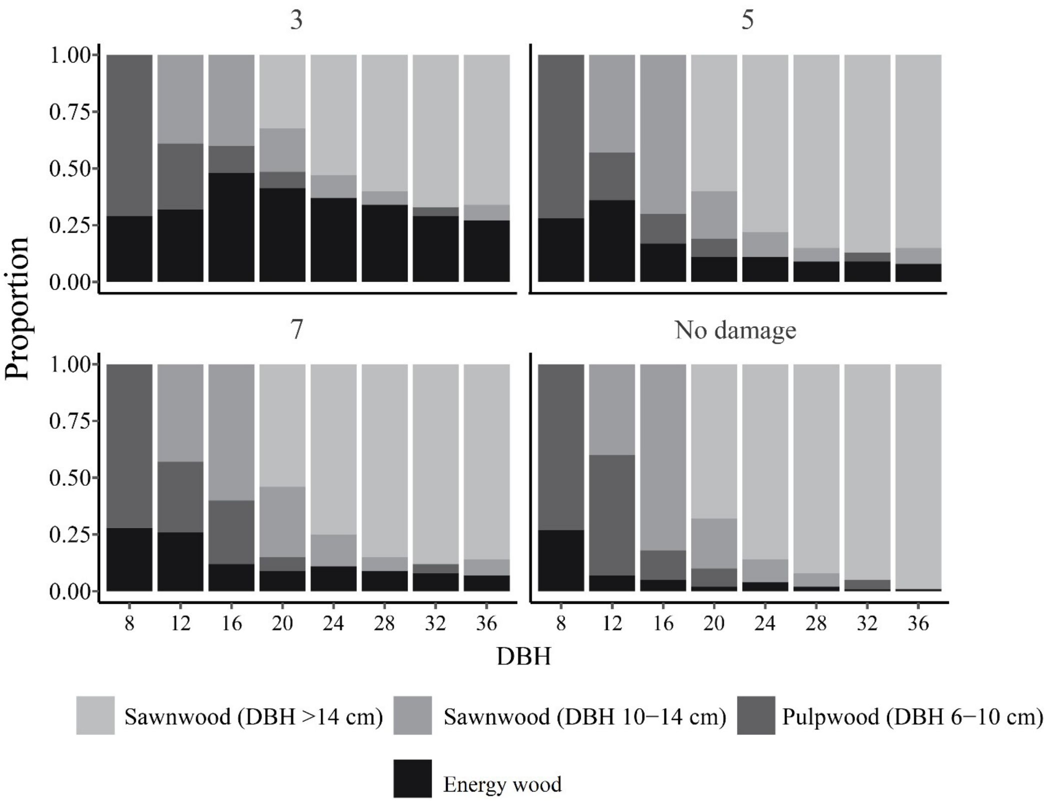

Figure 2. Potential recovered timber assortments by diameter at breast height (DBH) class and stem breakage height.

Table 1. Estimates of Pearson chi-square test of independence. Only significant differences between groups are shown. DBH: diameter height at breast height (cm)

DBH	Groups	Chi-square	*p*-value
12	Uprooted – 3 m	23.1	< 0.001
12	Uprooted – 5 m	33.5	< 0.001
12	Uprooted – 7 m	16.8	< 0.001
16	Uprooted – 3 m	49.4	< 0.001
16	Uprooted – 7 m	11.8	0.008
16	3 m – 5 m	23	< 0.001
16	3 m – 7 m	32	< 0.001
20	Uprooted – 3 m	48.6	< 0.001
20	Uprooted – 7 m	7.8	0.04
20	3 m – 5 m	25.9	< 0.001
20	3 m – 7 m	29.1	< 0.001
24	Uprooted – 3 m	34.4	< 0.001
24	3 m – 5 m	18.9	< 0.001
24	3 m – 7 m	18.5	< 0.001
28	Uprooted – 3 m	35.1	< 0.001
28	Uprooted – 7 m	8.8	0.03
28	3 m – 5 m	18.8	< 0.001
28	3 m – 7 m	15.6	< 0.001
32	Uprooted – 3 m	30.9	< 0.001
32	3 m – 5 m	13.1	0.004
32	3 m – 7 m	14.7	0.002
36	Uprooted – 3 m	37.4	< 0.001
36	Uprooted – 5 m	13.2	0.004
36	3 m – 5 m	12.7	0.005
36	3 m – 7 m	14.4	0.002

Accordingly, the highest price recovered per stem was in 2007, but the lowest was in 2009 (Figure 3). The mean price per stem increased with an increasing DBH. Over the analysed period, the highest price was observed for the uprooted stem, but the lowest was for a stem with breakage at 3 m. The price differences between stem breakages at 5 and 7 m were minimal. For the DBH classes at 16, 20, 24, 28, 32, and 36 cm, the mean price per single stem between uprooted trees and stems with breakage at 5 and 7 m were without significant differences (Figure 4). For the same DBH classes, economic loss caused by stem breakage at 5 and 7 m in comparison to the uprooted stem was 10%, but for stems with breakage at 3 m, it was 35%. In the DBH class of 8 cm, the price fluctuations over the studied period were minimal. In the DBH class of 12 cm, the uprooted stem and stem breakage at 7 m had significantly higher prices than for stem breakage at 3 and 5 m.

Discussion

The most negative economic influence on price was the stem breakage at 3 m (Figures 3–4). In Latvia, the saw log quality requirements determine that the minimal length is 3 m (LVM, 2019). When the stem breakage occurs at 3 m in height, then the first cut log, which usually is the most valuable assortment of the whole stem, is damaged and downgraded to a considerably lower quality assortment (energy wood; Figure 1). Consequently, stem breakage at 3 m had the most significant negative effect on the total stem monetary value in comparison to other stem breakage heights (Figures 3–4). When the stem breakage occurred at 5 or 7 m, the negative effect was significantly smaller on the total stem monetary value, as the top parts of the stem are usually less valuable timber assortments.

In our study, we assumed that only a certain proportion of the stem is damaged

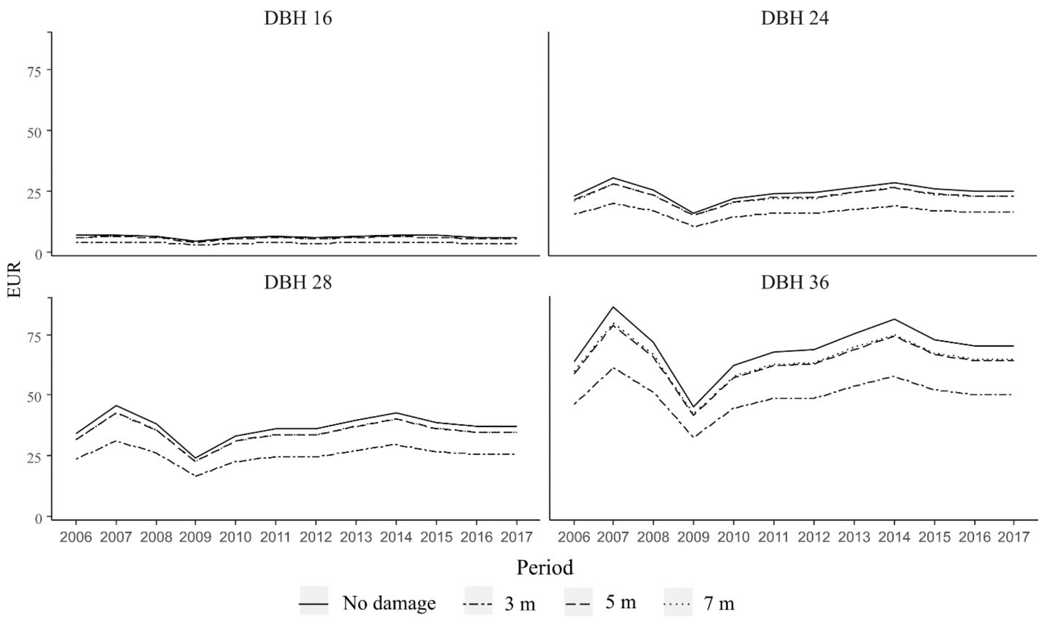

Figure 3. Value of recovered single stem (€/m^3) by diameter at breast height (DBH) and stem breakage height in 2006–2017. I – period (January–June); II – period (July–December).

by breakage (in total, 1.3 m above/below the breakage height). Other studies have not investigated stem breakage influence on the mechanical properties of recovered timber for the Scots pine. However, a study about stem breakage for the Sitka spruce (*Picea sitchensis* (Bong.) Carr.) revealed that only certain parts of the stem are damaged by breakage (on average, 1.4 m above and below the breakage height, ranging from 0 to 3.3 m), and other parts of the stem were used as good quality assortments for sawmills (Nieuwenhuis & Fitzpatrick, 2002). We believe that our study results represent the average estimates of the total stem monetary value that could be recovered from wind-damaged trees. To improve the estimates of recovered timber value, further research should empirically investigate stem breakage heights, the average length of shattering for different tree species, and its influence on the mechanical quality of the whole stem.

After severe wind storms, timber price drops are common due to the vast abundance of wood on the market (Hanewinkel & Peyron, 2013). This was also observed in Latvia after the January 2005 wind storm when the price dropped by 35% (LVM, 2006). In our analysed period, we did not include the year 2005; however, a similar price drop was observed in 2009 during the global financial crisis, which could depict a similar price drop as after a major wind storm. The price fluctuations in the market (-35%) appear to affect the monetary value of timber more significantly than stem breakage at 5 and 7 m (Figure 3), which decreased the timber value by 9–10%. In a study in Ireland, the stem breakage of the Sitka spruce decreased the stem volume by 27% (Nieuwenhuis & Fitzpatrick, 2002). However, as previous studies show, in windfalls, only a certain proportion of all trees are broken, and a large proportion of trees are uprooted or undamaged (Nieuwenhuis & Fitzpatrick, 2002; Szwagrzyk *et al.*, 2017; Kärhä *et al.*, 2018). Therefore, the overall loss per hectare can be less dramatic, for example, 2.6% in the Sitka

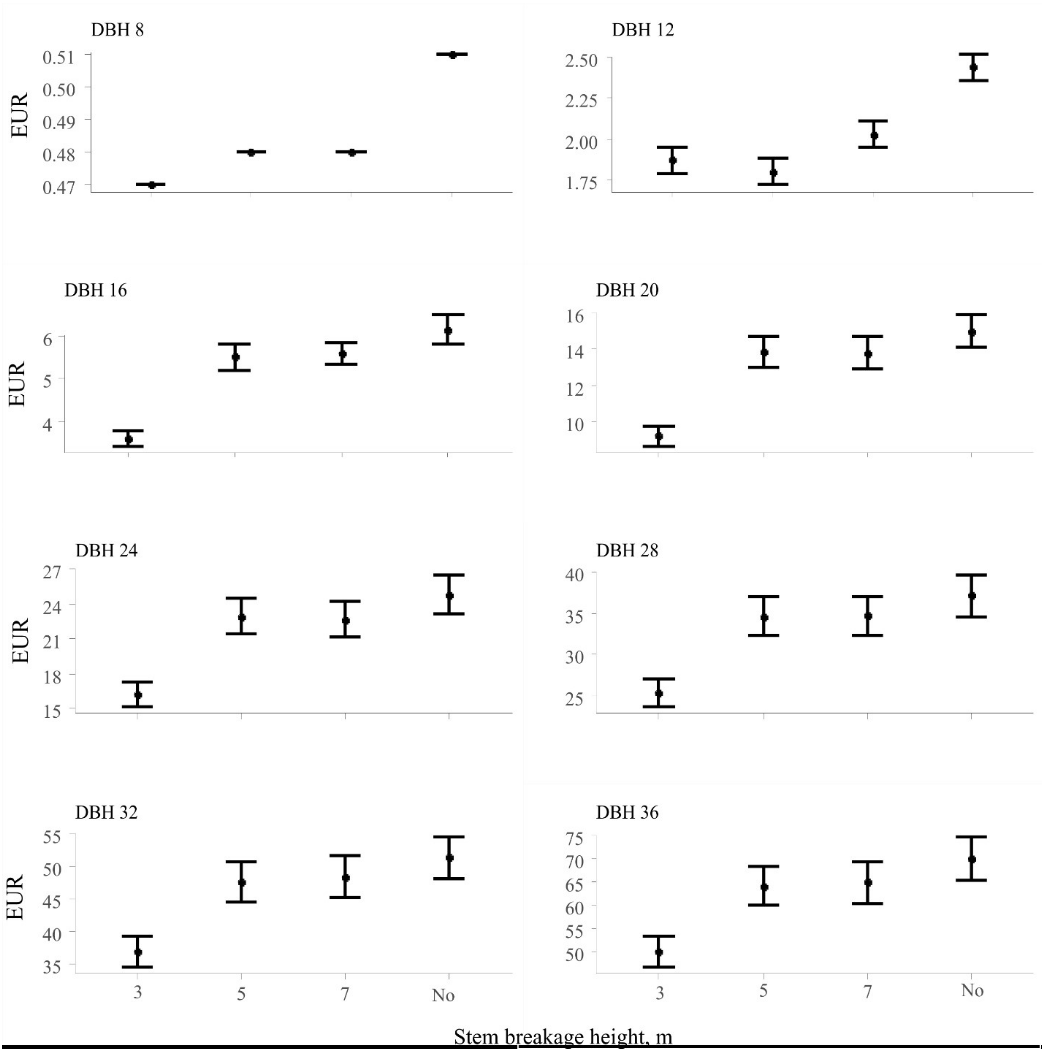

Figure 4. Mean recovered single stem value per m^3 by diameter at breast height (DBH) class and stem breakage height in 2006–2017 in Latvia. Note that *y*-axes are different.

spruce-dominated stand (Nieuwenhuis & Fitzpatrick, 2002).

The study in Finland assessed that in windfalls: 1) cutting costs increase by 35–64%, depending on the stem volume (0.3–1.5 m^3), 2) the total time spent in cutting operations increases by 23–49%, and 3) the mean hourly productivity of cutting decreases by 19–33% in comparison to common undamaged stand harvesting conditions (Kärhä *et al.*, 2018). In mountainous regions, harvesting costs of salvages in windfalls can exceed the revenue from recovered timber (Iranparast Bodaghi *et al.*, 2018). In our study, we did not assess the logging cost, as our study was based on theoretical assumptions. However, further research could use empirical data from windfall harvesting operations and compare them with the revenue from recovered timber to assess the economic justification of salvage-logging operations.

Conclusions

Our study results show that, when the first cut log is damaged by stem breakage, the monetary value downgrades significantly. Over the analysed period, timber price fluctuations in the market could have the same negative effect on the recovered timber value as the damaged first cut log by stem breakage.

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