ABIOTIC RISKS OF MANAGING YOUNG FOREST STANDS OF NORWAY SPRUCE (*PICEA ABIES* (L.) KARST.)

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Abstract
According to the forecast, in future the number of storms in Latvia is going to increase. The wind and the snow are risk factors influencing damages of forests; the least tolerant species against wind damages is *Picea abies* (L.) Karst. It is impossible to avoid the damages caused by weather conditions – windbreaks, windthrows, snowbreaks, snow crushes and snowthrows in forests, since they reoccur in certain periods of time. The aim of the research was to analyze the impact of abiotic risk factors on the management of young *Picea abies* (L.) Karst. stands. Young stands of Norway spruce were researched in all regions of Latvia in 2011 and 2012. These stands were up to 40 years old. In total, 75 stands were measured and surveyed, and 257 sample plots were arranged, where the following damages were identified: frost damages, snow crushes, snowbreaks, snowthrows, windfall and windthrows. The sample plot method was used. The intensity of damages is higher on drained soils. The linear correlation between occurrence and intensity of impact damages caused by abiotic factors was significant ($r = 0.988 > r_{0.05} = 0.253$). There is no significant ($p = 0.686 > \alpha = 0.05$) difference between the intensity of impact damages caused by abiotic risk factors in the stands with regular and irregular shapes of forest compartments. Irregular form forest plots have formed naturally, occurrence of abiotic factors there is 7.5% but the factor intensity – 6.7% and that is higher than in regular forest plots where abovementioned parameters reach 4.7% and 2.9%.
Key words: occurrence, intensity, snowbreaks, snow crushes, windbreaks.

Introduction

Forest ecosystem is under impact of both biotic and abiotic factors. The effect of inanimate nature factors has increased. It is indicated by the data collected during the last few years. For example, in year 2011 most of the damage was caused by abiotic factors – 21.3% (Annual Report of the State Forest Service, 2011). Increasingly often it is forecast that winds will become stronger and the number of storms will increase in the territory of Latvia in future (Donis, 2010b). Wind and snow are risk factors which cause more and more damage to the forest. In windfalls the trees are mostly broken directly under the crown level. That is why, the most vulnerable are lanky trees and the ones with a dense wood structure and different damage. We consider it a normal phenomenon when individual windthown trees speed up the ecological succession process. Because of the flat root system, the less resistant tree species to wind damage is Norway spruce (Picea abies) which grows on mineral soil wetlands (The State Forest Service (SFS) Preparation of digital forest map, 2007). In the forest site types on drained soils proportion of broken trees is four times less than proportion of windthrown trees (Donis, 2006). After windfalls there is a possibility of formation of new growing conditions and substrates (Bambe, 2008).

In winter, in Norway spruce forest stands, snow accumulates on tree crowns more than in other forest stands. Due to the conical shape of the tree crown with steep or pendulous branches, the load of the snow on the crowns is evened (Zālītis, 2006). Trees can be windthrown because of the heaviness of snow. It is called a snowbreak. Snowbreaks usually happen in thinned and too dense forest stands, and also in places where the groundwater level is high. Especially endangered are unthinned young forest stands with a lot of diseased, depressed trees, and trees with asymmetric crowns and tilted stems. It is not possible to avoid windfalls, windbreaks, snowbreaks, snow crushes and snowfalls because they appear after certain periods of time. That can bring great losses to the forest owners. The losses can be reduced by forehanded thinning. Often there is a need of clear cutting in forest stands after snowbreaks and windbreaks. That is because of the cracks in tree stems which appear after breaking. Because of this, it is not possible to use stems as an industrial timber and usually they are sold for pulpwood, firewood and chips.

In Latvia severe storms have been recorded in 1795, 1872, 1876, 1967, 1969, 1998, 2000 (Rinkus, 1999), in 2001 (Bambe, 2008), in years 2005 and 2010 (www.vmd.gov.lv/?sadala=359). One of the last severe storms raged in Latvian forests in 2001. Throughout that year large forest areas were toppled both in private and state forest in Zemgale and Latgale. 1022.6 hectares of stands were recognized as dead because of windfalls and windbreaks that comprised 53% of all dead forest stands. Different damage was done to groups of trees as well as to individual trees in the forest stands. Severely damaged forest stands, where density of healthy trees is under the value of critical cross-section area, must be clear cut to avoid fast reproduction of European spruce bark beetle (*Ips typographus* L.*)* and spreading of fungi *Ophiostoma*

Syd. and P. Syd. which reduce the wood quality (Rinkus, 1999; Luksa and Teders, 2001).

Relatively recently – on January 8-9, 2005 severe storm raged in the northern regions of Europe; it reached Latgale as well. As the evaluation of forest stands' extent showed, 19 thousand hectares of forest stands had been destroyed in windfalls and snowbreaks between year 1991 and 2010, so we can conclude that this particular storm had caused the most severe damage to the forest sector. Because of the storm in 2005, a lot of trees were tilted permanently, tree crowns were broken partly or completely. Norway spruce (*Picea abies*) unmixed stands and Scots pine (*Pinus sylvestris*) young forest stands, seasoning and post-mature stands were those that suffered the most. Because of the above-mentioned, the aim of this research is to analyze the risk factors - windfalls, windbreaks, snowfalls, snowbreaks and snow crushes - in the management of Norway spruce young forest stands.

The objectives are:

1) to carry out the analysis of occurrence and intensity of abiotic risk factors of young forest stands in different regions of Latvia;
2) to give assessment of correlation between the sanitary conditions and the location of forest plots in forest area.

Materials and Methods

The research examines up to 40 year old Norway spruce (*Picea abies*) young forest stands, surveyed in the years 2011 and 2012. The empiric material was collected in the year 2011 in 34 stands, in four regions of Latvia. All together 125 temporary sample plots were created in 14 unmixed stands and 20 mixed stands where abiotic damages were detected in 11 Norway spruce (*Picea abies*) stands that had been injured by various factors – frost, snow and wind. Stands for the research were selected randomly. The following damages were detected: wind-broken and wind-thrown trees, snow-crushed, snow-broken and snow-fallen trees (damage by frost – frost crack, windbreak - a fence, line of trees, etc, serving as a protection from the wind by breaking its force, windthrow - the uprooting of trees by wind (Harper Collins, 2013), snow crush - of the snow bent trees (Dolacis, 1998), snowbreak - the breaking of trees by snow, snowfall – an amount of snow that falls in a

Table 1

Characterization of Norway spruce (*Picea abies*) young forests stands damaged by abiotic factors used in research

Research objects	Coordinates (XY)	Stand* composition	Forest site type	$D_{av.}$*, cm	H_{av}*, m	Number of trees per hectare	Spatial shape
34 young forest stands surveyed in 2011, with 11 different kinds of abiotic damages observed in them							
Jelgava 21/14	484807.9; 6287541.3	$5E4B1M_7$	*Myrtillosa mel.*	1.9	2.0	4100	regular
Skede 8/35 (2)	425715.8; 6347181.0	$10E_{32}$	*Oxalidosa*	13.3	15.7	2350	not regular
Jelgava 32/10	484863.4; 6286320.2	$9E1P_{33}$	*Myrtillosa mel.*	14.4	16.0	5800	not regular
Viesite 1/4	580207.1; 6253710.3	$7E2B1A_8$	*Oxalidosa*	2.7	3.6	5530	not regular
Skede 9/14	424443.2; 6346511.6	$6E3B1Ba_5$	*Oxalidosa*	2.0	2.8	3240	not regular
Kalsnava 102/3	615019.4; 6285982.0	$6B4E_{20}$	*Myrtillosa turf. mel.*	5.1	6.0	6850	not regular
Viesite 143/27	585145.5; 6246343.0	$10E_{38}$	*Myrtillosa mel.*	15.4	13.7	1210	regular
Kalsnava 153/1	614652.5; 6284536.1	$10E_{35}$	*Myrtillosa mel.*	16.6	16.9	1150	regular
Dagda 128/4	708813.1; 6233142.0	$10E_{14}$	*Hylocomiosa*	9.9	11.5	3060	not regular
Kalsnava 21/5	616433.1; 6358080.9	$6E2P2B_{19}$	*Oxalidosa turf. mel.*	0.9	6.0	2600	regular
Kalsnava 133/10	615013.6; 6284537.4	$6E4P_{36}$	*Hylocomiosa*	14.8	13.5	960	regular
41 young stands surveyed in 2012, with 1 kind of abiotic damage observed in them							
Jelgava 32/15	484276.9; 6286130.9	$10E_{38}$	*Hylocomiosa*	15.0	15.0	2320	not regular

* $D_{av.}$ – average tree diameter, $H_{av.}$ – average tree height, E – *Picea abies*, B – *Alnus incana*, M – *Alnus glutinosa*, P – *Pinus sylvestris*, B – *Betula* sp., number – stand structure and age.

Table 2

Sample plot radius, area and coefficient (k) for estimation of number of trees

No.	Average tree height, m	Sample plot radius, m	Square sample plot size, m	Sample plot area, m^2	Coefficient (k) to estimate number of trees	Min number of sample plots per ha	Measured sample area, m^2 ha^{-1}
1.	≤ 12.0	3.99	10.0 × 5.0	50	200	4	0.02
2.	12.0 ≤	7.98	-	200	50	2	0.04

Table 3

Damage degrees of abiotic factors

Damage evaluation	Damage degree
Trees without indications of weakening or growth disturbances	0
Economically insignificant damages or faults (few broken branches, small stem damages)	1
Economically significant damages (trees with one or more small stem damages that do not exceed half of the stem diameter, etc.)	2
Highly damaged (damages of the central shoot of tree, its premature die-back; withered, broken top; stem of a tree is bent and cannot take a vertical position; tree with one or more stem damages where scars exceed half of stem diameter; visible resin galls on all length of tree stem)	3
Trees died in the current year (needles and leafs are yellow and brown)	4
Dead trees	5

single storm or in a particular period of time (Merriam – Webster, 2013). Characterization of Norway spruce (*Picea abies*) young forests stands damaged by abiotic factors is presented in Table 1. No damage was observed in pure Norway spruce (*Picea abies*) stands in *Hylocomiosa* and *Oxalidosa* site types if they were surrounded by at least two young forest and seasoning stands as well as in mixed spruce-birch young forest stands in *Oxalidosa* forest site type. By calculating the coefficient of tree slenderness, which is the proportion of average tree height and diameter (H : D), the stability of the young stands of spruce in snowbreaks is found (Skudra and Dreimanis, 1993).

However, in the year 2012 the empirical data were collected in 132 temporary sample plots in 41 stands based on the components of the stands where 15 were pure stands and 26 mixed stands. The number of sample plots depends on area of forest plots (Table 2). Most of them were round sample plots, only in stands with high density square sample plots were used and stationed on diagonals or transects in identical distances on a systematic basis, covering all area of the stand. The ruling indicator for choosing the type of sample plots was the average tree height of the stand. With the average tree height of up to 12 m a 50 m^2 sample plots were created with a circle radius of 3.99 m, but in stands with average tree height H ≥ 12.0 m a sample plot of 200 m^2 with a 7.98 m radius was created (Table 2).

In each of the temporary sample plots trees were counted, diameter at breast height (DBH) was measured (with a precision of 1 mm). To measure DBH at 1.3 m height from the root flare the following instruments were used: electric sliding calliper or simple calliper. Heights for 20 – 30 trees were measured using VERTEX measuring instrument with a precision of 0.1 m. The coordinates of each young growth were determined with a GPS device LKS-92 by transforming geographic coordinates into XY system (The State Forest Service (SFS) Preparation of digital forest map, 2007). Damages of abiotic factors were divided into six damage degrees (Table 3).

To calculate these indicators, it is necessary to estimate the number of trees per hectare, using the following formula (1):

$$N = \frac{Np \times 10000}{L} \tag{1}$$

where N – number of trees per hectare after sample plot inventory data, pieces ha^{-1};
Np – number of trees in the sample plot, pieces;
L – area of sample plot, m^2.

Damage occurrence proportion was estimated using formula (2):

$$P = \frac{n \times 100}{N} \quad (2)$$

where P – damage occurrence proportion, %;
n – number of damaged trees, pieces ha^{-1};
N – total number of measured trees, pieces ha^{-1}.

Damage intensity was estimated using formula (3):

$$R = \frac{\sum n_i b_i \times 100}{N \times k} \quad (3)$$

where R – damage intensity, %;
n_i – number of damaged trees, pieces ha^{-1};
b_i – degree of damage;
N – total number of measured trees, pieces ha^{-1};
k – highest degree of damages (points).

To find out how young stands of Norway spruce are influenced by stands next to them, the location in woodland was defined. Forest plot forms (regular and irregular) were found with the help of the State Forest Service geographical information system (GIS) maps ArcGIS 9.1, 9.2 and 9.3 (The State Forest Service (SFS) Preparation of digital forest map, 2007). Correlation and regression analyses were used for finding out the relevance between the occurance and intensity of damages.

Results and Discussion

Periodical changes in the weather cause snowbreaks, snowfalls, windbreaks and windfalls, that in the forests of Latvia often lead to damages for individual trees as well whole stands. The forests may suffer from insect and fungal attacks, because the sanitary conditions deteriorate after the damage. The analysis of the collected data in the forests of Jelgava, Skede, Viesite, Kalsnava and Dagda areas showed that Norway spruce is often damaged by snowbreaks and snow crushes (79%). The windbreaks are also commonly met in Latvian forests and the occurrence is 19% (in Figure 1 – Figure 3) summary data from Table 1 have been used).

Norway spruce is a tree species which is resistant to frost. Small majority of damage was observed in pure Norway spruce stands, while damage occurrence and intensity of impact was higher in mixed stands. The results of this research showed that frost damage is found just in one of the 75 measured and surveyed young forest stands in Jelgava forest region and occurrence of damages reaches 2%, while in other regions frost damage was not detected. Young forest Norway spruce stands were most severely affected by the snow crushes, snowbreaks and snowfalls in Kalsnava and Dagda regions; while tree damage in Viesīte was significantly smaller, where several types of abiotic risk factors were observed: snow crushes, snowbreaks, windthrows and windbreaks. In Skede region frost and snow crush damages were found in insignificant amount (Figure 1).

All young forest stands were divided in several height groups (up to 5 m; 5.1 – 10; 10.1 m and more) to determine which of them have suffered the most by abiotic factors. Tree damage occurrence in the first group varies from 4.9 – 7.2% and intensity – 2.0 – 6.0%, in the second - occurrence 19.7 – 53.9% and intensity 2.9 – 6.0%, while in the third group respectively -

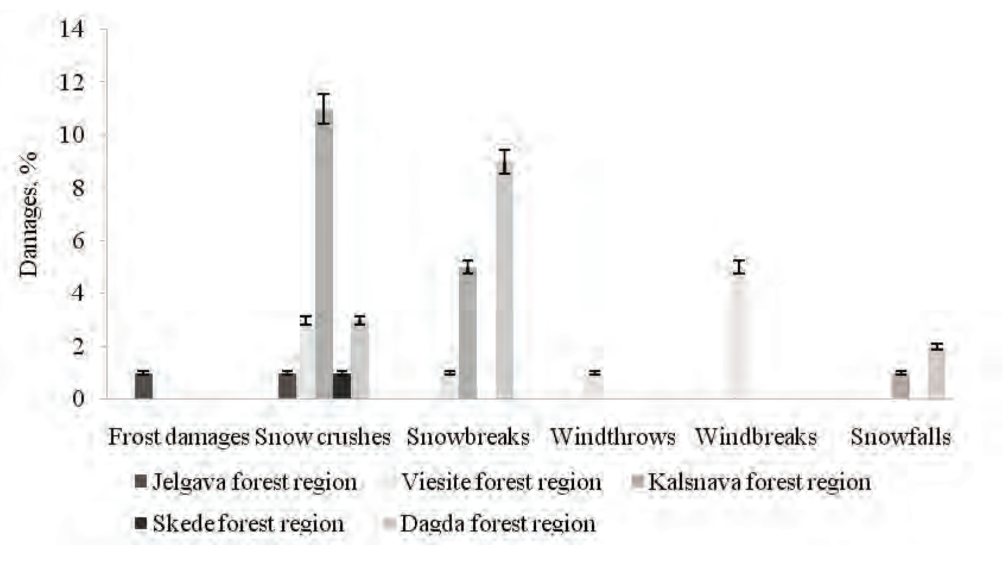

Figure 1. Distribution of abiotic risk factors in different regions of Latvia.

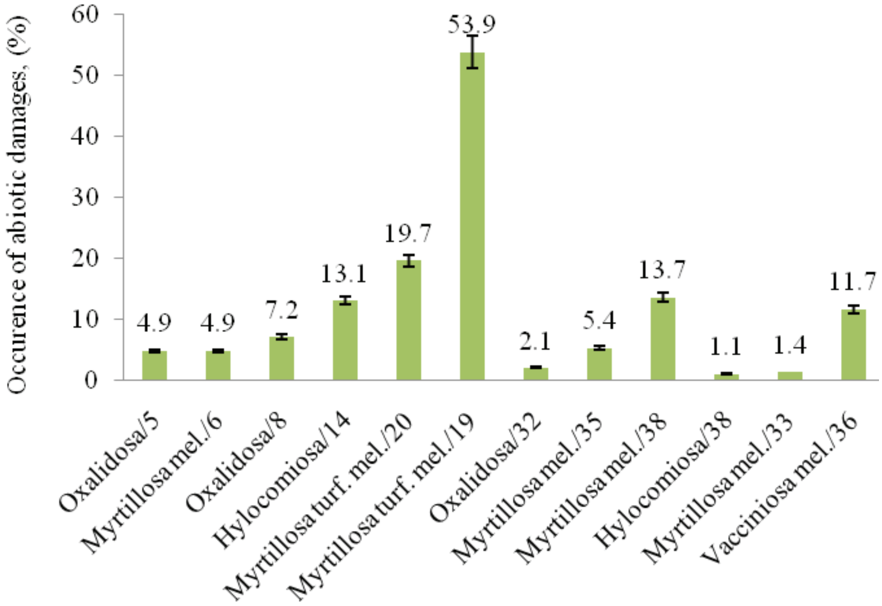

Figure 2. Correlation between forest site type and stand age and the occurrence of abiotic factors.

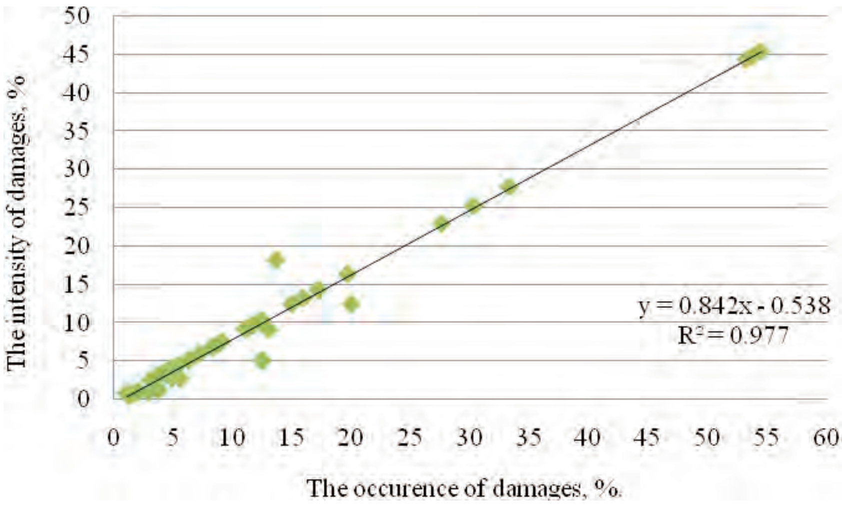

Figure 3. Correlation between abiotic factors occurrence and intensity of damage in spruce young forest stands ($r_{fact} = 0.988 > r_{crit} = 0.253$).

1.1– 13.7% and 0.9 – 18.3%. The most significant damages of snow crush were found in 19-year-old spruce young stands on *Oxalidosa turf. mel*. drained soil with an average height 6.0 m, insignificant – in *Oxalidosa* and *Hylocomiosa* with tree ages ranges 5 – 36 years and with average tree height 11.5 – 16.9 m. Other authors have mentioned previously that in drained forest site types there are more abiotic risks of damages than in other types of forests (Donis, 2006). Looking for the relation between the stand average tree height groups and occurrence of abiotic risks damages analysis of variance showed that there is no significant difference between the stand average tree height groups ($p = 0.522 > \alpha = 0.05$), also there are no significant differences between different regions - Jelgava, Viesite, Skede, Dagda and Kalsnava ($p = 0.535 > \alpha = 0.05$) (Figure 2).

Research of correlation between the occurrence and intensity of the damage of abiotic factors correlation analysis shows significant linear correlation: $r = 0.988 > r_{0.05} = 0.253$ (Figure 3).

After assessing the location of young forest stands in the woodland and objects around them, the research results have shown that the most significant damage is observed in Kalsnava - 21/5. This stand is growing on *Oxalidosa turf. mel.* drained soils and has a regular form but there is a block ride in the north side (Table 1) while on the other three sides it is surrounded by the middle forest Scots pine stand and two seasoning forest stands. The occurrence of abiotic damages reaches even 53.9% and density 44.9%. J. Donis (2006) concluded that damage intensity in young forest stands depends on a proximal stand structure and infrastructure objects. It means that the forest plot location in the woodland is a significant risk factor for abiotic factor damage intensity that is indicated in our research as well.

After investigation of the location of other forest stands in their woodlands, it was concluded that in stands Kalsnava 102/3, Viesite 143/27 and Kalsnava 133/10 parameters of damage occurrence and intensity differ and are higher than in other young forest stands. Intensity of snowcrushes and snowbreaks in Kalsnava 102/3 reach 16.4%. It should be added that this object is surrounded by birch seasoning stands. After comparing damage between separate sample plots, it was found that there was no significant damage in the first and third ones but in those laid at the very roadside intensity of damage reached 10.4 and 4.0%. The same regularity refers to the young forest stands Dagda 128/4, Viesite 1/4 and Skede 9/14 where more tree damage was observed and it was more intensive in sample plots laid near block rides and forest roads. High ratio of occurrence and intensity could be explained by the fact, that these stands belong to the risk group – unstable stands endangered by snowbreaks and snow crushes with coefficient of slenderness 90 – 120. This means that young forest stands with high density impacts stability against abiotic factors.

After examining the location of woodland and surrounding stands in the research object Viesite 143/27, we may conclude the following – the forest plot is regular, quadrangular; the intensity of windfalls and windbreaks is quite high – 18.3%. Situation can be explained with block roads laying on two sides and being surrounded by two seasoning forest stands. Young forest stand Kalsnava 133/10 shows a quite high ratio of snowfalls and snowbreaks – 9.7%. The occurrence of damage and level of damage intensity in the first and second sample plot is 11.1% and 9.3% respectively and is evaluated as high, but in the third no damage was observed. It could be explained with the shape of the forest plot that was narrow and outstretched along the block road.

After assessing the abiotic risk factors, it is possible to conclude that the periodic damage caused by them is the reason for destruction of huge amount of trees. Wind damage is the cause for uninterrupted economic losses for forest management in several European countries (Zeng et al., 2004; Уланова, 2006). Situation with windfalls is similar because it is not possible to avoid them in almost all types of boreal forests (Ulanova, 2000). For example, research results in Finland show, that wind is the main abiotic factor which causes material losses even more than snow does (Heinonen et al., 2011). Our research deals with the wind impact because it is the second most important factor after the snow damage (19%). Young forest stands and middle forest are those mostly affected by snowbreaks and snowfalls as well as snow crushes which are the reasons for forming of cracks in tree stems or staying bended so the possibility of growing qualitative timber is lost (Ņesterovs, 1954).

To minimize and manage the abiotic risks, it is essential to create the strategy for dealing with natural disasters; there is a need for strict management plan and careful attention, paid to spatial planning (Ткаченко, 1955; Slodicak and Novak, 2006; Donis, 2010a; Panayotov, 2011). Irregular form forest plots have formed naturally, occurrence of abiotic factors there is 7.5% but factor intensity – 6.7% and that is higher than in regular forest plots where abovementioned parameters reach 4.7% and 2.9%. Difference of intensity of abiotic damage factors between regular and irregular forest plots is not significant ($p = 0.686 > \alpha = 0.05$).

Conclusions

1. One of the most important abiotic factors, which is found in all forest districts represented in this research and causes significant impact to Norway spruce young forest stands, is the snow crush.
2. Block rides, roads, amelioration system ditches, water bodies, clear-cut areas and location of the stand in woodland play significant role as factors of the intensity of abiotic damage risk.
3. The most significant damage is observed in those young forest stands of Norway spruce which are located beside the block rides and are surrounded by at least two seasoning stands or middle-forest. In these stands the level of damage occurrence reaches 53.9% and intensity of damage – 44.9%.
4. Shape (regular or irregular) of the forest plot is not a significant abiotic risk factor ($p = 0.686 > \alpha = 0.05$).

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References

1. Bambe B. (2008) Veģetācijas dinamika 2005. gada janvāra vētras postītos mežos (Dynamic of vegetation in forests suffered in forest storm in January 2005). *Ģeogrāfija. Ģeoloģija. Vides zinātne: Referātu tēzes*. Latvijas Universitāte, Rīga, 292. lpp. (in Latvian).
2. Valsts meža dienests (2011) Valsts meža dienesta 2011. gada publiskais pārskats (Annual Report of the State Forest Service 2011). Available at: http://www.vmd.gov.lv/doc_upl/vmd_publiskais_parskats_2011.pdf, 15 January 2013. (in Latvian).
3. Harper Collins (2013) Definition of windthrow, windbreak, windfall. The Collins English Dictionary. Available at: www.collinsdictionary.com/dictionary, 14 March 2012.
4. Merriam – Webster (2013) Definition of snowfall, snowbreak. An Enciclopedia Britannika Company Merriam_Webster. Available at: www.merriam-webster.com/dictionary, 14 March 2012.
5. Dolacis J. (1998) *Mežtehnikas, mežsaimniecības un kokrūpniecības terminu vārdnīca* (Dictionary of forestry, the forest industry and the wood processing). Pimais izdevums, Antera, Rīga. 6512 lpp. (in Latvian).
6. Donis J. (2006) *Ekstrēmu vēju ātrumu ietekmes uz kokaudzes noturību novērtējums, lēmuma pieņemšanas atbalsta sistēmas izstrāde* (Evaluation of extreme wind speed impact on steadiness of forest stand, elaboration of the support system of decision making). Zemkopības Ministrijas Meža Attīstības fonda pasūtītais pētījums, LVMI Silava, Salaspils, 64 lpp. (in Latvian).
7. Donis J. (2010a) Klimata izmaiņu radītie meža audzēšanas riski un to mazināšanas iespējas: vējš un uguns (Climate change caused risks on forest growing and facilities of minimization of them: wind and fire). Available at: www.zm.gov.lv/doc_upl/J_Donis_1_dala.pdf, 26 November 2012. (in Latvian).
8. Donis J. (2010b) Klimata izmaiņu radītie meža audzēšanas riski un to samazināšanas iespējas. In: Jansons Ā. (eds) *Meža apsaimniekošana klimata izmaiņu kontekstā* (Climate change caused risks on forest growing and facilities of minimization of them. Forest management in context of climate change). LVMI Silava, Salaspils, 18-20. lpp. (in Latvian).
9. Heinonen T., Pukkala T., Ikonen V.-P., Peltola H., Gregow H., Venäläinen A. (2011) Consideration of strong winds, their directional distribution and snow loading in wind risk assessment related to landscape level forest planning. *Forest Ecology and Management,* 261, pp. 710-719.
10. Luksa M., Teders M. (2001) Vējgāzes Latvijā un Igaunijā (Windfalls in Latvia and Estonia). *Baltijas Koks,* 12 (20), 20.-21. lpp. (in Latvian).
11. Ņesterovs V. (1954) *Vispārīgā mežkopība* (Common silviculture). Latvijas valsts izdevniecība, Rīga, 610 lpp. (in Latvian).
12. Panayotov M., Kulakowski D., Laranjeiro Dos Santos L., Bebi P. (2011) Wind disturbances shape old Norway spruce – dominated forest in Bulgaria. *Forest Ecology and Management,* 262, pp. 470-481.
13. Rinkus E. (1999) 1998. gada snieglauzēs bojāto audžu sanitārā stāvokļa rezultāti (Results in sanitary conditions in year 1998 snowbreak damaged forest stands). *Meža dzīve,* 2, 14-15. lpp. (in Latvian).
14. Rūba J. (2012) *Parastās egles (Picea abies (L.) Karst.) jaunaudžu sanitārais stāvoklis Zemgales, Kurzemes un Vidzemes reģionā* (Sanitary condition of young Norway spruce *Picea abies* (L.) Karst. stands in Zemgale, Kurzeme and Vidzeme regions). Maģistra darbs. LLU, Jelgava, 61 lpp. (in Latvian).
15. Skudra P., Dreimanis A. (1993) *Mežsaimniecības pamati* (Fundamentals of forestry). Zvaigzne, Rīga, 262. lpp. (in Latvian).
16. Slodicak M., Novak J. (2006) Silvicultural measures to increase the mechanical stability of pure secondary Norway spruce stands before conversion. *Forest Ecology and Management,* 224, pp. 252-257.
17. Ulanova N.G. (2000) The effects of windthrow on forests at different spatial scales: a review. *Forest Ecology and Management,* 135, pp. 155-167.
18. Valsts meža dienests (2007) Meža digitālā karte (Preparation of digital forest map). Available at: karte.vmd.gov.lv:7777/vmdgis/main.jsp, 26 February 2013. (in Latvian).
19. Zālītis P. (2006) *Mežkopības priekšnosacījumi* (Preconditions of silviculture). LVMI Silava, Salaspils, 219 lpp. (in Latvian).
20. Zeng H., Peltola H., Talkkari A., Venäläinen A., Strandman H., Kellomäki S., Wang K. (2004) Influence of clear-cutting on the risk of wind damage at forest edges. *Forest Ecology and Management,* 203, pp. 77-88.
21. Ткаченко М.Е. (1955) *Общее лесоведение* (Common siviculture). Издание 2, Гослесбумиздат, Москва: - Ленинград, 597 с. (in Russian).
22. Уланова Н.Г. (2006) *Восстановительная динамика растительности сплошных вырубок и массовых ветровалов в ельниках Южной тайги* (Dynamic of vegetation regeneration after clear-cuttings and massive windfalls in Southern taiga). Диссертация доктора биологических наук, Моск. гос. ун-т им. М.В. Ломоносова, Москва, 424 с. (in Russian).